THE DEVELOPMENT AND INFLUENCE OF VISUAL HIERARCHICAL
PROCESSING STYLES

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ABSTRACT

JENNIFER GIBSON: The Development and Influence of Visual Hierarchical Processing
Styles
(Under the direction of Dr. J. Steven Reznick)

Perceptual and cognitive processing styles are human tendencies to perceive the
world in specific and predictable ways. One such processing style commonly observed
among typical adults is the "global bias." When viewing hierarchical information, or
information with at least one global or "whole" and one local or "part" quality, typical
adults are usually faster at processing global information and are easily distracted by the
global information if it conflicts with the local. Conversely, individuals with autism
spectrum disorders (ASD) appear to lack the typical global bias and tend to demonstrate
either no bias or a local bias. Researchers are currently working to understand how the
typical adult global bias emerges and the consequences that different hierarchical
processing styles may have on perceptual input and behavioral output among typical and
atypical populations. This dissertation makes advances in the understanding of the
typical developmental trajectory of the global bias, the generalizability of processing
styles, and relations between processing styles and object exploration and play during the
second six months of life. Infants aged 6, 9, and 12 months participated in a cross-
sectional, multi-method study including a visual familiarization task, manual
familiarization task, sequential touching task, and free-play session. The results indicated
that at 12 months of age, the majority of infants demonstrate a local bias and that this
local bias generalizes across both the visual and manual familiarization tasks.

Additionally, exploration and play behaviors significantly correlated with a local or global bias during the familiarization tasks, suggesting that hierarchical processing is related to the way infants interact with their environment.

DEDICATION

To my family for always encouraging me to follow my heart, embrace life's journey, and enjoy every moment of my adventures.

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INTRODUCTION

The human perceptual system is a seamless integration of sensation and attention, allowing our mind to develop coherent representations of the world around us. We are able to make sense of objects by parsing elements and binding them together to create complicated visual scenes (Colombo, 2001; Bhatt & Quinn, 2011). An especially sophisticated property of visual perception is our ability to understand everything we see as both whole entities as well as constituent features. For example, a flower is not only a whole flower but also an arrangement of petals, leaves, and a stem. The ability to process such hierarchical information, or information that contains at least one "whole" and one "part" property, efficiently and effectively is essential due to the prevalence of hierarchical information in our perceptual world.

Many of the early empirical investigations of hierarchical processing were driven by the dueling perspectives of the structuralists and Gestalt theorists. Structuralists believe that an individual first processes small, constituent elements of the world around him or her. With the experience and maturation of necessary neural substrates, the individual can then piece the elements together to form a representation of the whole (e.g., Hebb, 1949; Cohen & Younger, 1984; Schwarzer, Zauner, & Jovanovic, 2007). In contrast, Gestalt psychologists argue that individuals first process a whole pattern, utilizing scene characteristics such as common movement, depth, linearity, color, lightness, or form (e.g., Zuckerman & Rock, 1957; Kohler, 1967). The Gestalt theorists

argue that the whole is greater than the summation of the elements that create it, carrying its own meaning and properties in addition to the meaning and properties of the elements. Only once the whole has been processed can the individual make sense of the smaller pieces.

Previous research has consistently demonstrated that typically developing adults process visual hierarchical information with a "global bias." Adults are usually faster at responding to global properties, and information at the global level can interfere with processing of local properties if the two levels are incongruent (Navon, 1977; Navon, 1981; Neiworth, Gleichman, Olinick, & Lamp, 2006).

The global bias, however, does not appear to be universal among adults. Growing evidence suggests that individuals with autism spectrum disorders (ASD) do not process hierarchical information with the typical global bias processing style. Rather, it appears that individuals with ASD process hierarchical information with either a) no visual bias, demonstrated by equal responses to local and global information (enhanced perceptual function theory, Mottron, Dawson, Soulières, Hubert, & Burack, 2006), or b) a "local bias" (weak central coherence theory, Frith & Happé, 1994; Happé & Frith, 2006). An abundance of previous research has demonstrated the atypical lack of a global bias among individuals with ASD (e.g., Bölte, Holtman, Poustka, Scheurich, & Schmidt, 2007; Booth, Charlton, Hughes, & Happé, 2003; Jolliffe & Baron-Cohen, 1997; Mottron & Belleville, 1993; Mottron, Belleville, & Ménard, 1999; Scherf, Luna, Kimchi, Minshew, & Behrmann, 2008).

Despite a relatively large accumulation of literature concerning the displayed hierarchical processing styles of typical adults and individuals with ASD, little is known

about the *development* of hierarchical processing styles or *the consequences* that a processing style may have on daily perception, cognition, or behavior. Therefore, although it is clear that differences in processing styles exist among typically developing adults and individuals with ASD, very little is understood about these differences, how they emerge, why they exist, or how they may affect downstream cognition and behavior, including the manifestation of clinical symptoms among individuals with ASD.

The developmental trajectories of hierarchical processing styles among typically developing adults and individuals with ASD are unknown. Concerning typical development, most researchers suggest that hierarchical information processing styles transition from local- to global-biased during the first year of life, depending on stimuli complexity (Cohen, 1998; Cohen & Cashon, 2001; Colombo, 2001; Schwarzer, et al., 2007; Younger & Cohen, 1986). Other researchers have suggested that infants are global-biased from birth (Macchi Cassia, Simion, Milani, & Umiltà, 2002) or, in contrast, that a local bias in infancy persists into childhood or adolescence before transitioning to the typical adult global bias (Elkind, Koegler, & Go, 1964; Neiworth, et al., 2006; Poirel, Mellet, Houdé, & Pineau, 2008; Porporino, Shore, Iarocci, & Burack, 2004; Scherf, Behrmann, Kimchi, & Luna, 2009). Concerning atypical development among individuals with ASD, it remains unclear when, how, or why the development of hierarchical information processing styles begin to differ from typically developing peers. An understanding of atypical development will continue to be difficult until the developmental trajectory of typical development is clarified as a platform for comparison.

Similarly unclear is the generalizability of visual hierarchical information processing styles to other sensory domains or naturalistic experiences. Previous research

by Mottron and colleagues (2000) has demonstrated that the atypical hierarchical processing styles demonstrated by individuals with ASD are also evident in the auditory modality. Individuals with ASD demonstrated typical global processing but superior local processing compared to peers when listening to musical melodies (Mottron, Peretz, & Ménard, 2000). However, a thorough literature scan suggests that no previous research has addressed the generalizability of an individual's visual hierarchical processing style to other exploratory modalities or naturalistic settings, such as the processing of hierarchical objects. Therefore, it remains unclear if visual hierarchical processing styles are isolated phenomena specific to the visual system when viewing images or if they represent a more global perceptual or cognitive processing style. This distinction could have significant impacts on the construction of broader perceptions and related behavioral responses.

By extension, it is unclear what broader consequences may result from having a particular hierarchical processing style. Theoretical discussions of ASD have suggested that atypical hierarchical processing styles may be related to the expression of phenotypic diagnostic symptoms as well as savant talents exhibited by individuals with ASD (Happé, 1999; Happé & Frith, 2006; Happé & Booth, 2008; Mottron, et al., 2006). Similarly, it is likely that hierarchical processing styles may influence typical infant behaviors, such as object exploration and play. Support for this hypothesis comes from research demonstrating that typical infants show a pattern of playing with toys that begins with close visual and tactile exploration of single objects, transitions to more relational behaviors involving multiple toys, and towards the end of the first year finally results in symbolically relating multiple objects (Fenson, Kagan, Kearsley, & Zelazo, 1976).

Because much of the research literature suggests that the infant visual processing style is transitioning from local to global visual processing at this time, it is not unreasonable to suggest that the transition from individual object and detail exploration to global object integration may also be related to the visual processing transition. Additionally, previous research has demonstrated that infants at high-risk for ASD employ atypical visual strategies compared to low-risk peers when inspecting and exploring objects, including long fixations towards one object (greater than 10 seconds), examining objects from odd or unusual angles, squinting during object examination, or blinking excessively during object examination (Mottron, Mineau, Martel, St-Charles Bernier, Berthiaume, Dawson, Lemay, Palardy, Charman, & Faubert, 2007; Ozonoff, Macari, Young, Goldring, Thompson, & Rogers, 2008). Despite supporting evidence, a thorough scan of the published literature reveals no research that has explicitly correlated an infant's demonstrated hierarchical processing style with object exploration behaviors.

I conducted my dissertation to better understand the developmental trajectory and generalizability of visual hierarchical information processing styles as well as the relation between processing styles and object exploration. To achieve this goal, I addressed three specific aims.

Aim 1: To clarify the pattern of typical visual hierarchical processing styles demonstrated by infants from 6 to 12 months of age.

Research findings on how the developmental trajectory of hierarchical information processing styles proceeds through 6, 9, and 12 months of age tend to be inconsistent and are focused heavily on processing capabilities rather than processing styles. For example, many studies have evaluated if infants are capable of creating a mental construct of a global form given particular local information (e.g., Kellman &

Spelke, 1983; Quinn, Brown, & Streppa, 1997; Quinn, Burke, & Rush, 1993; Slater, Johnson, Brown, & Badenoch, 1996; Van Giffen & Haith, 1984). My dissertation focuses on the saliency of global versus local information to an infant during the formation of his or her mental representation. Aim 1 is achieved using a visual familiarization task with hierarchical visual images.

Based on previous research, I hypothesized that the 6-month-olds would show a bias for the local property of the familiarization stimuli and that the 12-month-olds would show a bias for the global property of the familiarization stimuli. I expected that the 9-month-olds would show a pattern that is transitional between the 6- and 12-month-old groups. Specifically, some 9-month-olds would show a local bias while others would have started the transition to a global bias. Therefore as a group, the bias would either be weak in one direction or possibly not evident. These results would support previous findings that infants transition from a local bias to a global bias during their first year of life (e.g., Younger & Cohen, 1986).

Aim 2: To understand if infants will demonstrate the same hierarchical information processing styles in a more naturalistic situation.

Most of the previous research on hierarchical information processing styles in infancy has been limited to visual images. Although previous ASD research has suggested that processing styles may be pervasive and consistent across visual and auditory sensory domains (Mottron, et al., 2000), there has been no previous research to my knowledge exploring if processing styles within individuals are consistent across stimulus modalities or during a more naturalistic situation, like object exploration. Aim 2 is achieved by comparing the hierarchical information processing style demonstrated by

an infant on a visual familiarization task and the processing style demonstrated by that infant on a manual familiarization task.

Although there is no previous research from which to base a hypothesis, I expected that the infants would show the same hierarchical processing style in the visual and manual familiarization tasks, both at the individual and group levels. Therefore, I expected that the 6-month-olds would show a bias for the local property of the familiarization stimuli, the 12-month-olds would show a bias for the global property of the familiarization stimuli, and the 9-month-olds would show a transitional pattern of biases for the local or global property of the familiarization stimuli.

Aim 3: To explore the relation between hierarchical information processing styles and object exploration behaviors.

Previous theories have suggested that atypical hierarchical information processing styles could play a role in the development of diagnostic symptoms exhibited by individuals with ASD (Happé, 1999; Happé & Frith, 2006; Happé & Booth, 2008; Mottron, et al., 2006). However, I am not aware of any previous research that has evaluated the relation between processing style and behavioral output. To address aim 3, I included an exploratory component to evaluate possible correlations between hierarchical processing styles and infant object exploration.

I hypothesized that some of the object exploration measures would be significantly correlated with the hierarchical processing styles demonstrated by the infants within each age group. These findings would support previous claims that hierarchical perceptual processing may be related to behavioral output (Happé, 1999; Happé & Frith, 2006; Happé & Booth, 2008; Mottron, et al., 2006).

CHAPTER 2

METHODS

Participants

A total of 90 healthy, full-term infants aged 6, 9, and 12 months from central North Carolina were included in this study (80% White, 13% multiple races, 3% Asian, 2% Black/African-American, 1% Hispanic/Latino). An additional 11 infants participated, but their data were not included due to fussiness (7), being the twin of a participant (2), or experimenter / equipment error (2). The infants were given an age-appropriate toy as a gift for participating in the study. All of the infants participated in five tasks: a visual familiarization task, a change detection task, a manual familiarization task, a sequential touching task, and a play task. However, not all of the infants' data were included in the analyses for every experimental task. Attrition for each task is described in detail in the Results section, and Table 1 summarizes the total infant participation as well as number of participants for each experimental task.

Table 1: Description of Participants for Each Task

		6-month-olds	9-month-olds	12-month-olds
Total	Total N (Age)	30 (6.56)	31 (9.56)	29 (12.51)
	Males	15	15	14
	Females	15	16	15
Visual	Total N (Age)	25 (6.57)	29 (9.57)	27 (12.51)
	Males	13	13	13
Familiarization	Females	12	16	14
	Excluded	5	2	2
Change	Total N (Age)	25 (6.57)	28 (9.58)	27 (12.51)
	Males	13	13	13
Detection	Females	12	15	14
	Excluded	5	3	2
Manual	Total N (Age)	27 (6.58)	28 (9.54)	26 (12.52)
	Males	14	13	13
Familiarization	Females	13	15	13
	Excluded	3	3	3
Sequential	Total N (Age)	28 (6.53)	31 (9.56)	25 (12.51)
	Males	14	15	13
Touching	Females	14	16	12
	Excluded	2	0	4
Play (Duck)	Total N (Age)	27 (6.55)	31 (9.56)	24 (12.49)
	Males	14	15	12
	Females	13	16	12
	Excluded	3	0	5
Play (Truck)	Total N (Age)	28 (6.55)	31 (9.56)	25 (12.51)
	Males	14	15	13
	Females	14	16	12
	Excluded	2	0	4

Visual Familiarization Task

The infants sat on his or her parent's or family member's lap facing a 19"
computer monitor at a distance of approximately 60 cm. The experimenter sat across
from the infant and controlled the stimuli from an attached computer. The entire room
was darkened, and a black partition hid the experimenter from the infant's view so that
there were no environmental distracters. The stimuli were presented on the computer

monitor using Habit X software (Cohen, Atkinson, & Chaput, 2000) that was controlled by the experimenter.

The infant viewed a navy hierarchical local-global pairing of <u>one</u> of the following randomly assigned images: an S made of local triangles, an S made of local diamonds, an A made of local triangles, or an A made of local diamonds (see Figure 1). The same image was presented 6 times for 15 seconds, totaling 90 seconds of exposure to the familiarization stimulus. After the familiarization period, the infants viewed a paired-choice of two test stimuli. One of the test stimuli was identical to the familiarization stimulus at the global level but different at the local. The other test stimulus was identical to the familiarization stimulus at the local level but different at the global level (Figure 1). Because infants of this age range typically show a preference for novel stimuli, it was expected that the infant would look towards the novel stimulus during the test trials. Each test trial paired the novelty of a local change with the novelty of a global change and, based on the infant's novelty preference, was used to estimate which change the infant found most salient. The change that elicited the most infant preference during the test trials was assumed to represent the level that the infant found most salient during familiarization, thus making the change at test the most novel. The test stimuli were shown twice for 10 seconds each, counterbalancing the sides of presentation.

Figure 1: Visual Familiarization Design and Stimuli Example

The global A and S familiarization images were approximately 12 cm high and 12.7 cm or 9 cm wide, respectively. The local diamond and triangle images were approximately 1.25 cm high and 1.25 cm wide. The total familiarization display subtended approximately 12° horizontal and either 12° (A) or 9° (S) vertical visual angle from the infant's viewpoint. Each of the elements subtended approximately 1.2° horizontal and 1.2° vertical visual angle. The test stimuli consisted of the same images, sized approximately 12 cm high and either 12.7 cm (A) or 9 cm (S) wide, made of diamonds and triangles approximately 1.25 cm high and 1.25 cm wide separated by a distance of 9 cm. The entire test display subtended approximately 28° horizontal and 12° vertical visual angle from the infant's viewpoint. Similar familiarization designs have been utilized with success in previous visual change detection and hierarchical processing research (e.g., Colombo, Freeseman, Coldren, & Frick, 1995; Quinn, Bhatt, Brush, Grimes, & Sharpnack, 2002).

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Change Detection Task

The visual acuity of infants aged 6 to 12 months of age is believed to be fairly stable and, on average, somewhere between 20/20 and 20/100 (Dobson & Teller, 1978; Mayer & Dobson, 1982; McDonald, Dobson, Sebris, Baitch, Varner, & Teller, 1985; Sokol, 1978). Following the definition of 20/20, a person with 20/20 visual acuity has a minimum angle of resolution of 1 arcminute or $1/60°$ at approximately 6 m, and a person with 20/100 visual acuity has a minimum angle of resolution of 5 arcminutes or $5/60°$ at approximately 6 m (Holladay, 1997). Therefore, an infant with visual acuity somewhere between 20/20 and 20/100 should have a minimum angle of resolution between $0.02°$ and $0.08°$ in the present configuration in which the infant is approximately 60 cm from the presented stimulus. Accordingly, the 6- to 12-month-old infants should easily be able to detect, parse, and accurately perceive each of the local elements that subtend a minimum angle of $1.2°$, which is much larger than the size that is necessary for the worst predicted visual acuity.

To verify that the stimuli were appropriate given infant visual acuity, the infants also participated in a change detection task immediately following the visual familiarization task. The infants viewed two simultaneous streams of visual information for approximately 20 seconds. In one visual stream, the stimulus was a repeated, unchanging diamond. In the second visual stream, the stimuli were repetitions of alternating diamonds and triangles. If the infants could detect the differences between the local elements of the changing and unchanging stream, the infants should look reliably longer at a stream of choice. If the infants were not able to distinguish between the two local elements, both streams should look similar, and no preference should be detected.

The images were identical to the local elements of the visual familiarization task, sized approximately 1.25 cm high and 1.25 cm wide and subtending approximately 1.2° horizontal and 1.2° vertical visual angle. The visual streams were separated by 28.5 cm and subtended a total visual angle of 27° horizontal and 1.2° vertical.

Manual Familiarization Task

To explore the generalizability of a local or global processing style to a naturalistic setting, the infants also participated in a manual familiarization paradigm. The infant sat on his or her parent's or family member's lap close to a table in a position that allowed the infant to easily reach for and play with objects on the table. The experimenter sat across from the infant at a distance of approximately 75 cm. The infant was given one of the following hierarchical local-global objects: an S made of local triangles, an S made of local diamonds, an A made of local triangles, or an A made of local diamonds (see Figure 2). The selected object differed from the image that the infant viewed in the visual familiarization task in both the global and local properties. For example, if the infant viewed an A made of local squares in the visual familiarization task (as in Figure 1), he or she was given an S made of local triangles in the manual familiarization task (as in Figure 2). The infant was given the choice between either blue or pink objects to increase interest in the objects. The same object was presented within reaching distance at the midline 6 times for approximately 15 seconds, totaling roughly 90 seconds of exposure to the familiarization stimulus. After the familiarization period, the infants were given a paired-choice test. One of the test stimuli was identical to the familiarization stimulus at the global level but different at the local. The other test stimulus was identical to the familiarization stimulus at the local level but different at the

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global level (Figure 2). Because infants in this age range typically show a preference for novel stimuli, it was expected that the infant would attend to the novel stimulus at test. As with the visual familiarization task, the test trials paired the novelty of a local change with the novelty of a global change and, based on the infant's novelty preference, was used to estimate which change was the most salient. The change that the infant attended to most during the test trials was assumed to reflect the aspect of the stimulus that the infant found most salient during familiarization, which made the change at test in that level the more novel change. The test stimuli were given to the infant twice for 10 seconds, counterbalancing the sides. The familiarization and test stimuli objects were placed within the infant's reach and were equally accessible. Similar object familiarization designs with longer durations and sequential test trials have been utilized with success in previous categorization and attention studies (Oakes, Madole, & Cohen, 1991; Oakes & Tellinghuisen, 1994). The present version of the task was altered slightly to match the visual familiarization paradigm more exactly and to allow for more direct comparisons between the preference results elicited by the two similar tasks.

The global A and S familiarization objects were made of light foam material and thus were ideal for easy grasping, lifting, and manipulation. Because successful reaching and grasping typically begins around 4 months of age (von Hofsten, 1969), it was expected that all of the 6-month-old (as well as the 9- and 12-month-old) infants would have adequate expertise in reaching and grasping, and thus be able to manipulate the lightweight objects for exploration purposes, such as looking, touching, and mouthing. As expected, all of the infants were able to easily reach for, grasp, and manipulate the experimental stimuli.

Figure 2: Manual Familiarization Design and Stimuli Example

The global familiarization objects were approximately 12 cm high and either 12.7 cm (A) or 9 cm (S) wide. The local diamond and triangle elements were approximately 1.25 cm in high and 1.25 cm wide. The test stimuli consisted of the same objects, sized approximately 12cm high and either 12.7 cm (A) or 9 cm (S) wide, made of diamonds and triangles approximately 1.25 cm high and 1.25 cm wide, and separated by a distance of approximately 9 cm so that they were equally accessible.

The objects were identical in size to the images presented during the visual familiarization tasks. Assuming that the arm lengths of the 6- to 12-month-old infants were no greater than 60 cm (approximately 2 feet), the toys placed within the infants reach and in the infant's grasp were no farther than 60 cm from the infant at all times. During much of the task, the objects were much closer as the infant visually, manually, and orally explored them. If the infant threw or dropped the object, the experimenter

immediately returned it to within reaching distance. Given this configuration, the

minimum visual angles were approximately equal to or larger than those calculated for

the visual familiarization task. Because the visual acuity of infants 6 to 12 months of age

is believed to be fairly stable and on average somewhere between 20/20 and 20/100 (as

described above), a 6- to 12-month-old infant should have an angle of resolution between

0.02° and 0.08° at 60 cm. Therefore, the infants should easily be able to detect, parse,

and accurately perceive each of the local elements that subtend a minimum angle of 1.2°,

which is much larger than what is necessary for the worst predicted visual acuity, and the

global configurations for both the familiarization and test stimuli.

Sequential Touching Task

During the sequential touching task, the infant remained seated on his or her

parent's or family member's lap close to a table in a position that allowed the infant to

easily reach for and play with objects on the table. The experimenter sat across from the

infant at a distance of approximately 75 cm and presented the infant with a tray of eight

items. Four of the items shared one global property (four elephants), and four shared a

different global property (four monkeys). A different four (two from each global

property) shared one local property (red hearts), and the remaining four shared a different

local property (yellow stars). In Figure 3, the stimuli are organized to demonstrate the

shared properties. The tray was available for the infant to explore for two minutes, with

all of the items arranged randomly and within reaching distance. Sequential touching

tasks have been successfully used many times in previous research to demonstrate

categorization, including categorization based on whole or part properties (Mandler,

Bauer, & McDonough, 1991; Mandler, Fivush, & Reznick, 1987; Oakes, Plumert,

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Lansink, & Merryman; 1996; Rakison & Butterworth, 1998; Starkey, 1981). Although this task may have been less effective for the 6-month-olds due to motor and attention issues, it had great potential to be informative in the 9- and 12-month-old age groups (Starkey, 1981) and was worth conducting as an aspect of object exploration for the 6-month-old age group.

Figure 3: Sequential Touching Stimuli

Play Exploration Task

During the free-play period, the infant continued to remain seated on his or her parent's or family member's lap across the table from the experimenter at a distance of approximately 75 cm. The experimenter presented the infant with a toy truck for three minutes and a rubber duck for three minutes to play with as he or she normally would (see Figure 4). The order of presentation of the truck and duck was randomly assigned for each infant to avoid any potential order influence. Both the truck and duck have local properties (e.g., the duck's bow) and global properties (e.g., the entire duck) that allow for ample and detectable exploration at either level of specificity. The two objects were chosen due to their similarity of multiple local properties but also for specific differences

that might elicit differential behavior, such as the presence of a face or not (e.g., the duck

had a face but the truck did not), the soft texture or hard plastic (e.g., the duck was soft

and the truck was hard), and the immobile or mobile local features (e.g., aspects of the

duck could not move but the car wheels could rotate). These properties are confounded,

but a systematic difference between the free-play stimuli could be interpreted within the

context of discovery.

Figure 4: Free-play Stimuli

Data Coding

Video recordings of the entire study were captured using a USB webcam for the

visual familiarization and change detection task and a mounted wall camera for the

manual familiarization, sequential touching, and play tasks. Students in the laboratory

were trained to code the videos by receiving detailed explanations of each of the variables

of interest by experienced coders and were observed and helped while coding the first

video(s). I carefully monitored data from new coders for any systematic errors.

Trained observers coded the video recordings of each task using custom software with 0.2s frames of the video (Libertus, 2008). This software allows coders to progress through the video by looking at still frames from every 0.2 seconds of the task. The coders then mark the variables of interests for each frame. This technique allows coders to proceed through the videos as slowly (or quickly) as necessary and supports a high level of precision.

For all tasks, the observers coded "looking time" at the task stimuli, and the coding software provided summary statistics of the total time spent looking at each stimulus. Looking time was defined as time spent looking at an image based on the infant's fixation direction during visual familiarization and change detection tasks or looking at an object during the manual familiarization, sequential touching, and play tasks.

For the manual familiarization, sequential touching, and play tasks, the trained observers also used the video recordings and custom software to capture infant manual behavior. The observers coded touching, grasping, mouthing, bimanual interaction, lifting, and fingering. Touching was defined as time spent with the fingers placed on any part of the object. Grasping was defined as time spent with the fingers curled around the object. Mouthing was defined as time spent with the object on or in the mouth or being explored by the tongue. Bimanual interaction was defined as time spent with both hands on one object. Lifting was defined as the amount of time that an object was completely lifted from the table. Fingering was defined as time spent engaging in detailed exploration using the fingers on a part of an object. The coding software provided total summary times for each of the coded manual behaviors for every child for each task

separately. Finally, for the sequential touching task, trained observers recorded the number of interactions with each of the eight objects and the sequential order of these interactions.

CHAPTER 3

RESULTS

Visual Familiarization Task

Data from 81 of the 90 participants were used for visual familiarization analyses.

Data from the remaining 9 infants were not used due to experimenter error, fussiness, or

maternal distraction. Table 2 summarizes the distribution of participants.

Table 2: Description of Participants for the Visual Familiarization Task

		6-month-olds	9-month-olds	12-month-olds
Visual **Familiarization**	**Total N (Age)**	25 (6.57)	29 (9.57)	27 (12.51)
	Males	13	13	13
	Females	12	16	14
	Excluded:			
	Exp. Error	3	1	0
	Fussiness	1	1	1
	Distraction	1	0	1

The primary variables of interest were the percentage of looking time during the

familiarization period and the proportion of looking time at each of the two test stimuli

during the test trials. Proportion of looking time at each of the two test stimuli was

calculated by dividing the infant's looking time towards one of the stimuli by the total

looking time during the test trials. The use of percentage of looking time and proportion

of looking time is the standard technique for analyzing familiarization and paired choice

paradigms. Statistically, this practice suffers from placing individuals on a continuous

scale despite the fact that the paradigm is meant to dichotomously identify a "choice" at

the test trials. For the purpose of cohesion with previous research, a continuous scale is

used in this study for all tasks; however, it is important to keep this conceptual flaw in mind.

All coders were blind to the infant's familiarization stimulus or the specific locations (left or right) of the presented test stimuli. For the purpose of measurement reliability, a second coder recoded a random subset of a fourth of the videos (25 of 81 videos). A third coder settled discrepancies greater than 20% during the test trials for 6 of the videos, and the original codes from coder 1 or coder 2 that most closely matched coder 3 were used in the final analyses. For two videos, a fourth coder was necessary to settle inconsistencies among the first three coders. In one case, the third and fourth coder matched most closely, and the data from coder 3 was used in the final analyses. In the second case, coder 4 matched most closely with coder 2, and the data from coder 2 was maintained for the final data analyses. Reliability was compared for percentage of looking time at each of the two test stimuli during the duration of the test trials, with reliability defined as the Pearson's correlation between two different coders. Several individual coders acted as "coder 1" and / or "coder 2" to avoid any systematic errors that could affect the Pearson's correlation without reflecting coder agreement. The reliability was 84% for the globally changed stimulus and 90% for the locally changed stimulus. These reliability figures were considered to be good considering the technology (webcam) and close spatial proximity of the test stimuli (9 cm).

As can be seen in Table 3, the average percentage of looking time as well as the pattern of looking time during familiarization was similar for the three age groups. All of the groups demonstrated a decrease in looking between the first and second half of the familiarization trials, indicating some degree of habituation throughout the duration of the

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familiarization period. Percentage of looking time between groups did not differ for the first half of the familiarization trials, the second half of the familiarization trials, the entirety of the familiarization trains, or the decrease in looking time from the first to the second half of the familiarization trials (all $F_{2,78} < 1.14$, $p > 0.33$).

Table 3: Percentage of Looking Time During the Familiarization Trials for the Visual Familiarization Task

		First Half of Familiarization	Second Half of Familiarization	Total
6-month-olds	Mean (Standard Deviation)	52.88% (16.21%)	44.52% (15.87%)	48.00% (14.36%)
9-month-olds	Mean (Standard Deviation)	50.38% (15.90%)	42.69% (17.03%)	46.55% (14.79%)
12-month-olds	Mean (Standard Deviation)	54.85% (19.39%)	49.07% (15.71%)	51.93% (15.52%)
Total	Mean (Standard Deviation)	52.33% (17.12%)	45.38% (16.27%)	48.79% (14.90%)

No effect of sex was detected for any of the age groups (6-month-olds: $F_{1,23} = 0.59$, $p = 0.45$; 9-month-olds: $F_{1,27} = 0.17$, $p = 0.69$; 12-month-olds: $F_{1,25} = 0.49$, $p = 0.49$) or overall ($F_{1,79} = 0.13$, $p = 0.72$). Similarly, there was no effect of sex on the duration of looking time during the test trials ($F_{1,79} = 0.41$, $p = 0.52$); therefore, males and females were combined for further analyses.

An age group difference was detected for duration of looking time during the test trials ($F_{2,75} = 4.91$, $p = 0.01$), and a Tukey's HSD indicated that this significant difference was supported largely by a significant difference in duration of looking time between the 9-month-olds and the 12-month-olds ($p = 0.008$). Because test trial comparisons were based on proportion of looking and, thus, take into account differences in duration of

looking time, this significance should be of little impact. However, it is a potentially

important context to remember when interpreting the results.

Paired-samples t-tests indicated no preference during the test trials for the 6-

month-old (t=-0.91, p=0.37) or 9-month-old (t=0.43, p=0.67) infants. In contrast, 12-

month-old infants significantly preferred the test stimulus with the changed local

elements (t=-3.10, p=0.005).[1] Based on the paradigm assumptions, the results indicate

that the 12-month-olds, on average, were more likely to have a locally-biased processing

style during familiarization, making the local change more saliently novel during test

(Figure 5). A distribution of the proportion of looking time at the test stimulus with the

changed global element can be seen in Figure 6.

Figure 5: Proportion of Looking Time at the Locally and Globally Changed Stimuli
During the Visual Familiarization Test Trials

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[1] The same analyses were conducted with subsets of the infants, including only infants
that demonstrated a decrease in looking between the first and second half of the
familiarization period, excluding infants that showed a 0% or 100% preference for one of
the test stimuli, or both. Only the direction of preference was altered for the 9-month-old
infants; however, the difference was minimal due to the fact the 9-month-old infants
have, on average, nearly no preference. For the 6- and 12-month-olds, neither the
direction nor the significance of the results was altered; therefore, data from all 81 infants
were included for the analyses.

Figure 6: Distribution of the Proportion of Looking Time at the Globally Changed
Stimulus During the Visual Familiarization Test Trials

Differences in the proportion of looking time at each of the test stimuli between

groups approached significance ($F_{2,78}$=2.75, p=0.07), and a Tukey's HSD multiple

comparison test suggested that the pattern was largely attributable to the differences

between the 9- and 12-month-old averages (p=0.056). These results support the

hypothesis that an important developmental shift in visual hierarchical processing occurs

between 9 and 12 months of age.

Change Detection Task

Data from 80 of the 90 participants were used for the change detection analyses.

Data from the remaining 10 infants were not used due to experimenter error, fussiness, or

maternal / sibling distraction. Table 4 summarizes the distribution of participants.

Table 4: Description of Participants for the Change Detection Task

		6-month-olds	9-month-olds	12-month-olds
	Total N (Age)	25 (6.57)	28 (9.58)	27 (12.51)
Change	**Males**	13	13	13
	Females	12	15	14
Detection	**Excluded:**			
	Experimenter Error	3	1	0
	Fussiness	1	1	1
	Distraction	1	1	1

The primary variable of interest was the proportion of looking time at each of the two streams of stimuli. Proportion of looking time at each stream was calculated by dividing the infant's looking time towards each stream by the total looking time during the trial. A second coder recoded a random subset of a fourth of the videos (25 of 80 videos). A third coder settled discrepancies greater than 20% during the test trials for 3 of the videos, and the original codes from coder 1 or coder 2 that most closely matched coder 3 were used in the final analyses. Reliability was compared for percentage of looking time at each of the two streams of stimuli and was 95% for the changing stream and 89% for the unchanging stream.

No effect of sex was detected for any of the age groups (6-month-olds: $F_{1,23}=1.80$, p=0.19; 9-month-olds: $F_{1,26}=0.001$, p=0.98; 12-month-olds: $F_{1,25}=0.39$, p=0.54) or overall ($F_{1,78}=0.05$, p=0.82); therefore, males and females were combined for further analyses.

Paired-samples t-tests indicated that every age group had a significant preference on average for the changing stimuli stream (Figure 7). Six-month-olds looked proportionally 70.08% of the time at the changing stream (t=6.41, p=0.000), 9-month-olds looked proportionally 65% of the time at the changing stream (t=4.28, p=0.000), and 12-month-olds looked proportionally 69% of the time at the changing stream (t=5.13, p=0.000).[2]

In addition, 76 of the 80 infants demonstrated a preference for one of the streams by at least 10%, indicating that they could detect a difference in the two visual streams.

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[2] The same analyses were conducted excluding infants that demonstrated a 0% or 100% preference for one of the stimulus streams. Neither the direction nor the significance of the results was altered by this deletion; therefore, data from all 80 infants were included for the analyses.
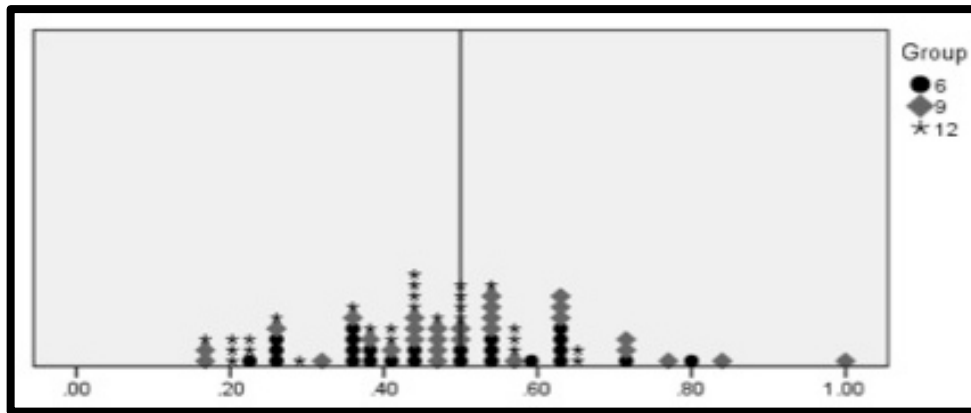
A distribution of the proportion of time spent looking at the changing stream can be seen in Figure 8. Taken together, the group results as well as the individual preferences give strong evidence that the infants could easily detect, parse, and differentiate the local elements of the visual familiarization stimuli.

Figure 7: Proportion of Looking Time at the Changing and Unchanging Stimulus Streams During the Change Detection Task

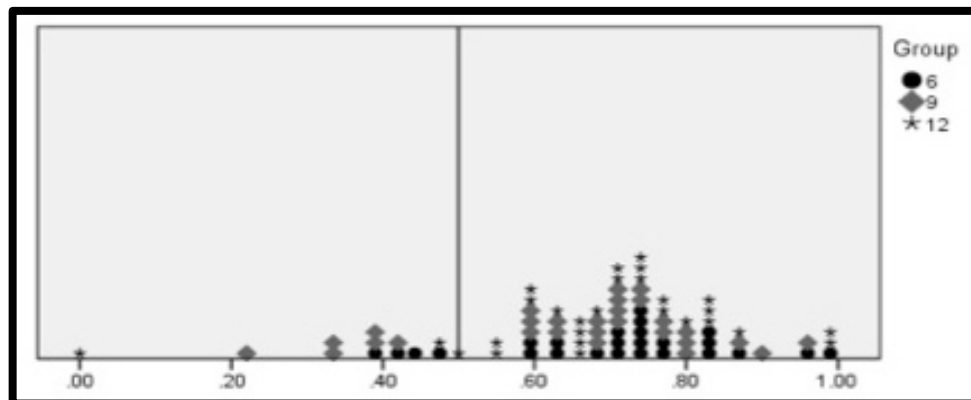Figure 8: Distribution of the Proportion of Looking Time at the Changing Stream During the Change Detection Task

Interestingly, individual looking times or preference on the change detection task were not correlated with proportion of time spent looking at either of the test stimuli during the visual familiarization test trials (r=-0.04, p=0.74).

Manual Familiarization Task

Data from 81 of the 90 participants were used for manual familiarization analyses.
Data from the remaining 9 infants were not used due to experimenter error or equipment
failure. Table 5 summarizes the distribution of participants.

Table 5: Description of Participants for the Manual Familiarization Task

		6-month-olds	9-month-olds	12-month-olds
	Total N (Age)	27 (6.58)	28 (9.54)	26 (12.52)
Manual	**Males**	14	13	13
	Females	13	15	13
Familiarization	**Excluded:**			
	Exp. Error	3	3	1
	Equip. Failure	0	0	2

The primary variables of interest were the percentage of looking and manual
interaction time during the familiarization period as well as the proportion of looking and
manual interaction time towards each of the two test stimuli during the test trials. Manual
interaction included time spent touching, grasping, mouthing, lifting, bimanual
exploration, and / or fingering. Proportion of looking time towards each of the two test
stimuli was calculated by dividing the infant's looking time towards one of the stimuli by
the total looking time during the test trials. Similarly, proportion of manual interaction
towards each of the two test stimuli was calculated by dividing the infant's manual
interaction towards one of the stimuli by the total duration of manual interaction towards
either of the stimuli during the test trials. This means that in some cases, an infant could
have more summed manual interaction time than the duration of the trial because two
toys were available to the infant throughout the test trials. Likewise, an infant could
receive a proportion of 0 for both stimuli if infant did not touch anything during test. A
score of 0 was preferred over discarding the data because "not touching" the stimuli at

test is a valid response, especially if the infant demonstrates the ability to manually interact during familiarization. Finally, a third variable was created for the test trial stimuli consisting of the sum of looking and manual interaction time for one test stimulus divided by the total amount of time the infant looked at or manually interacted with the test stimuli. In this way, a variable indicating the proportion of attention, considering both visual and manual attention, was created for each test stimulus. This variable may be a better indicator of preference because it takes into account the shift from manual (and oral) exploration to visual exploration as the infant ages across the first year.

A second coder recoded a random subset of a fourth of the videos (20 of 81 videos). Reliability was compared for percentage of looking and percentage of manual interaction towards each of the test stimuli during the duration of the test trials. For looking time, reliability was 82% for the globally changed stimulus and 93% for the locally changed stimulus, and for manual interaction, reliability was 98% for the globally changed stimulus and 99.8% for the locally changed stimulus. These reliability figures are considered to be good considering the distance of the camera for the visual codes.

Considering only the percentage of looking time during the familiarization trials (Table 6), the average percentage of looking time differed significantly across age groups for the first half of the familiarization trials ($F_{2,78}$=4.43, p=0.02), the second half of the familiarization trials ($F_{2,78}$=5.59, p=0.005), and the entirety of the familiarization trials ($F_{2,78}$=5.67, p=0.005). Tukey HSD multiple comparisons indicated a significant difference between the 6-month-olds and the 9-month-olds for the first half of the familiarization trials (p=0.01), between the 6-month-olds and both the 9- and 12-month-olds for the second half of the familiarization trials (p=0.02 and p=0.008, respectively),

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and between the 6-month-olds and both the 9- and 12-month-olds for the entirety of the

familiarization trials (p=0.007 and p=0.03, respectively). Despite differences in

familiarization, all of the age groups demonstrated a decrease in looking, indicating some

degree of visual habituation throughout the duration of the familiarization period.

Differences in the decrease in looking from the first half to the second half of the

familiarization trials were not significant across age groups ($F_{2,78}$=2.29, p=0.11).

Table 6: Percentage of Looking Time During the Familiarization Trials for the Manual
Familiarization Task

		First Half of Familiarization	Second Half of Familiarization	Total
6-month-olds	Mean (Standard Deviation)	65.04% (17.12%)	59.07% (19.21%)	61.93% (16.04%)
9-month-olds	Mean (Standard Deviation)	51.64% (16.29%)	46.93% (14.50%)	49.36% (13.92%)
12-month-olds	Mean (Standard Deviation)	57.85% (16.67%)	45.08% (15.99%)	51.23% (14.48%)
Total	Mean (Standard Deviation)	58.10% (17.39%)	50.38% (17.59%)	54.15% (15.68%)

Considering only the percentage of manual interaction time during the

familiarization trials (Table 7), the average percentage of manual interaction time differed

significantly across age groups for the second half of the familiarization trials ($F_{2,78}$=3.64,

p=0.03) and trended towards significance for the entirety of the familiarization trials

($F_{2,78}$=2.88, p=0.06). Tukey HSD multiple comparisons indicated a significant difference

between the 6-month-olds and the 12-month-olds for the second half of the

familiarization trials (p=0.02) and a difference trending towards significance between the

6-month-olds and the 12-month-olds for the entirety of the familiarization trials

(p=0.054). All of the age groups demonstrated a decrease in manual interaction, again

indicating some degree of habituation for manual interaction throughout the duration of

the familiarization period. Differences in the decrease in manual interaction from the

first half to the second half of the familiarization trials were not significant across age

groups ($F_{2,78}$=1.64, p=0.20).

Table 7: Percentage of Manual Interaction Time During the Familiarization Trials for the Manual Familiarization Task

		First Half of Familiarization	Second Half of Familiarization	Total
6-month-olds	Mean (Standard Deviation)	93.78% (5.37%)	90.85% (11.76%)	91.26% (10.66%)
9-month-olds	Mean (Standard Deviation)	86.04% (21.59%)	81.14% (28.77%)	83.50% (24.70%)
12-month-olds	Mean (Standard Deviation)	85.19% (16.54%)	74.46% (15.99%)	79.38% (14.48%)
Total	Mean (Standard Deviation)	88.35% (16.35%)	82.23% (23.00%)	84.77% (18.77%)

The differences in looking time and manual interaction during familiarization are

not surprising considering the changes in exploratory behavior, motor skills, and attention

occurring as the infant develops from 6 to 12 months of age. Around 6 months of age,

when successful reaching is still a relatively new accomplishment, exploration is reliant

on visual exploration with considerable manual and sensory exploration, often involving

uncoordinated lifting and mouthing. However, as manual dexterity increases,

coordination of visual and manual exploration also increases.

Additionally, the simplistic nature of the manual familiarization stimuli may have

engaged the 6-month-olds to visually explore longer than the 9- or 12-month-olds. Thus,

differences in looking and manual interaction times may easily be attributed to developmental changes in domains other than cognitive processing. It is important to note is that significant differences in the decrease in looking and manual interaction time did not differ between the age groups, suggesting similar patterns of habituation regardless of differences in baseline looking or manual interaction times.

A univariate ANOVA revealed no significant main effects or interactions for age group, sex, or color condition for the proportion of time looking at each of the test stimuli (all $F < 2.17$, $p > 0.12$), proportion of time manually interacting with each of the test stimuli (all $F < 3.68$, $p > 0.057$), or proportion of attention towards each of the test stimuli (all $F < 2.40$, $p > 0.09$).

The results did indicate a significant interaction between sex and color condition for total duration of visual looking ($F_{1,69} = 5.12$, $p < 0.03$). Because data analyses were conducted on proportion of looking, which takes into account differences in duration of looking, the impact of this significance should be minimal. However, it should be considered in the context of interpreting the data. There were no other significant main effects or interactions for age group, sex, or color condition for the duration of looking during the test trials (all $F < 2.73$, $p > 0.07$). Likewise, there were no significant main effects or interactions for age group, sex, or color condition for the duration of manual interaction during the test trials (all $F < 2.97$, $p > 0.0.09$). Therefore, sex and condition were combined for further analyses.

Interestingly, the main effect of color condition did trend towards significance for the proportion of time manually interacting with each of the test stimuli ($F_{2,69} = 2.98$, $p = 0.57$). Further investigation revealed that the 12-month-old infants differed in their

preference for stimuli that differed in color. Specifically, 12-month-old infants who had

the pink stimuli with blue local elements were more likely to manually interact (but not

visually look at) the global change at test as compared to 12-month-old infants who had

the blue stimuli with pink local elements (F=6.16, p=0.02). The cause of this difference

is unclear, as there is no previously established reason that blue or pink stimuli should

influence preference. No influence of color was demonstrated overall or for any other

age groups on any of the variables (all F<3.44, p>0.07), and there were no detectable

differences for sex that could be influencing the differential preference based on color.

Because the influence of color was only present for one age group on one variable and

the meaning of the influence is not known, subjects with blue and pink stimuli were

combined for further analyses, but this effect warrants future research.

Paired samples t-tests for each age group and the age groups combined revealed

no preference for either test stimulus for the proportion of looking time (all t<±1.39,

p>0.18), manual interaction (all t<±1.60, p>0.12), or the integrated attention variable (all

t<±1.01, p>0.32)[3].

The 9- and 12-month-old infant groups both had participants that did not interact

with one or both of the test stimuli. When these infants were removed from the 9-month-

old group, neither the direction nor the significance of the results was influenced;

therefore, data from all 28 9-month-olds were included for the analyses. However, the

fact that one 9-month-old did not touch either test stimulus despite demonstrating manual

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[3] The same analyses were conducted with two subsets of the infants: including only
infants that demonstrated a decrease in looking or in manual exploration between the first
and second half of the familiarization period. Only minimal fluctuations in the direction
of preference could be seen due to the fact that the proportions of looking, manual
interaction, or attention were all close to 50% for each stimulus on average when all
subjects were included. Significance was not influenced.

interaction during familiarization did influence the group's averages. This infant was coded as 0 manual interaction for the stimulus that represented the local change as well as the stimulus that represented the global change; therefore, the summation of the proportions of manual interaction with each test stimulus do not add perfectly to 1.00 as they do for each of the other groups. However, as mentioned previously, this scoring system was preferred to removing the data because not touching the test stimuli after demonstrating the ability to manually interact is a valid response to the objects.

When the one infant who only interacted with the global change was removed from the 12-month-old group, a shift in the analyses occurred. The direction did not change; however, the significance of the difference in the proportion of manual interaction with test stimuli did. The 12-month-old infants showed a preference for the local change during the test trials that trended towards significance (t=-1.98, p=0.059). These values are depicted in Figure 9.

Figure 10 displays the distributions of the proportion of looking time (a), manual interaction (b), and attention (c) towards the globally changed stimulus during the test trials for each age group. It is clear from Figure 10 that the 6-month-olds showed much more variability than the 9- or 12-month-olds for the looking time and attention variables; however, it can also be seen that most infants looked at, manually interacted with, or attended to the globally changed test stimulus approximately 50% of the time.

(a)

(b)

(c)

Figure 9: Proportion of Looking Time (a), Manual Interaction (b) and Attention (c) Towards the Globally and Locally Changed Stimuli During the Manual Familiarization Test Trials

(a)

(b)

(c)

Figure 10: Distribution of the Proportion of Looking Time (a), Manual Interaction (b), or Attention (c) Towards the Globally Changed Stimulus During the Manual Familiarization Test Trials

Concerning relations with the visual familiarization and change detection tasks, none of the variables from the manual familiarization task correlated with infant behavior on either the visual familiarization or the change detection tasks (all $r < \pm 0.18$, $p > 0.13$).

Finally, a within-subjects ANOVA indicated an interaction between proportion of looking times during the visual and manual familiarization tasks and age group trending towards significance ($F = 2.52$, $p = 0.09$). However, there were no main effects of either looking times during the two tasks ($F = 1.49$, $p = 0.23$) or age group ($F = 0.77$, $p = 0.47$). Likewise, a within-subjects ANOVA revealed an interaction trending towards significance for looking time during the visual familiarization task, manual interaction

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during the manual familiarization task, and age group (F=2.96, p=0.06). However, there was also a main effect trending towards significance of age group for manual interaction during the manual familiarization task (F=2.69, p=0.07); a Tukey HSD multiple comparison test indicated that this trend is largely due to a difference approaching significance between the 6- and the 9-month-old groups (p=0.07)[4]. The interactions between age group and within-subject factors of proportion of looking time to the globally changed stimulus during the visual familiarization test trials with proportion of looking time to the globally changed stimulus during the manual familiarization test trials (a) as well as proportion of looking time to the globally changed stimulus during the visual familiarization test trails and proportion of manual interaction with the globally changed during the manual familiarization test trials (b) are plotted in Figure 11.

(a)

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[4] All subjects were included in the within-subjects ANOVAs, including those infants who did not manually interact with one or both of the test stimuli. Not manually interacting with the test stimuli is a valid response to the stimuli, and because we do not yet understand what would constitute an "outlier" in the context of a within-subjects analysis for visual and manual familiarization, I opted include all subjects in the analyses.

(b)

Figure 11: Interactions for Within-Subject Factors and Age Group for Preference for the Globally Changed Stimulus in the Visual Familiarization and Manual Familiarization Tasks

The interactions suggest that infants have, on average, a processing style or underlying cognitive mechanism that is accessed across visual and manual familiarization tasks and that the nature and / or utilization of this mechanism may change as the infant develops through the second half of the first year. For proportion of looking times at the globally changed stimulus across tasks, it appears that variability in looking at the globally changed stimulus for visual image tasks converges on more object-based activities, regardless of age group. However, for proportion of looking time during the visual familiarization task and manual interaction time during the manual familiarization task towards the globally changed stimulus, both 6- and 12-month-old infants demonstrate higher engagement for manual interaction in the manual familiarization task. In contrast, 9-month-olds demonstrate higher engagement for looking times in the visual familiarization task.

In both interaction examples, 6- and 12-month-olds demonstrate increases in exploration during the manual familiarization task (albeit, this increase is small for the 6-month-old looking times across tasks) and the 9-month-olds show a decrease in exploration during the manual familiarization task. These patterns may simply reflect developmental patterns of motor control, with 6-month-olds participating in more oral exploration, 12-month-olds actively utilizing coordinated manual manipulations, and 9-month-olds falling in the middle of the transition. However, it may also indicate that for 6- and 12-month-old infants, the saliency of the globally changed stimulus is greater during manual exploration than during visual exploration. Thus, global processing may be more utilized or more easily demonstrated by the 6- and 12-month-olds when the stimulus is an object.

Sequential Touching Task

Data from 84 of the 90 participants were used for the sequential touching analyses. Data from the remaining 6 infants were not used due to fussiness or equipment failure. Table 8 summarizes the distribution of participants.

Table 8: Description of Participants for the Sequential Touching Task

		6-month-olds	9-month-olds	12-month-olds
	Total N (Age)	28 (6.53)	31 (9.56)	25 (12.51)
Sequential	**Males**	14	15	13
	Females	14	16	12
Touching	**Excluded:**			
	Fussiness	2	0	2
	Equipment Failure	0	0	2

The primary variables of interest were the percentage of looking and manual interaction time during the sequential touching task. A second coder recoded a random subset of a fourth of the videos (21 of 83 videos). Reliability was 95% for percent

looking time and 97% for percent manual interaction with the toys. Additional indices of sequential touching (vis., total number of objects touched, order of sequential touching, and fingering) were measured but not included in data analyses due to poor reliability. The total number of objects touched and the sequential order of interaction with the objects had extremely poor inter- and intra-rater consistency, likely due to the distance of the camera and the angle of the camera from the infant. Reliability for fingering was poor at 20%. Future research will need to take into account the challenge of coding specific, often slight, behavioral patterns by utilizing a different recording method.

No overall effect of sex was detected for looking at or manually interacting with the sequential touching stimuli (all $F < 0.52$, $p > 0.47$). Therefore, data from males and females were combined for further correlational analyses.

The amount of time the infants manually interacted with the sequential touching stimuli significantly correlated with age ($r = -0.25$, $p = 0.02$), indicating that older infants were less likely to manually interact with the objects. Not surprisingly, manual interaction was also significantly correlated with looking time during the sequential touching ask ($r = 0.32$, $p = 0.003$) such that infants who looked at the objects more also manually interact with the objects for more time.

Play Exploration Task

Data from 82 of the 90 participants were used for the analyses of duck play behavior, and data from 84 of the 90 participants were used for the analyses of truck play behavior. Data from the remaining 6 infants not included for the analyses of both duck and truck play behavior were not used due to fussiness or equipment failure. An

additional 2 infants were not included for the analyses of duck play behavior due to fussiness. Table 9 summarizes the distribution of participants.

Table 9: Description of Participants for the Play Tasks

		6-month-olds	9-month-olds	12-month-olds
Play (Duck)	**Total N (Age)**	27 (6.55)	31 (9.56)	24 (12.49)
	Males	14	15	12
	Females	13	16	12
	Excluded			
	Fussiness	3	0	3
	Equip. Failure	0	0	2
Play (Truck)	**Total N (Age)**	28 (6.55)	31 (9.56)	25 (12.51)
	Males	14	15	13
	Females	14	16	12
	Excluded			
	Fussiness	2	0	2
	Equip. Failure	0	0	2

The primary variables of interest were percentage of time looking, touching, grasping, lifting, mouthing, and bimanually interacting with the toy. A second coder recoded a random subset of a fourth of the videos (20 of 80 videos for the duck, 21 of 82 videos for the truck). Reliability was calculated by comparing percentage of time the infant was coded as looking (92% for duck, 90% for truck), touching (97% for duck, 98% for truck), grasping (88% for duck, 96% for truck), lifting (91% for duck, 96% for truck), mouthing (99.8% for duck, 98% for truck), and bimanually interacting (95% for duck, 95% for truck) with the toys. Fingering was also coded but was not included in the data analysis due to poor reliability (10% for duck, 0.01% for truck).

Overall, no effect of sex was detected for looking, touching, grasping, lifting, mouthing, or bimanually interacting with either the duck or the truck (all $F<3.02$, $p>0.09$). Data from males and females were combined for further correlational analyses.

A large number of the play behaviors were significantly correlated within and between the duck and truck (Table 10). This is not surprising within a specific toy because many of the behaviors build off one another. For example, infants looking at a toy are more likely to touch the toy than infants not looking at it. Likewise, an infant touching a toy is more likely to grasp the toy than an infant not touching it, etc. The fact that play behaviors were highly correlated between toys suggests that the infants were playing with the toys in similar ways despite many perceptual, conceptual, and functional differences between the duck and truck.

Table 10: Correlations of Play Behaviors Between the Duck and Truck
(r = Pearson Correlation, *= Significant at the p=0.05 level)

			Truck					
			Looking	Touching	Grasping	Lifting	Mouthing	Bimanual Interaction
Duck	Looking	r	0.49	0.17	0.13	-0.23	-0.12	-0.10
		p	0.00*	0.13	0.25	0.04*	0.29	0.36
		n	82	82	82	82	82	82
	Touching	r	0.12	0.59	0.55	0.23	0.36	0.39
		p	0.28	0.00*	0.00*	0.04*	0.001*	0.00*
		n	82	82	82	82	82	82
	Grasping	r	0.09	0.52	0.51	0.30	0.32	0.34
		p	0.42	0.00*	0.00*	0.01*	0.003*	0.002*
		n	82	82	82	82	82	82
	Lifting	r	0.02	0.27	0.28	0.41	0.28	0.29
		p	0.88	0.02*	0.01*	0.00*	0.01*	0.008*
		n	82	82	82	82	82	82
	Mouthing	r	-0.09	0.03	0.06	0.22	0.35	0.27
		p	0.42	0.79	0.58	0.05*	0.001*	0.02*
		n	82	82	82	82	82	82
	Bimanual Interaction	r	-0.01	0.29	0.32	0.22	0.40	0.52
		p	0.92	0.01*	0.003*	0.05*	0.00*	0.00*
		n	82	82	82	82	82	82

The percentage of time manually interacting with the sequential touching task objects was significantly and positively related to several play behaviors including touching the duck, grasping the duck, grasping the truck, lifting the truck, and mouthing the truck (all r>0.22, p<0.052), indicating that infants who manually interacted with one

set of toys also manually interacted with other toys. Interestingly, percentage of time manually interacting with the sequential touching toys was significantly negatively correlated with looking at the truck (r=-0.22, 0.05). The reason for this relation is unclear.

Additionally, age significantly correlated with duck and truck mouthing (r=-0.30, p=0.01 and r=-0.36, p=0.001, respectively) and duck and truck bimanual interaction (r=-0.28, p=0.01 and r=-0.21, p=0.053). All four correlations suggest that mouthing and bimanual behavior decrease as the infant ages, likely due to the increased dexterity and reliance on visual exploration.

Similarly, the proportion looking time at the globally changed stimulus during the manual familiarization task test trials correlated significantly with bimanual interaction with the truck (r=-0.23, p=0.05). It is likely that age is a third confounded variable in this context. Age and bimanual interaction were negatively correlated, and 12-month-old infants showed a manual interaction preference that trended toward significance for the locally changed stimulus. It is possible that the infants preferring the locally changed stimulus are also the infants who do not show much bimanual interaction, thus causing a negative correlation between proportion of time looking at the globally changed stimulus during the manual familiarization test trials and bimanual interaction with the truck.

Conversely, however, significant interactions between the proportion of manual interaction with the globally changed stimulus during the manual familiarization task test trials and lifting, mouthing, and bimanually interacting with the duck were all positive

(r=0.36, p=0.002; r=0.40, p=0.00; r=0.27, p=0.02)[5]. Similarly, proportion of attention given to the globally changed stimulus during the manual familiarization task test trials and lifting and mouthing the duck were significantly positively correlated (r=0.30, p=0.008 and r=0.24, p=0.04, respectively). The meaning of these correlations is unclear, and future research should investigate the driving factors behind these relations. However, these correlations do support the hypothesis that hierarchical processing is significantly related to play behaviors. Further research is necessary to understand the intricacies of this relation.

In the spirit of creative exploratory research, one additional statistically significant and challenging-to-understand correlation was observed. The proportion of time looking at the changing stream during the change detection task negatively correlated with visually looking at the truck (r=-0.26, p=0.03). Future research will need to explore the meaning of this relation and potential third variables that might be driving the correlation.

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[5] Because the proportion of infants preferring the stimulus reflecting the local or global change was not reciprocates among 9-month-old infants, correlations were rerun with proportion of manual interaction with the locally changed test stimulus during the manual familiarization task. Conversely to the proportion of preference for the globally changed stimulus, the proportion of preference for the locally changed stimulus was negatively correlated with duck mouthing and lifting (r=-0.28, p=0.02; r=-0.24, p=0.04).

CHAPTER 4

DISCUSSION

This dissertation included four paradigms in a multi-method, cross-sectional design aimed at understand visual hierarchical processing and its possible generalizability to more realistic and natural experiences with objects as well as relations with play and exploratory behavior for 6-, 9-, and 12-month-old infants. The results provided by each task individually as well as collectively have provided exciting results that advance our understanding of hierarchical processing and open new avenues for research to continue to understand infant development.

The visual familiarization task addressed aim 1, which was to clarify the pattern of typical visual hierarchical processing styles demonstrated by infants from 6 to 12 months of age. Counter to the hypothesized results, only the 12-month-olds showed a significant group preference during the test trials, and the group preference was for the test stimulus with the local change, not the global change as was predicted.

Several potential explanations for this pattern are possible. The first is that the methods or stimuli were potentially inappropriate for infants 6, 9, and 12 months of age. However, the methodology was a well-established familiarization paradigm that has been used to effectively evaluate infant perception (e.g., Colombo, et al., 1995; Gibson & Needham, in preparation; Quinn, et al., 2002). Similarly, the stimuli were modeled after stimuli commonly used in infancy studies of hierarchical visual processing styles and should roughly equal the stimuli complexity of previous research. Therefore, these

unexpected results are unlikely to reflect an error in methodology and can be interpreted as a reflection of infant perception.

One potential explanation addresses processing speed and attention to the familiarization stimulus, especially considering this paradigm was experimenter-controlled (familiarization) rather than infant-controlled (habituation) and, thus, every infant was exposed to the familiarization stimuli for the same duration regardless of processing speed or attention.

Previous research has suggested that 4-month-old infants who spend more time looking at an image of a face demonstrate different patterns of looking on visual hierarchical processing tasks than infants who spend less time looking at the image of a face (Colombo, et al., 1995). In that study, infants who looked at the face stimulus for longer periods of time showed no preference during the test trials of hierarchical tasks, regardless of how long they were familiarized to a specific hierarchical stimulus. Infants who looked at the face stimulus for shorter periods of time, in contrast, showed a global preference with short familiarization times and a local preference with long familiarization times (Colombo, et al., 1995). In that particular study, a "long familiarization" time was 30 s for 4-month-old infants. Thus, it could be a reasonable possibility that the 12-month-olds in the present experiment were demonstrating the same pattern as the "short lookers" in the experiment by Colombo and colleagues (1995). In the current study, the 12-month-olds were actually global biased and had already processed the global information such that they were processing the local information when they encountered the test trials. However, the 12-month-old group in this study did

not show a significantly different looking pattern in comparison with the 6- or 9-month-old infants, making this explanation challenging if not improbable.

A second possible explanation is that these results support previous findings that a local bias, which is thought to be demonstrated first in infancy, continues through the first year before transitioning to the adult global bias (Elkind, et al., 1964; Neiworth, et al., 2006; Poirel, et al., 2008, Scherf, et al., 2009). It may be that the younger infants do not yet have an organized processing style that emerges until later in the first year and that the processing style that emerges first is the local bias.

Following the visual familiarization task, the infants participated in a change detection task, which served to support the results of the visual familiarization task by evaluating the infants' ability to visually parse and distinguish the local elements. As predicted, all of the age groups showed a significant preference for the changing stream, and all but 4 of the 80 infants demonstrated a preference of at least 10% for one of the streams. These results indicate that the vast majority, if not all, of the infants had the visual acuity needed to detect, parse, and discriminate between the local elements of the familiarization and test stimuli.

After the visual tasks, the infants participated in the manual familiarization task that addressed aim 2, which was to understand if infants would demonstrate the same hierarchical information processing styles in a more naturalistic situation. The same paradigm was used as in the visual familiarization task, but in this case, the infants were familiarized to, and tested with, objects containing both global and local elements.

Statistical analyses revealed similar patterns in both the visual and manual familiarization tasks. The 6- and 9-month-old infants did not show a preference during

the test trials, but 12-month-olds tended to prefer manual interaction with the locally

changed test stimulus. A within-subjects ANOVA supported this finding by revealing an

interaction between looking time at the globally changed stimulus during the visual

familiarization test trials, manual interaction with the globally changed stimulus during

the manual familiarization test trials, and age. As was discussed in the Results section,

this interaction suggests that infants have, on average, a processing style or underlying

cognitive mechanism that is accessed across visual and manual familiarization tasks and

that the nature and / or utilization of this mechanism may change as the infant develops

through the second half of the first year. The fact that the same patterns of preference

emerge for looking time at the visual familiarization task and manual interaction with the

manual familiarization task test trials, particularly for the 12-month-old infants, offers

compelling support that hierarchical processing represents a more overarching cognitive

style rather than a domain specific phenomenon.

Considering hierarchical processing styles as representing a more overarching

cognitive style has significant ramifications for the way we can begin to approach both

typical and atypical developmental questions. As previously discussed, individuals with

autism spectrum disorders (ASD) commonly demonstrate atypical hierarchical processing

styles and a preoccupation with parts. It is not unreasonable to suggest that the

atypicality demonstrated in hierarchical processing could greatly influence the

information individuals with ASD are perceiving, not only in the visual domain but also

when interacting with objects in the environment. This suggestion lends support to the

hypothesis that atypical perception could influence the development of atypical behaviors

common to ASD, especially if biases in hierarchical processing in both the visual and

manual domains can be seen as early as 12 months of age, when many other early

indicators of ASD have been detected (e.g., Gomez & Baird, 2005; Ozonoff, et al., 2008;

Watson, Baranek, Crais, Reznick, Dykstra, & Perryman, 2007).

Finally, the infants participated in a sequential touching task and a free-play task

with a duck and truck to address aim 3, which was to explore the relation between

hierarchical information processing styles and object exploration and play behaviors.

The results from these tasks support the hypothesis that hierarchical processing is related

to object exploration and are in line with previous claims that hierarchical perceptual

processing may be related to behavioral output (Happé, 1999; Happé & Frith, 2006;

Happé & Booth, 2008; Mottron, et al., 2006).

This dissertation had several limitations that should be addressed in future

research. The first limitation was the relatively small sample size. Although this study

had very low attrition rates within and across participants, each age group was composed

of approximately 30 participants. When individual task attrition is considered, sample

sizes were typically between 20 and 30. Power analyses indicate that smaller effect sizes,

which are not unreasonable to predict in infancy perception, may not have been detected.

Because 20 to 30 participants in each age group is not significantly different from many

of the previous sample sizes from infant perceptual research, I find this limitation to be

minimal but worth mentioning. Future studies should consider larger group sample sizes.

A second limitation was this study's reliance on the use of experimenter-

controlled familiarization rather than infant-controlled habituation. In an effort to make

the visual and manual familiarization tasks as similar as possible, I utilized a

familiarization technique because an infant-controlled sequence was not possible during

the live manual paradigm. Therefore, both tasks were constrained to familiarization so that the results could be compared reasonably. However, assumptions about novelty preferences during the test trials that are considered standard for infant-controlled habituation have been brought into question for experimenter-controlled familiarization because novelty preferences do not appear to be consistently demonstrated if the infant does not completely habituate to the familiarization stimuli (e.g., Aslin, 2007; Hunter, Ames, & Koopman, 1983; Sirois & Mareschal, 2002). If an experimenter chooses an exposure criterion that ends prior to an infant's habituation, the infant will likely not be displaying a novelty preference at test, and it is challenging to detect when this is the case using an experimenter-controlled familiarization. Despite this concern, the infants in the present study did show a decrease in looking time and / or manual interaction to the stimulus over the familiarization periods, indicating that some habituation had occurred. Similarly, when individual infants that showed a decrease in looking were the focus in the analyses, the results did not change. Thus, the decision to utilize familiarization to maximize the similarities between visual and manual familiarization tasks likely outweighed the criticism that could emerge for using familiarization rather than habituation in this study. If future research could accommodate habituation during a manual task, researchers should consider using infant-directed exposure to the stimuli so that the novelty assumptions are more explicitly appropriate.

A third limitation was the distance and angle of the camera used to film infant behavior. The camera was mounted in the corner of the room, behind the experimenter's shoulder. This is an ideal camera orientation to capture all of the interactions between experimenter, parent, and infant as well as the majority of interactions between the infant

and the object(s). However, a broad camera angle did not allow for more refined coding necessary for measuring subtle behaviors, such as fingering, or capturing the specific interaction sequences during the sequential touching task. Future research should utilize multiple camera angles, including one camera that is specifically set to focus on the infant's manual interaction with the objects.

Finally, as previously mentioned, we did not find a method for coding the sequential touching task reliably in a way that would reveal potentially crucial details such as the number and sequence of objects touched. This limitation was at least partially due to the distance and angle of the camera. However, it is possible that stimuli characteristics (such as size) or experimental characteristics (such as the child's relative position to the multiple objects) could have influenced the ability to code for these characteristics. Future research should note these difficulties and modify the paradigm to minimize any systematic issues that prevented accurate coding of details.

Despite limitations, this dissertation contributes significantly to our understanding of the development of hierarchical processing styles, the generalizability of hierarchical processing, and the relations between hierarchical processing and object exploration and play. Two exciting paths of research have emerged. The first path is for future research to investigate typical development of hierarchical processing as an overarching cognitive style rather than a perceptual phenomenon as well as its relation to object exploration and play. Future research should make sense of the unexpected results found in this study that 12-month-old infants demonstrate a local bias in both visual and manual familiarization tasks. These future studies should include manipulations that ensure infant habituation and the influence of differential looking times like Colombo and

colleagues (1995). Additionally, future research should focus on understanding what is surely a bidirectional relation between perception and behavior in relation to hierarchical processing. Understanding how perceptual biases influence behavior and how, in turn, that behavior influences perception from a descriptive and ultimately mechanistic viewpoint will be crucially important to understanding development.

The second path for future research is to begin investigating the development of individuals who will be diagnosed with ASD. Prospective research studies involving infants at a high risk for ASD should be conducted using the same paradigm to evaluate if similar patterns of development are observed among typical and atypical individuals. In particular, future research should evaluate if the relations between hierarchical processing styles and object exploration or play are maintained within a sample of individuals who are later diagnosed with ASD. As with typical development, understanding the bidirectional relation between perception and behavior is vitally important and may serve an atypical population to an even greater degree. Understanding this relation may allow researchers to better understand the emergence of symptoms characteristic of ASD as they relate to perception, which may lead to a better understanding of the etiology of the symptoms and, in turn, the disorder. A better understanding of the etiology of ASD will help researchers develop better identification and, ultimately, intervention strategies.

CHAPTER 5

CONCLUSIONS

As we observe and interact with the world around us, we are constantly integrating information from our environment into coherent representations of the world. In particular, our perceptual system allows us to make sense of hierarchical information, or information with at least one global or "whole" and one local or "part" characteristic. Previous research has demonstrated that typical adults and individuals with autism spectrum disorders (ASD) tend to demonstrate different hierarchical processing styles; however, it is unclear how these processing styles develop or what consequences processing styles may have on behavior. In this dissertation, 6-, 9-, and 12-month-old infants participated in a cross-sectional, multi-method study including visual familiarization, manual familiarization, sequential touching, and free play paradigms. The results indicated that 12-month-old infants have a local bias and that this bias is evident with both image and object stimuli, offering support to the idea of hierarchical processing as a general cognitive style rather than a perceptual phenomenon. Additionally, hierarchical processing styles appear to significantly correlate with exploration and play behavior, suggesting that hierarchical processing is significantly related to the way individuals interact with the world around them. The results have significant consequences for our understanding of hierarchical processing and open the door for future research on typical and atypical development.

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