INFANTS' USE OF LUMINANCE INFORMATION

IN OBJECT INDIVIDUATION

A Thesis

by

REBECCA JINDALEE WOODS

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

MASTER OF SCIENCE

May 2004

Major Subject: Psychology

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Approved as to style and content by:

Teresa Wilcox (Chair of Committee)	Carl Gabbard (Member)
Heather Bortfeld (Member)	Steve Rholes (Head of Department)

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ABSTRACT

Infants' Use of Luminance Information

in Object Individuation. (May 2004)

Rebecca Jindalee Woods, B.A., Stephen F. Austin State University

Chair of Advisory Committee: Dr. Teresa Wilcox

Recent research suggests that by 4 months of age infants are able to individuate objects using form features, such as shape and size, but surface features, such as pattern and color, are not used until later in the first year (Wilcox, 1999). The current study sought to investigate two possible explanations for this developmental hierarchy. The visual maturation hypothesis suggests that the order in which infants use features to individuate objects corresponds to the order in which they are most readily processed by the developing visual system. A second hypothesis, the information processing biases hypothesis, suggests that infants are biased to attend to form features because form features provide information that is relevant to reasoning about object interactions. One way to test these hypotheses is to investigate infants' ability to individuate objects based on luminance. Luminance is detected at birth, so, according to the visual maturation hypothesis, luminance, like shape and size, will be used to individuate objects early in the first year. However, luminance is a surface property, so according to the information processing biases hypothesis, luminance, like pattern and color, will be used to individuate objects late in the first year.

In the current study, 7-month-old (Experiment 1) and 11-month-old (Experiment 2) infants' use of luminance information in an object individuation task was investigated. The narrow-screen event-monitoring paradigm developed by Wilcox and Baillargeon (1998a) was used. Infants saw an event in which a ball moved behind a screen and a second ball emerged from behind the opposite edge of the screen. In one condition, the balls were identical, suggesting the presence of one object (same-luminance condition), and in another condition, the balls differed in luminance, suggesting the presence of two objects (different-luminance condition). The screen was either too narrow (narrow-screen event) or sufficiently wide (wide-screen event) to occlude two objects simultaneously.

Seven-month-olds looked equally at each event, whereas 11.5-month-old's looked longer at the narrow-screen event in the different-luminance condition. These results suggest that 11.5-month-olds, but not 7.5-month-olds used luminance information to conclude that two distinct objects were involved in the event, thus supporting the information processing biases hypothesis.

DEDICATION

To my devoted friend, Kristi

and

to my mother, Melane

ACKNOWLEDGEMENTS

I would like to thank my advisor, Teresa Wilcox, for her support, patience, and advice; John Mielke for his encouraging words; Kristin Atchison, Dana Heil, Abby Howell, Amanda McConnell, Erin Miller, Brenna Walker, and the undergraduate assistants of the Infant Cognition Laboratory at Texas A&M University for their help with data collection and for their friendly companionship; and the parents who kindly agreed to have their infants participate in the research.

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INTRODUCTION

One of our most basic cognitive abilities is the ability to represent the world in terms of distinct objects that persist through space and time. This capacity involves two essential components. The first is the ability to parse a visual display into specific entities; this ability is referred to as *object segregation.* The second is the ability to keep track of objects over time; this ability is termed *object individuation*. Recently, there has been a great deal of interest in the origins and the development of these two processes (e. g. Aguiar & Baillargeon, 2002; Needham, 1999, 2001; Needham & Baillargeon, 1998; Needham, Baillargeon, & Kaufman, 1997; Tremoulet, Leslie, & Hall, 2000; Wilcox, 1999; Wilcox & Baillargeon, 1998a, 1998b; Wilcox & Chapa, 2004; Wilcox & Schweinle, 2002, 2003). In an effort to create comprehensive models of object knowledge in infancy, researchers have studied questions about the extent of infants' ability to represent objects as distinct entities and about the nature and development of those abilities over time. For example, researchers are interested in learning the types of information that are attended to by infants when they are learning to individuate objects and the kinds of experiences that lead infants to attend to these types of information. Much of this research has indicated that, at an early age, infants are capable of using object features as a basis for individuation (Aguiar & Baillargeon, 2002; Wilcox & Baillargeon, 1998a,

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This thesis follows the style and format of *Developmental Science*.

1998b; Wilcox & Schweinle, 2003; Wilcox, 1999; see Wilcox, Schweinle & Chapa, 2003, for a review).

The use of feature information to individuate objects

Featural information can be divided into two broad categories: form features and surface features. Form features, such as shape, provide information about an object's 3-dimensional form. Surface features, such as color, convey information about the 2-dimensional surface of an object.

Recent research has revealed clear developmental hierarchies in the type of featural information to which infants attend when faced with an individuation problem (Wilcox, 1999). Wilcox examined infants' use of two form features, shape and size, and two surface features, color and pattern, to individuate objects. The outcome of these experiments indicated that form features were used by infants as young as 4.5 months to individuate objects, whereas surface features were not used until later in the first year. More specifically, pattern was used at 7.5 months and color at 11.5 months. Similar results have been found in research on object segregation (Needham, Baillargeon, & Kaufman, 1997), and identification (Tremoulet, Leslie, & Hall, 2001).

Explanations for infants' differential sensitivity to form and surface features

Research describing infants' sensitivity to form and surface features in object individuation tasks has proved valuable to our understanding of object knowledge in infancy, however, the reason for the observed hierarchy is unclear.

There are two possible explanations; one is based on the maturation of the visual system and the other is based on information processing biases.

One hypothesis, the visual maturation hypothesis, is that the nature of the developmental hierarchy is contingent upon the development of the visual system. According to this hypothesis, the order in which infants use featural information to individuate objects corresponds to the order in which features are detected as a result of the maturation of the visual system.

The developing visual system allows infants to detect form information (i.e. shape or size) at or shortly after birth (Bower, 1966; Slater *et al*., 1983; Slater *et al*., 1990; Slater *et al*., 1991; see Slater, 1996, for a review). In contrast, information about the surface features of an object is not readily processed for several months because the areas of the visual system that process those features are immature. For example, pattern vision is compromised by poor visual acuity. At birth infants are only able to see at low spatial frequencies making fine pattern vision unfeasible (Dobson & Teller, 1978; Banks & Salapatek, 1981; Skoczenski & Norcia, 1999; Zanker, *et. al.,* 1992; see Banks & Salapatek, 1983 and Banks & Shannon, 1993, for reviews). By 4 months, resolution acuity is sufficient to process broad stripe patterns (e. g. 1 cm wide) but does not approach adult levels until 6 or 7 months (Banks & Salapatek, 1978, 1983; Dobson & Teller, 1978), and vernier acuity does not reach adult levels until 5 to 8 years (Carkeet, *et al.,* 1997; Skoczenski & Norcia, 1999; Zanker, *et al*., 1992).

Color vision is also limited early in infancy. At birth, the visual system is unable to effectively process color information (Clavadetscher, *et al*., 1988; Rudduck & Harding, 1994). By two months, infants are able to make dichromatic discriminations (Maurer & Adams, 1987; Peeples & Teller, 1975; Teller, 1982), and although there is evidence of trichromatic vision by 3.5 months, infants' color vision remains poor until approximately 4 months (Teller & Bornstein, 1987; see Brown, 1990 for a review).

In summary, the visual maturation hypothesis provides a purely physiological explanation for the developmental hierarchy seen in infants' ability to use featural information in object individuation tasks. Infants demonstrate the ability to use shape and size information to individuate objects before they demonstrate the ability to use pattern and color information because they are able to process and make use of shape and size information earlier than pattern and color information.

However, a second hypothesis, the information processing biases hypothesis, suggests that the developmental hierarchy favoring form features reflects processing biases. According to this hypothesis, infants are biased to attend to form features because form features are more likely to remain stable over time and are important to the interpretation of most physical events (e.g. the shape or size of an object determines whether or not it will fit into a cup). In contrast, surface features are less likely to be perceived as an integral part of objects and have little bearing on the outcome of physical events (e.g. whether an object is red or blue has little to do with its ability to fit into a cup). Consequently, infants are more sensitive to form features when individuating objects.

Testing the hypotheses

How might one test these two hypotheses? One approach is to examine infants' use of an object property that is both available early in life and is a surface feature. The brightness of an object, measured by its luminance, is one such property. Newborns are capable of detecting spatial variations in luminance (luminance defined contrast discrimination), providing the contrast is high and spatial frequency is low (Adams & Maurer, 1984; Banks & Salapatek, 1978; Skoczenski, 2002) and by 2 months, infants are sensitive to even slight differences in luminance (Peeples & Teller, 1975), suggesting that infants' are able to detect luminance information as early as they are able to detect form information (shape and size). Because luminance is detected early, the visual maturation hypothesis predicts that infants will use luminance differences to individuate objects early. However, luminance is also a surface feature. Consequently, the information-processing hypothesis predicts that infants will use luminance differences to indicate the presence of distinct objects at approximately the same time that they use pattern or color differences (i.e. by 7 or 11 months). In order to test these hypotheses, the current study assesses infants' capacity to use luminance differences to individuate objects.

Methods for detecting object individuation in infants

The method most frequently used to assess infants' ability to individuate objects measures visual attention. For example, the violation-of-expectation paradigm first used by Baillargeon, Spelke, and Wasserman (1985) makes use of infants' tendency to look longer at events that are novel or surprising. Infants are presented with an event that is in accord with physical laws (consistent event) or one that violates physical laws (inconsistent event). If infants look longer at the inconsistent event than the consistent event, it is assumed that they have detected the incongruence between the physical law and the inconsistent event and are therefore aware of the physical law.

Using the violation of expectation paradigm, Wilcox and Baillargeon (1998a, 1998b) developed a task to assess infants' ability to use features to individuate objects. In this task, infants see a different- or a same-features test event. In the *different-features* test event, featurally distinct objects (e.g. a ball and a box) emerge successively to opposite sides of a narrow or a wide screen. The narrow screen is too narrow to occlude both objects at the same time, whereas the wide screen is sufficiently wide to hide both objects simultaneously (Figure 1).

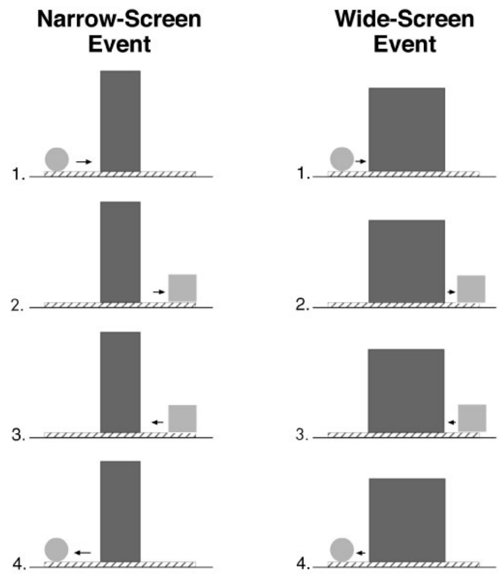

Figure 1 *Schematic drawing of the different-features narrow- and wide-screen test events*.

If infants (a) use the featural differences between the objects seen to each side of the screen to conclude that two distinct objects are present in the event and (b) correctly judge that both objects can fit behind the wide but not the narrow screen, then (c) the infants should find the narrow-screen event unexpected or surprising. Infants typically look longer at events they find novel or surprising, consequently, infants look longer at a different- features event when it is seen with a narrow rather than a wide screen. In the *same-features* test event, the objects seen to each side of the narrow or the wide screen are identical in appearance (e.g. a ball). If infants use the featural similarities of the objects seen on opposite sides of the screen to conclude that they are one and the same object, then infants should look equally at the narrow- and wide-screen events.

This task has been used successfully in numerous studies to investigate infants use of feature information in object individuation (e. g. Wilcox & Baillargeon, 1998a,1998b; Wilcox, 1999; Wilcox & Chapa, 2004). In addition, converging evidence using other paradigms provides further support for use of this method as a measure of object individuation (e. g. Tremoulet, Leslie, & Hall, 2000; Needham, Baillargeon, & Kaufman, 1997). Several additional conditions were included (Wilcox & Baillargeon, 1998a) to rule out purely perceptual explanations for infants' looking behavior.

The current research

The current research sought to test the visual maturation and the information processing biases hypotheses. Assessing infants' ability to use luminance as a basis for object individuation is ideal for this purpose because luminance is both detected early and is a surface property. Experiment 1 assessed 7.5-month-old's ability to use luminance as a basis for object individuation and Experiment 2 assessed 11-month-old infants' ability to use luminance information to individuate objects. The visual maturation hypothesis will be supported, if infants use luminance to individuate objects at an early age.

However, the information processing biases hypothesis will be supported, if infants use luminance to individuate objects late in the first year.

EXPERIMENT 1

Experiment 1 assesses the capacity of 7.5-month-old infants to use luminance as a basis for object individuation using the narrow-screen task of Wilcox and Baillargeon (1998a, 1998b). Infants saw a different- or a same-luminance test event. In the different-luminance event, infants saw a gray ball and a black ball emerge successively to opposite sides of a narrow screen or a wide screen (Figure 2). The gray and black balls varied only in their luminance measurements.

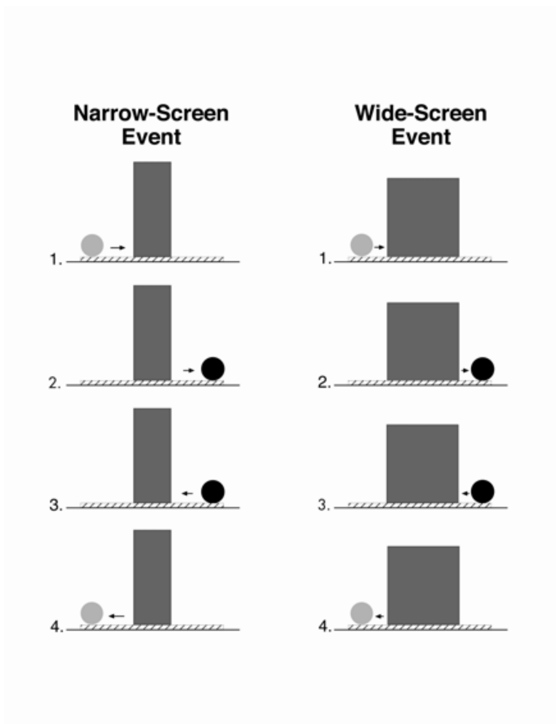

Figure 2 *Schematic drawing of the different-luminance narrow- and wide-screen test events*.

The same-luminance event was identical to the different-luminance event, with one exception: the black ball was replaced with a gray ball, so infants saw balls that were identical in their luminance measurements (Figure 3).

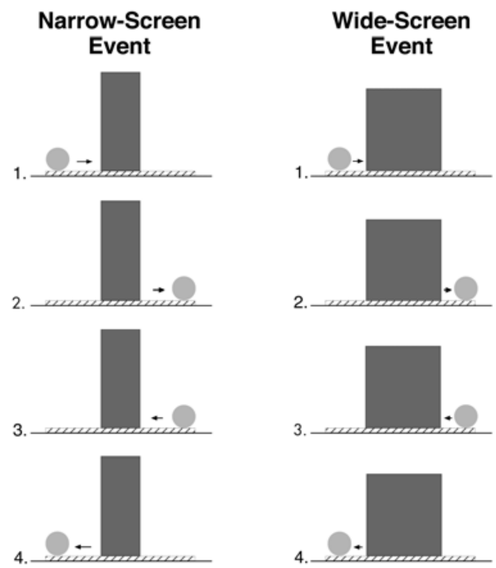

Figure 3 *Schematic drawing of the same-luminance narrow- and wide-screen test events*.

If 7.5-month-olds use luminance information to individuate objects, then the infants in the different-luminance condition should look longer at the narrow- than the wide-screen test event. Furthermore, the infants in the same-luminance condition should look equally at the two test events. This outcome would lend support to the visual maturation hypothesis. In contrast, if 7.5-month-olds fail to use luminance information to signal the presence of distinct objects, then the infants in the different- and same-luminance conditions should look equally at the narrow- and wide-screen events. This outcome would support the information-processing hypothesis.

Method

Participants

Forty healthy, full-term 7.5-month-old infants were tested (mean age = 7 months, 15 days; range = 7 months, 1 day to 7 months, 29 days). Data was collected from six additional infants but eliminated from analyses: 4 because of fussiness and 2 because of sustained thumb sucking.[1] Ten infants (6 male, 4 female) were pseudo-randomly assigned to each of four groups formed by crossing event (different- or same-luminance) with screen size (narrow or wide): different-luminance narrow-screen (*M* = 7 months, 13 days); different-luminance wide-screen (*M* = 7 months, 18 days); same-luminance narrow-screen (*M* = 7 months, 9 days); same-luminance wide-screen (*M* = 7 months, 14 days). In this and the next experiment, infants were recruited from birth announcements and commercially produced lists. Parents were offered reimbursement for their travel expenses but were not compensated for their participation.

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[1] In this and similar studies, infants who exhibit sustained thumb sucking have consistently high looking times.

Apparatus and stimuli

The apparatus consisted of a wooden cubicle 213-cm high, 105-cm wide, and 43.5-cm deep. The infant sat facing an opening 50 cm high and 93.3 cm wide in the front wall of the apparatus. A muslin-covered shade was lowered in front of the opening at the end of each trial. Two muslin-covered wooden frames, each 213 cm high and 68 cm wide, stood at an angle on either side of the apparatus. These frames isolated the infants from the experimental room. The floor and side walls of the apparatus were cream colored and the rear wall was covered with patterned contact paper. A platform 1.5-cm tall, 60 cm wide, and 19 cm deep covered with cream contact paper lay at the back of the apparatus, centered between the left and right walls. A piece of blue flannel, 6 cm wide, lay lengthwise down the center of the platform. Embedded in the center of the platform was a bi-level shelf consisting of an upper and lower shelf 16 cm apart. Each shelf was 12.7 cm wide, 13 cm deep, and 0.5 cm thick. The upper shelf sat level with the platform and the lower shelf extended underneath the platform. The bi-level could be lifted by means of a handle 19 cm long that extended from the upper shelf through an opening 16 cm high and 7 cm wide in the rear wall of the apparatus. When the bi-level shelf was lifted, the lower shelf became level with the platform. The bi-level remained hidden behind a screen throughout the experiment.

The familiarization screen consisted of a 30 cm wide and 41 cm high yellow matte board covered with clear contact paper. The narrow and wide test screens were constructed from dark blue matte board decorated with small gold stars and covered with clear contact paper. The narrow test screen was 15.5 cm wide and 41 cm high and the wide test screen was 30 cm wide and 33 cm high. The screens were mounted on a wooden stand that was centered in front of the platform. In addition to room lighting, four 20-W fluorescent light bulbs were affixed to interior walls of the apparatus.

The balls used in the familiarization and test events were made of painted Styrofoam, 10.25 cm in diameter. The balls were mounted on a Plexiglas base with a handle that extended underneath the back wall. By moving the handle along the bottom of the back wall, the experimenter could move the ball left and right along the platform. The luminance of the gray balls was 48 cd/m^2 and the luminance of the black ball was 18 cd/m^2. Luminance for all objects was measured at a centered, frontal view using a J1800 series LumaColorTM Photometer with a J1810 Chromaticity Head positioned 19 cm from the balls' most protruding point.

Events

Different-luminance narrow-screen condition

Familiarization event

At the beginning of each trial, the familiarization screen sat upright and centered in front of the platform. The gray ball sat at the left end of the platform with its center 6 cm from the left end of the platform. The black ball rested on the lower shelf of the bi-level. Each familiarization trial began with a brief pretrial during which the observers monitored the infants' looking at the ball until the computer signaled that the infant had looked for one cumulative second. After a 1-s pause, the gray ball moved to the right until it reached the upper shelf of the bi-level behind the screen (2 s). The handle of the balls base aligned with the handle of the bi-level. The bi-level was then lifted until the lower shelf was even with the platform (1 s); the black ball then moved to the right until its center was 6cm from the right edge of the platform (2 s). After a 1-s pause, the black ball returned behind the screen to its initial position on the lower shelf of the bi-level (2 s) and the bi-level was lowered so that the upper level was even with the platform (1 s). The gray ball then emerged from behind the screen and moved to the left until reaching its original starting position at the left end of the platform (2 s). The ball moved at a speed of about 12 cm/s. The entire event sequence took 12 s and was repeated until the end of the trial.

Test event

The test event was identical to the familiarization event except that the narrow test screen replaced the familiarization screen.

Different-luminance wide-screen condition

The familiarization and test events were identical to the different-luminance narrow-screen condition except that the wide test screen was used in place of the narrow test screen in the test event.

Same-luminance narrow- and wide-screen conditions

The familiarization and test events in the same-luminance narrow- and wide-screen conditions were identical to those in the different-luminance narrow- and wide-screen conditions, respectively, except that the black ball was replaced with the second gray ball that was identical to the original gray ball.

Procedure

Each infant sat on a parent’s lap centered in front of the apparatus. The infant’s head was approximately 78 cm from the objects on the platform. The parent was asked not to interact with the infant during the experiment and to keep his or her eyes closed or focused on the top of the infant’s head during each trial.

Each infant participated in a two-phase procedure that consisted of a familiarization and a test phase. During the familiarization phase, the infant saw the familiarization event appropriate for their condition on six successive trials. Each trial ended when the infant: (a) looked away for two consecutive seconds after having looked at the event for at least 12 cumulative seconds or (b) looked for 60 cumulative seconds without looking away for two consecutive seconds. The 12-s minimum value was chosen to ensure that the infants had the opportunity to see one complete event cycle on each trial. During the test phase, each infant saw the appropriate test event for their condition on four successive test trials. Each test trial ended when the infant: (a) looked away for two consecutive seconds after having looked at the event for at least six cumulative seconds or (b) looked for 60 cumulative seconds without looking away for two consecutive seconds. The 6-s minimum value was chosen to ensure that the infants had the opportunity to observe the second ball emerge to the right of the screen at least once on each test trial.

Two observers monitored the infants' looking behavior by watching the infant through peepholes on the cloth- covered frames positioned on either side of the apparatus. The observers each held a game pad connected to a computer and pressed a button when the infant attended to the event. The looking times recorded by the primary observer determined when a trial had ended and were used in the data analyses. Each trial was divided into 100-ms intervals, and the computer determined in each interval whether the two observers agreed on the direction of the infant's gaze. Inter-observer agreement was measured for 39 of the infants (for one of the infants data from only one observer was available) and was calculated for each test trial on the basis of the number of intervals in which the computer registered agreement out of the total number of intervals in the trial. Agreement averaged 92% per test trial per infant.

Preliminary analysis of the infants' mean looking times during the test trials did not yield a significant Sex X Event (different versus same luminance) X Screen Condition (narrow versus wide) interaction ($F(1,31) = 0.41$, $P = 0.53$); the data were therefore collapsed across sex in subsequent analyses.

Results

Familiarization trials

Infants' mean looking times during the familiarization trials were analyzed by means of a 2 x 2 analysis of variance (ANOVA) with event (different- or same- luminance) and screen size (narrow or wide) as between-subjects factors. The main effects of event ($F(1, 36) = 0.48$, $P = 0.50$) and screen size ($F(1,36) = 0.02$, $P = 0.88$) were not significant nor was the interaction between event and screen size ($F(1,36) = 0.53$, $P = 0.47$). These results indicate that the infants in the four conditions did not differ reliably in their mean looking times during the familiarization trials (different-luminance narrow-screen, $M = 37.52$, SD = 10.24; different-luminance wide-screen, $M = 34.60$, SD = 11.46; same-luminance narrow-screen, $M = 32.79$, SD = 9.95; same-luminance wide-screen, $M = 34.73$, SD = 10.50).

Test trials

The infants' looking times during test trials were averaged and from these, group means were calculated ($M = 19.39$, SD = 7.12; different-luminance wide-screen, $M = 18.54$, SD = 8.18; same-luminance narrow-screen, $M = 18.80$, SD = 7.54; same-luminance wide-screen, $M = 16.73$, SD = 9.12). To control for baseline differences between groups looking times were analyzed by means of a 2 X 2 analysis of covariance (ANCOVA) with event (different- or same-luminance) and screen size (narrow or wide) as between-subjects factors and familiarization trial as a covariate (adjusted means were: different-luminance narrow-screen, *M* = 18.27, SD = 5.66; different-luminance wide-screen, *M* = 16.71, SD = 5.61; same-luminance narrow-screen, *M* = 18.67, SD = 5.66; same-luminance wide-screen, *M* = 16.81, SD = 5.61), (Figure 4). The main effects of event ($F(1, 35) = 0.64$, $P = 0.43$) and screen size ($F(1, 35) = 0.01$, $P = 0.91$) were not significant, nor was the interaction between event and screen size ($F(1, 35) = 0.00$, $P = 0.93$) These results indicate that the infants in each of the four groups looked about equally during the test events.

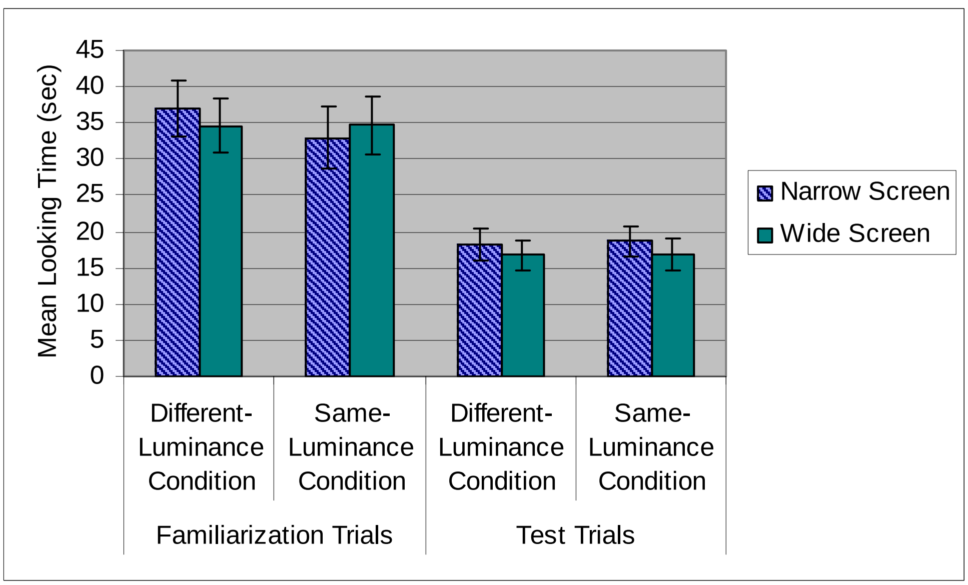

Figure 4 *Mean looking times of the 7.5-month-old infants in Experiment 1 during the familiarization and test trials*.

Discussion

The 7.5-month-olds in Experiment 1 in the different-luminance and same-luminance conditions looked equally at the narrow- and wide-screen test events.

These results suggest that the 7.5-month-olds failed to use luminance differences to individuate objects.

Infants are able to detect luminance differences at birth (Adams & Maurer, 1984; Banks & Salapatek, 1978; Peeples & Teller, 1975 see Skoczenski, 2002 and Banks & Ginsburg, 1985 for a review), however, luminance is not attended to as a means for individuating objects at 7 months. In contrast, shape and size (also detected at birth, Bower, 1966; Slater *et al.,* 1983; Slater *et al*., 1990; for a review, see Slater, 1996) are used as a basis for individuation by 4 months (Wilcox, 1999). Thus, these results are most consistent with the information processing biases hypothesis which proposes that infants view surface features, including luminance, as less relevant than form features when making individuation judgments and therefore do not attend to surface features until late in the first year. However, the negative results of Experiment 1 leave unanswered the question as to when infants do view luminance information as relevant to object individuation. A second experiment was conducted to examine older infants' use of luminance to individuate objects.

EXPERIMENT 2

Experiment 2 assesses developmental changes in infants' capacity to use luminance differences to individuate objects. If infants treat luminance as they do other surface features, we might expect them to identify luminance information as relevant to the individuation of objects near the same age that they identify other surface features relevant. Previous research has indicated that infants use pattern to signal the presence of two distinct objects at 7.5 months and color at 11.5 months (Wilcox, 1999). The results of Experiment 1 indicate that infants do not use luminance to individuate objects at 7.5 months. However, it is possible that infants will draw on luminance information at the same age that they use color information (i. e. 11 months). Consequently, Experiment 2 investigates 11.5-month-old's ability to use luminance to individuate objects using a procedure similar to that of Experiment 1. That is, infants saw the different- or same-luminance event with a narrow or wide screen.

Method

Participants

Participants were twenty-eight healthy, full-term 11.5-month-old infants (mean age = 11 months, 18 days; range = 11 months, 8 days to 12 months, 3 days). An additional three infants were tested, but were eliminated from the analysis: 2 because of procedural problems and 1 because of sustained thumb sucking. Seven infants (4 male, 3 female) were pseudo-randomly assigned to each of the four groups: different-luminance narrow-screen (*M* = 11 months, 22 days); different-luminance wide-screen (*M* = 11 months, 18 days); same-luminance narrow-screen (*M* = 11 months, 19 days); same-luminance wide-screen (*M* = 11 months, 17 days).

Apparatus and stimuli

The apparatus and stimuli used in Experiment 2 were identical to those used in Experiment 1.

Events and procedure

The familiarization and test events in the different- and same-luminance narrow- and wide-screen conditions were identical to those of the different- and same-luminance narrow- and wide-screen conditions of Experiment 1. The procedure was identical to that of Experiment 1 except for the number of familiarization and test trials. Because older infants typically become bored more quickly than younger infants, the 11.5-month-old's were presented with four (rather than six) familiarization trials and two (rather than four) test trials.

Inter-observer agreement was calculated in the same manner as Experiment 1. Inter-observer agreement averaged 92% per test trial per infant. Preliminary analysis of the infants' mean looking times during the test trials did not yield a significant Sex X Event (different versus same luminance) X Screen Condition (narrow versus wide) interaction ($F(1,20) = 0.00$, $P = 0.97$); the data were therefore collapsed across sex in subsequent analyses.

Results

Familiarization trials

Looking times during familiarization trials were averaged over the four trials. The infants' mean looking times were analyzed by a 2 x 2 ANOVA with event (different- or same- luminance) and screen size (narrow or wide) as between-subjects factors. The main effects of event ($F(1,24) = 3.71$, $P = 0.07$) and screen size ($F(1,24) = 0.93$, $P = 0.35$) were not significant. In addition, the interaction of event X screen size was not significant ($F(1,24) = 0.31$, $P = 0.58$). These results indicate that looking times during familiarization trials for the infants in the four conditions were not reliably different (different-luminance narrow-screen, $M = 36.22$, SD = 13.03; different-luminance wide-screen, $M = 34.76$, SD = 10.15; same-luminance narrow-screen, $M = 31.31$, SD = 8.18; same-luminance wide-screen, $M = 25.87$, SD = 4.34).

Test trials

Looking times during test trials were averaged over the two test trials (different-luminance, narrow-screen, $M = 30.44$, SD = 11.88; different-luminance, wide-screen $M = 17.31$, SD = 9.43; same-luminance, narrow-screen $M = 15.34$, SD = 6.60; same-luminance, wide-screen $M = 15.37$, SD = 7.70). To control for baseline differences, infants mean looking times (Figure 5) were analyzed by means of a 2 X 2 ANCOVA with event (different- or same-luminance) and screen size (narrow or wide) as between-subjects factors and familiarization trial as a covariate. The main effect of event ($F(1,23) = 3.27$, $P =$

0.08) and screen size ($F(1,23) = 2.63$, $P = 0.12$) were not significant. The interaction between event and screen size, however, was significant ($F(1,23) = 4.52$, $P = 0.04$). Planned comparisons, using adjusted means, indicated that the mean looking time of the infants who saw the different-luminance, narrow-screen event ($M = 29.21$, SD = 9.10) was reliably longer than that of the infants who saw the different-luminance, wide-screen event ($M = 16.52$, SD = 8.96), $F(1,23) = 7.19$, $P < 0.05$; the mean looking time of infants who saw the same-luminance, narrow-screen event ($M = 15.55$, SD = 8.86) and wide-screen event ($M = 17.17$, SD = 9.39) did not reliably differ, $F(1,23) = 0.12$.

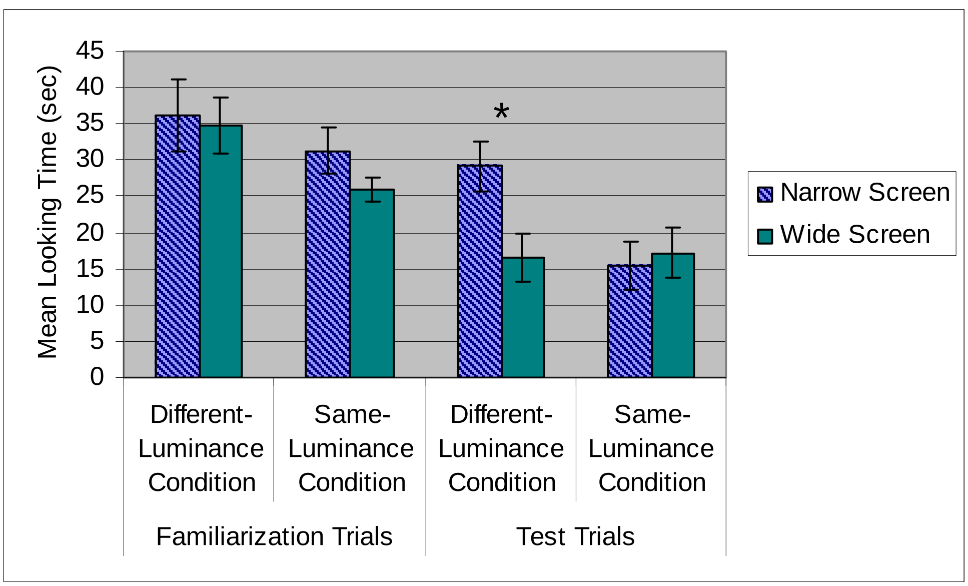

Figure 5 *Mean looking times of the 11.5-month-old infants in Experiment 2 during the familiarization and test trials.*

Discussion

The 11.5-month-old infants, who saw the different-luminance events in Experiment 2 looked significantly longer at the narrow- than the wide-screen test events whereas 11.5-month-olds who saw the same-luminance events looked equally at the narrow and wide-screen test events. These results suggest that the 11.5-month-old infants: (a) concluded that the gray ball, seen to the left side of the screen, and the black ball, seen to the right side of the screen, were distinct objects; (b) accurately judged that the combined width of the two balls allowed them to be concealed behind the wide, but not the narrow screen; and that (c) infants who saw the different-luminance, narrow-screen event were surprised when this judgment was violated. These results suggest that luminance, like other surface properties, is used as a basis for object individuation late in the first year, thus further supporting the information processing biases hypothesis.

CONCLUSIONS

Results from Experiment 1 indicate that by 7.5 months, infants look about equally at the narrow- and wide-screen test events in both the different- and same-luminance conditions, suggesting that by 7.5 months, infants do not use the luminance of objects as a basis for object individuation. In contrast, results from Experiment 2 indicate that 11.5-month-old infants look longer at the narrow- than the wide-screen event in the different- but not the same-luminance condition, suggesting that by 11.5 months, infants have identified the luminance of objects as a relevant source of information for individuation. These results, in conjunction with previous studies conducted by Wilcox (1999), provide support for the information processing biases hypothesis which predicts that infants will use surface features (including luminance) later than they use form features to individuate objects.

The significant of luminance to visual perception

Results from the current study indicate that infants begin to attend to luminance information when individuating objects at the end of the first year, the same time that they begin to spontaneously attend to other surface properties of objects. This is intriguing because the information derived from luminance is essential for visual perception. Unlike other surface properties, luminance is a uniquely basic element of our perception of the visual world. Differences in luminance between adjacent areas (*contrast*) define form.[2]

However, as a surface feature, luminance also has the ability to provide additional information once form has been extracted. Within each form, luminance can enhance the description of the object by providing more detailed information. Thus, the function of luminance is twofold: Contrast defined by luminance can be used in form perception, for example, to separate figure from ground. It can also be recognized as an integral property of the object itself and may then be used to identify an object or, as in object individuation, be used to keep track of objects through space and time.

Unlike color, luminance information is available at birth; therefore during the first several months of life luminance is the primary means for conveying information about form in both static and moving displays. During these first few months, luminance information may be attended to for the sole purpose of extracting form information. The current study supports this supposition by providing evidence that luminance information, while used extensively as an indicator of form, is not attended to in its capacity as a surface property of objects until much later.

[2] It should be noted that form can also be perceived as a result of contrasting color; however color information is not essential for maneuvering within a 3-dimensional world. For example, achromatopsics can see only shades of gray, yet are able function relatively well in a color-free environment.

The current research suggests that the hierarchical nature of infants' use of object features for individuation and other cognitive tasks cannot be entirely explained by the visual system's capacity to process feature information. However, the nature and development of the visual system may provide a foundation for this trend.

Neurological foundations

Research investigating the development of visual pathways provides a neurological account of infants' greater attention to form than to surface information and helps to explain why luminance is more likely to be used to convey form than it is to be bound to objects as a defining feature.

Livingstone and Hubel (1987, 1988) discuss psychophysical evidence for two distinct pathways within the human visual processing stream. The magnocellular pathway begins in the magnocellular layers of the lateral geniculate nucleus (LGN) and projects information to the primary visual cortex (V1). Johnson (1990) provides evidence that the magnocellular pathway becomes functionally mature at approximately 2 months postnatal. On the other hand, the parvocellular pathway, originating in the parvocellular layers of the LGN and projecting to V1, does not mature until infants are about 3-6 months (Johnson, 1990). The magnocellular stream has been identified as being responsible primarily for motion, depth, and location information whereas, the parvocellular stream is important for the processing of form, pattern, and color information. Luminance information is processed by both of these systems, but each system treats this information in different ways.

Within the earlier maturing magnocellular stream, luminance contrast (particularly for moving stimuli) is used to convey information about shape and size information, however, the coding for the relative luminance of the object itself is lost (e. g. orientation cells will fire just as strongly for black on white as they will for white on black).

The parvocellular stream also processes luminance information, but rather than being selective for contrast, the parvocellular stream treats luminance as it does color. Information is used to describe the surfaces of objects and enables us to distinguish between surfaces. Without this information, all homogeneous surfaces would look the same (e. g. the green “go” light would look identical to the red “stop” light).

The differential development of the magno- and parvocellular pathways provides a neurological basis for infants’ greater sensitivity to form information. Within the magnocellular stream, luminance information itself is lost in favor of the information it carries (i. e. form), therefore luminance information in its function as a surface feature is carried only through the parvocellular stream which, it has been suggested (Johnson, 1990), develops later than the magnocellular stream. Form information, on the other hand, also processed by both the magnocellular (e. g. through motion) and the parvocellular (e. g. through orientation selectivity) systems, is preserved in both streams and at higher levels of processing. Thus, even at this early level of visual processing, form information has an advantage over surface information. It seems that our visual system is set up to ensure the processing of form information thus beginning a chain of events that lead infants to attend to form in favor of surface features.

As the magno- and parvocellular streams project to higher visual areas, form retains its advantage over surface features. Beyond the LGN and primary visual cortex, object information is processed by two major pathways (Underlieder & Mishkin, 1982). Information from the magnocellular pathway projects primarily to the dorsal (parietal or “where”) stream which processes information about the temporal and spatial properties of an object (e. g. location, motion, size, and crude shape for grasping). Information from the parvocellular pathway projects primarily to the ventral (temporal or “what”) stream, which processes information used for object recognition (e.g. color, face information, shape, and size). Both streams process form information (extracted from motion in the dorsal pathway and from contour in the ventral pathway), but only the ventral stream processes surface information.

There is evidence to suggest that infants are poor at integrating information from these two streams (Mareschal, Plunkett, & Harris, 1999). This could be because integration relies on frontal lobe maturation (Rao, *et al.*, 1997). If the streams are competing, ventral stream information may be suppressed or filtered so that information from the dorsal stream, which includes size and shape, may "win" until the frontal lobe matures enough to incorporate the two streams and allow other forms of information, including brightness (luminance), into the interpretation. Thus, occlusion events, which require use of the dorsal processing stream, may suppress or filter out information from the ventral stream, in which case color or brightness information will be omitted or degraded, and, in effect, disrupt the "binding" process.

Perceptual foundations

Evidence from the neurosciences suggests that the visual system is designed to ensure the processing of form. However, neurological distinctions within the visual object-processing stream are not the only method through which the perceptual system provides form features an advantage over surface features. As previously discussed, form information has a perceptual advantage over surface information because it is detected earlier than surface information. In addition, form is a more stable form of information, and it is an amodal property of objects.

Feature constancies

The perceptual stability of object features may also encourage infants to attend to form rather than surface features. There is evidence to suggest that form feature constancies are in place earlier than surface feature constancies. Feature constancies involve the ability to perceive a feature as stable despite changes in retinal image (e. g. edge orientation) or environment (e. g. lighting conditions). Form features have an advantage because they appear relatively stable from birth or shortly afterward (Bower, 1966; Granrud, 1987; Slater & Morison, 1985; Slater *et al*., 1990) whereas surface features do not appear stable for several months (Dannemiller, 1989; Dannemiller & Hanko, 1987).

Newborn infants demonstrate size constancy, the ability to perceive an object's constant physical size despite changes in its distance and retinal image size (Granrud, 1987; Slater, *et al*., 1990; see Slater, 1996, for a review). Similarly, infants demonstrate shape constancy, the ability to perceive the stability of an objects shape, despite changes in orientation, at birth (Bower, 1966; Slater & Morison, 1985). Thus, as soon as infants can see, form information appears stable and therefore more reliable.

In contrast, surface feature constancies are relatively late to develop. There is evidence to suggest that color constancy (the ability to perceive an object's color as constant, despite changes in lighting conditions) and lightness constancy (the ability to perceive an object's luminance as constant, despite changes in lighting) are not developed until approximately 4 months (Chien, Palmer & Teller, 2003; Dannemiller, 1989; Dannemiller & Hanko, 1987). In addition, even in adults, color and brightness/luminance constancy can be easily perturbed by changes within the environment. For example, by altering lighting, color constancy can be disrupted as can lightness constancy. Shape or size constancy can also be disrupted, however, under most conditions shape and size constancy remain unperturbed, whereas color and brightness constancy are more likely to be disrupted. This means that form has two perceptual advantages over surface features. Form constancies are in place at or near birth and they are not as easily disrupted than surface features.

Multi-modal processing

Form has another perceptual advantage over surface features in that it is amodal, meaning that it can be perceived through multiple modalities. Form can be detected through both vision and touch, whereas, surface features are specific to the visual modality. For example, we can experience shape and size information visually, orally, and haptically. In contrast the color and brightness of an object can only be seen. We are unable to feel the color or brightness of an object.

The importance of form in a 3-dimensional environment

It seems that the visual system is set up in a way that facilitates the processing of form information. Why might this be? A plausible explanation lies in the type of information that the various features convey. Form provides perhaps lower-level or basic information about how objects move through space and interact with other objects. This is information that we use to determine how an object should be acted upon, as for reaching or grasping, information necessary for maneuvering within a 3-dimensional environment. Surface features, on the other hand, convey information about the 2-dimensional surface of an object, and therefore provide limited information about how the object interacts with other objects or forms or about how objects should be acted upon. Rather, surface features convey more complex or detailed information about, for example, the usefulness of objects, (e. g. whether a fruit is ripe or a plant is poisonous). This information supplements the information provided by form and would in many cases prove meaningless in the absence of form. Perceiving and understanding form is important for function within the environment. It makes sense that infants would first identify the features most important to functioning within the physical world as relevant to making object distinctions.

This is the premise upon which the information-processing biases hypothesis is founded. Form features are important for predicting the outcome of physical events and are, therefore more relevant when making individuation judgments. Surface features are less important than form features for predicting the outcome of physical events. Consequently, early in the first year, infants do not readily identify surface features, including luminance and color, as relevant to the individuation problem.

Concluding remarks

Although neurological and perceptual development provide physiological foundations for the hierarchical feature use in infancy, they cannot account for this phenomenon entirely. Consider that shape and size information are readily detected by infants near birth, as is luminance information, while pattern and color information is poor for several months.

If infants are biased to attend first to form features, and shape and size information are available at or shortly after birth, it stands to reason that infants would begin applying these features when reasoning about physical events.

Although luminance information is available, it may either be ignored or attended to solely as a means to convey information about shape or size (Putaansuu & von Hofsten, 1991).

In addition, infants may be able to gain more experience with form features because form features are amodal, whereas surface features are specific to the visual modality. Feature constancies further encourage attention to form because form features appear more stable than surface features. Moreover, as infants gain experience with the physical world, those experiences further validate attention to form features. Infants see that, for example, it is an object's shape and size that determine whether it will fit behind an occluder or into a container. Consequently, while observing the interactions between objects, infants come to understand that form features are reliable predictors of the outcomes of physical events. Thus, infants are greatly encouraged to attend to form features when reasoning about how objects will interact.

Nevertheless, by 11.5 months, infants identify luminance and color information relevant to the individuation problem. This indicates that, during the first year, as infants interact with and learn about objects, these experiences lead them to attend to surface features and regard them, in addition to form features, as valuable forms of information for making judgments about object individuation and other areas of physical reasoning.

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