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Infants' ability to use luminance information to individuate objects

Rebecca J. Woods*, Teresa Wilcox

Department of Psychology, Texas A&M University, 4235 TAMU, College Station, TX 77843, USA

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Abstract

Recent research indicates that infants first use form and then surface features as the basis for individuating objects. However, very little is known about the underlying basis for infants' differential sensitivity to form than surface features. The present research assessed infants' sensitivity to luminance differences. Like other surface properties, luminance information typically reveals little about an object. Unlike other surface properties (e.g. pattern, color), the visual system can detect luminance differences at birth. The outcome of two experiments indicated that 11.5-month-olds, but not 7.5-month-olds, used luminance differences to individuate objects. These results suggest that it is not the age at which infants can detect a feature, but the nature of the information carried by the feature, that determines infants' capacity to individuate objects.

Keywords: Object individuation; Infancy; Luminance

1. Introduction

The visual environment provides rich information about the objects with which we come in contact. One of the primary tasks of visual cognition is to determine the identity of objects when perceptual contact is lost and then regained. Because our capacity to individuate objects forms the basis for more complex thought and behavior, cognitive

* Corresponding author. Tel.: +1 979 862 8934; fax: +1 979 845 4727.
E-mail address: rjindalee@neo.tamu.edu (R.J. Woods).

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scientists have spent a great deal of effort to identify the origins and development of this capacity. This research has revealed intriguing changes in the type of information to which infants are most sensitive.

1.1. Infants' differential sensitivity to object features

Object features can be divided into two broad categories: those that specify the 3-dimensional form of an object and those that convey information about surface properties. Wilcox (1999) systematically investigated infants' sensitivity to two form features—shape and size—and two surface features—color and pattern. Results revealed that by 4.5 months infants use differences in shape and size, but that it is not until 7.5 months that infants use pattern and 11.5 months that they use color, as the basis for object individuation. These results are consistent with those obtained in studies of object segregation (Needham, 1999; Needham, Baillargeon, & Kaufman, 1997) and identification (Tremoulet, Leslie, & Hall, 2001), where infants have also demonstrated greater sensitivity to form than surface features. Despite this, surprisingly little is known about the underlying basis for infants' early preferential use of form features. This is problematic because cognitive scientists cannot fully specify conceptual models of object individuation with this gap in knowledge.

1.2. The underlying basis for infants' differential sensitivity to form and surface features

There are at least two possible explanations for infants' differential sensitivity to form and surface features. One hypothesis focuses on information processing biases. According to this hypothesis, when infants, who have limited information processing capacities, are faced with an individuation problem they attend to those features that are most intimately tied to objects and, hence, make the most reliable predictions about an objects' identity. Form features specify the physical nature of objects: the space they occupy, their substance, and how they move and interact with other objects. The form of an object rarely changes or becomes altered. In addition, form features are important for interpreting physical events. For example, the size and shape of an object determines whether it can fit into a container or serve as a source of support for another object. In contrast, color information has little predictive value. Although color features typically co-occur with other object properties that are meaningful, color information is not unambiguously linked to objects or relevant to understanding the way in which the physical world operates. In addition, color is often perceived by infants as unstable across viewing conditions (Dannemiller, 1989; Dannemiller & Hanko, 1987). Because of these factors, infants do not view color information as particularly salient when tracking objects across space and time. In support of this hypothesis, there is evidence that viewing events in which color is predictive (e.g. the color of an object predicts its function), or engaging in activities that link color information to individual objects (e.g., combined visual and tactile exploration), can increase infants' sensitivity to color information in a subsequent individuation task (Wilcox & Chapa, 2004; Wilcox, Chapa, & Woods, 2004). That is, infants' bias to attend to form features, which arises (at least in part) from their experiences in the physical world, can be altered by select experiences.

The second hypothesis focuses on the nature of the developing visual system. Because visual acuity (Dobson & Teller, 1978; Skoczenski & Norcia, 1999) and color vision are initially quite poor (Clavadetscher, Brown, Ankrum, & Teller, 1988; Teller & Bornstein, 1987), young infants have difficulty acquiring pattern and color information. In contrast, infants perceive shape and size differences from birth (Slater, Mattock, & Brown, 1990; Slater, Morison, & Rose, 1983). Hence, from the early days of life infants have greater experience with form features. The visual maturation hypothesis states, then, that if the capacity to detect a feature develops early, infants' will use that feature to individuate objects relatively early. In contrast, if the capacity to detect a feature develops late, lack of experience will delay infants' use of that feature.

One way to test these two hypotheses—and the approach taken in the present research—is to assess the development of infants' sensitivity to features they can perceive at birth (or soon after), but that are surface properties. The brightness of an object, as measured by its luminance, is one such property. Newborns are capable of detecting spatial variations in luminance, providing contrast is high and spatial frequency is low (e.g. Adams & Maurer, 1984; Skoczenski, 2002) and by 2 months infants are sensitive to even slight differences in luminance (Peeples & Teller, 1975). At the same time, luminance, like color, is not reliably or unambiguously linked to objects. If young infants use luminance differences to signal the presence of distinct objects, it would support the visual maturation hypothesis (i.e. perceptual development determines when a visual property will be used to individuate objects). In contrast, if infants fail to use luminance differences to individuate objects until later in the first year, it would support the processing bias hypothesis (i.e. infants are more sensitive to features that are intimately tied to objects).

1.3. The present research

The present research assesses 7.5- and 11.5-month-olds' capacity to use luminance differences to individuate objects using the narrow-screen task. Data obtained using other methods indicate that the narrow-screen task is a reliable measure of infants' developing capacity to individuate objects (McCurry, Wilcox, & Woods, 2005; Wilcox & Baillargeon, 1998a,b; Wilcox & Chapa, 2004; Wilcox & Schweinle, 2003).

2. Experiment 1

Infants aged 7.5 months were assigned to a different-luminance or a same-luminance condition. In the *different-luminance* condition (Fig. 1), infants saw a test event in which a grey ball and a black ball emerged successively to opposite sides of a screen that was either too narrow (narrow-screen event) or sufficiently wide (wide-screen event) to hide both balls simultaneously. In the *same-luminance* condition, the objects seen to each side of the screen were identical in luminance; they were both grey. If the infants in

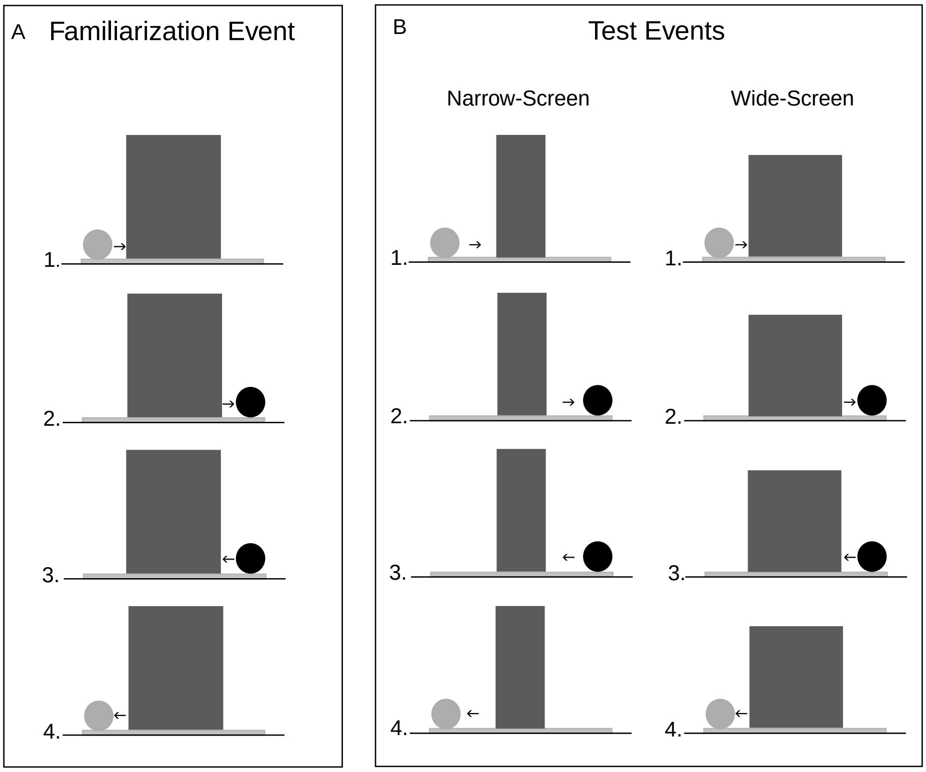

Fig. 1. The different-luminance familiarization and test events seen by the infants in Experiments 1 and 2. Infants first saw a *familiarization event* (A). At the start of each familiarization trial, the grey ball sat at the left end of the platform. The familiarization screen stood upright and centered in front of the platform and the black ball sat behind the screen. After the infant looked at the grey ball for 1 s, the ball paused (1 s) and then moved behind the right edge of the screen (2 s); after a brief interval (1 s) the black ball emerged from behind the screen and moved to the right until its center was 6 cm from the right end of the platform (2 s). After a pause (1 s), the event just described was seen in reverse. The entire 12-s event sequence was then repeated continuously until the trial ended. After the familiarization event, infants saw either a narrow-screen or a wide-screen *test event* (B). The test events were identical to the familiarization event except that the familiarization screen was replaced with the narrow or the wide test screen. The familiarization and test events in the same-luminance condition were identical to those in the different-luminance condition except that the grey ball was seen to both sides of the screen.

the different-luminance condition (a) use the luminance difference between the grey and the black ball to conclude that they constitute two distinct objects and (b) recognize that both balls can fit behind the wide but not the narrow screen, then they should find the narrow—but not the wide-screen event unexpected (i.e. infants should look reliably longer at the narrow-than wide-screen test event). Furthermore, if infants in the same-luminance condition (a) infer that the grey balls seen to each side of the screen are one and the same and (b) recognize that the ball can fit behind either screen, they should look equally at the narrow- and wide-screen events.

2.1. Method

2.1.1. Participants

Participants were 40 healthy, term infants (M age = 7 months, 14 days). Six additional infants were tested, but eliminated from analyses because of fussiness ($N=4$) and sustained thumb sucking ($N=2$). 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).

2.1.2. Apparatus and stimuli

The apparatus consisted of a wooden cubicle 213 cm high, 105 cm wide and 43.5 cm deep. The infant sat on their parent's lap facing an opening 51 cm high and 93 cm wide in the front wall of the apparatus. The floor and walls of the apparatus were cream or covered with lightly patterned contact paper. A platform 1.5 cm high, 60 cm wide, and 19 cm deep lay at the back wall and centered between the left and right walls.

The balls used in the familiarization and test events were 10.25 cm in diameter and made of Styrofoam: two were painted grey (48 cd/m^2) and one was painted black (18 cd/m^2). Luminance was measured at a centered, frontal view using a J1800 series LumaColor^{TM} Photometer with a J1810 Chromaticity Head positioned 19 cm from the balls' most protruding point. Research indicates that by 2 months infants can detect luminance differences smaller than 1 cd/m^2 (Peeples & Teller, 1975). The luminance difference between the grey and the black ball in the present experiment was 30 cd/m^2, which is of a much greater magnitude. Each ball was attached to a clear Plexiglas base and each base had a 16 cm handle that protruded through an opening 3.25 cm high between the back wall and floor of the apparatus; the opening was masked by cream-colored fringe. An experimenter, concealed behind the apparatus, could move the balls left and right along the platform using the Plexiglas handle.

The familiarization screen consisted of a 30 cm wide and 41 cm high yellow matte board. The narrow (15.5 × 41 cm) and wide (30 × 33 cm) test screens were constructed from dark-blue matte board and decorated with small, gold stars. The screens were mounted on a wooden stand centered in front of the platform.

Embedded in the center of the platform was a metal bi-level with an upper and lower shelf 16 cm apart; each shelf was 12.7 cm wide and 13 cm deep. When behind the screen the grey ball was on the top shelf and the black ball on the bottom shelf. The bi-level could be lifted and lowered by means of a handle that protruded through an opening in the apparatus's back wall, allowing for the grey ball and the black ball to emerge successively from behind the screen.

A muslin-covered shade was lowered in front of the opening in the front wall of the apparatus 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 thus isolating the infants from the experimental room. In addition to room lighting, a 20-watt fluorescent bulb was affixed inside each wall of the apparatus.

2.1.3. Procedure

Infants participated in a two-phase procedure consisting of a familiarization and test phase. During the *familiarization* phase, infants saw the familiarization event appropriate for their condition on six successive trials. Each trial ended when the infant (a) looked away for 2 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 2 consecutive seconds. During the *test* phase, the infants saw the test event appropriate for their condition on four successive trials. Trial termination criteria were the same except that minimum looking time was 6 (rather than 12) seconds. The infant's looking behavior was monitored by two observers who watched the infant through peepholes in the frames to either side of the apparatus. Inter-observer agreement for this and the following experiment averaged 92%.

2.2. Results and discussion

2.2.1. Familiarization trials

Infants' looking times during the six familiarization trials were averaged and analyzed by means of a 2×2 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 the two ($F(1,36)=0.53$, $P=0.47$). 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, and wide-screen, $M=34.60$, SD=11.46; same-luminance narrow-screen, $M=32.79$, SD=9.95, and wide-screen, $M=34.73$, SD=10.50).

2.2.2. Test trials

Infants' looking times during the four test trials were averaged and analyzed by means of a 2×2 analysis of covariance (ANCOVA) with event and screen size as between-subjects factors and familiarization trial as a covariate. Although analysis of the familiarization data did not yield a main effect of event, there is sometimes a tendency for infants to look longer at different-features than same-features events (Wilcox, 1999; Wilcox & Baillargeon, 1998b). An ANCOVA allows us to assess the extent to which differences in looking times to the test events are obtained after adjusting for differences in familiarization looking times. It was implemented here to maintain consistency across experiments. The main effects of event ($F(1, 36)=0.64$, $P=0.43$) and screen size ($F(1, 36)=0.01$, $P=0.91$) were not significant, nor was the interaction between event and screen size ($F(1, 36)=0.01$, $P=0.94$). The infants in each of the four groups looked about equally during the test events (Fig. 2. Adjusted means: different-luminance narrow-screen, $M=15.18$, SD=6.77 and wide-screen, $M=14.97$, SD=6.71; same-luminance narrow-screen, $M=16.74$, SD=6.75 and wide-screen, $M=16.83$, SD=6.71).

The outcome of Experiment 1 suggests that the 7.5-month-olds failed to use the luminance difference to individuate the balls. Despite the fact that infants are sensitive to differences in luminance from the early days of life, they do not draw on these differences

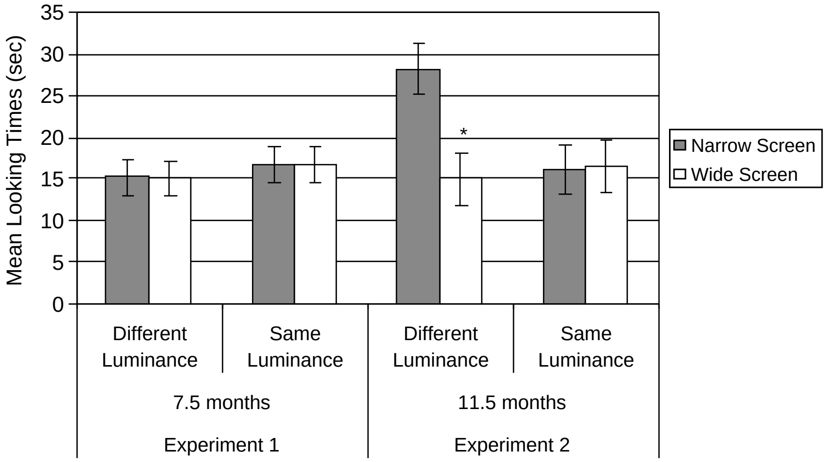

Fig. 2. Adjusted mean looking times (and standard errors) to the different- and same-luminance, narrow- and wide-screen test events in Experiments 1 and 2. Significant differences ($P<0.05$) in looking times between the narrow- and wide-screen conditions are marked by an asterisk. Prior to adjustment, means and standard deviations were: Experiment 1, different-luminance narrow-screen $M=19.39$, SD = 7.12 and wide-screen $M=18.54$, SD = 8.18; same-luminance narrow-screen $M=15.80$, SD = 7.54 and wide-screen $M=16.73$, SD = 9.12. Experiment 2, different-luminance narrow-screen $M=29.08$, SD = 11.59 and wide-screen $M=17.31$, SD = 8.73; same-luminance narrow-screen $M=14.88$, SD = 6.24 and wide-screen $M=14.34$, SD = 7.70.

to signal the presence of distinct objects. The next experiment tests older infants' sensitivity to luminance differences.

3. Experiment 2

The narrow-screen task was modified slightly and used to assess 11.5-month-olds' capacity to use luminance differences to individuate objects.

3.1. Method

3.1.1. Participants

Participants were 32 infants (*M* age = 11 months, 18 days). An additional seven infants were tested but eliminated from analyses because of procedural problems ($N=2$), fussiness ($N=2$), and sustained thumb sucking ($N=3$). Eight infants (4 male, 4 female) were assigned to each of four conditions formed by crossing event and screen size.

3.1.2. Apparatus and procedure

The apparatus and procedure were identical to those of Experiment 1 except that the procedure was shortened. Because older infants typically become bored more quickly than younger infants, 11.5-month-old's were presented with four (rather than six) familiarization trials and two (rather than four) test trials.

3.2. Results and discussion

3.2.1. Familiarization trials

Infants' mean looking times during the familiarization trials were analyzed in the same manner as those of Experiment 1. The main effect of event was significant ($F(1,28)=4.49$, $P=0.04$). The infants who saw the different-luminance event (narrow-screen, $M=34.80$, SD = 12.71; wide-screen, $M=35.82$, SD = 9.87) looked reliably longer during the familiarization trials than those who saw the same-luminance event (narrow-screen, $M=31.67$, SD = 7.64; wide-screen, $M=25.19$, SD = 4.46). The main effect of screen size ($F(1,28)=0.71$, $P=0.41$) and the event x screen size interaction ($F(1,28)=1.33$, $P=0.26$) were not significant.

3.2.2. Test trials

Infants' mean looking times during test trials were analyzed in the same manner as those of Experiment 1. The main effects of event ($F(1,28)=3.92$, $P=0.06$) and screen size ($F(1,28)=3.06$, $P=0.09$) were not significant. The event × screen size interaction was significant ($F(1,28)=5.04$, $P=0.03$). Planned comparisons, using adjusted means (Fig. 2), indicated that the infants who saw the different-luminance, narrow-screen event ($M=28.17$, SD = 8.54) looked reliably longer than those who saw the different-luminance, wide-screen event ($M=16.06$, SD = 8.64), $F(1,28)=8.28$, $P<0.05$. In contrast, mean looking times of the infants who saw the same-luminance, narrow-screen ($M=14.99$, SD = 8.42) and wide-screen ($M=16.56$, SD = 9.03) events did not reliably differ, $F(1,28)=0.14$.

Unlike the 7.5-month-olds, who failed to use the luminance difference to individuate the balls, the 11.5-month-olds demonstrated sensitivity to the luminance difference.

4. General discussion

In the present research infants failed to use luminance differences to individuate objects until 11.5 months, even though the luminance differences used were well within the range of their capacity to detect. These results join an increasing number of reports that infants are less sensitive to surface than form features when individuating objects. In addition, these results provide insight into the underlying basis for this developmental hierarchy. Like shape and size information, infants perceive luminance differences at birth or soon after. In contrast to shape and size information, infants do not use differences in luminance to individuate objects until the end of the first year. Hence, the outcome of Experiments 1 and 2 suggest that infants' differential sensitivity to form and surface features is better explained by a bias to attend to features that are intimately linked to objects than to visual maturation. These results are striking because young infants use discontinuities in luminance in edge processing, and it is the identification of edges that leads to shape descriptions. For very young infants, who have poor visual acuity and color vision, luminance differences are particularly helpful for defining shape. Young infants' failure to draw on luminance differences to individuate objects suggests that the feature hierarchy observed in lower level visual processing, which depends on the extent to which information can be detected, is different from that observed in higher level object processing, which depends on the extent to which this information holds meaning. Current research is aimed towards identifying mechanisms that support infants' changing sensitivity to surface features during the first year.

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