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Posture Support Improves Object Individuation in Infants

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A hierarchical progression in infants' ability to use surface features, such as color, as a basis for object individuation in the first year has been well established (Tremoulet, Leslie, & Hall, 2000; Wilcox, 1999). There is evidence, however, that infants' sensitivity to surface features can be increased through multisensory (i.e., visuohaptic) exploration of objects (Wilcox, Woods, Chapa, & McCurry, 2007). Three studies were conducted to investigate the effect of multisensory experience on infants' sensitivity to pattern information. Experiments 1 and 2 confirmed that 5.5- and 6.5-month-olds do not spontaneously use pattern differences to individuate objects and revealed that 6.5- but not 5.5-month-olds can be primed to attend to pattern differences if allowed multisensory experience with the objects prior to the individuation task. However, the 5.5-month-olds also had greater difficulty maintaining a self-sitting posture during the multisensory priming experience. In Experiment 3, 4.5- and 5.5-month-olds were given full postural support during the multisensory exploration period. In this situation, the 5.5-month-olds successfully individuated the objects, but even with full postural support, 4.5-month-old infants did not use the pattern differences to individuate the objects. These results demonstrate that multisensory priming is effective with infants as young as 5.5 months and extends multisensory priming to another surface feature, pattern. Furthermore, these results indicate that constraints are placed on the multisensory experience by the physical and motor development of the infant.

Keywords: object individuation, infant, multisensory, sitting, posture

One of the primary tasks of visual cognition is to track the identity of objects through discontinuities in space and time, allowing us to determine whether an object currently in view is the same object or a different object than one seen before. Given the importance of object individuation to human cognition, developmental scientists have invested a great deal of effort to identify the ontogeny of this capacity (Leslie & Kaldy, 2001; Tremoulet, Leslie, & Hall, 2000; Van de Walle, Carey, & Prevor, 2000; Wilcox, 1999; Wilcox & Baillargeon, 1998a, 1998b; Woods & Wilcox, 2006, 2010; Xu, 1999; Xu & Carey, 1996). A number of studies have uncovered a hierarchical progression in infants' sensitivity to featural information, with infants first demonstrating sensitivity to form features, such as shape or size, and then to surface features, such as pattern, color, or luminance, as the basis for individuating objects (Needham, 1999; Tremoulet et al., 2000; Wilcox, 1999; Woods & Wilcox, 2006, 2010). More recent research has focused on identifying the mechanisms that underlie infants' later emerging ability to recognize surface features as relevant to object individuation. This research has revealed select experiences that can lead infants to attend to surface features at an age younger than they do so spontaneously (Wilcox & Chapa, 2004; Wilcox, Smith, & Woods, 2010; Wilcox, Woods, & Chapa, 2008; Wilcox, Woods, Chapa, & McCurry, 2007).

One type of experience that is known to prime infants to use surface features to individuate objects is multisensory exploration. There is evidence that 11.5-month-olds, but not infants 10.5 months or younger, use color differences as the basis for individuating objects (Wilcox, 1999; Wilcox et al., 2007; Woods & Wilcox, 2010). In one set of studies, Wilcox and her colleagues (Wilcox et al., 2007) presented 10.5-month-olds with a green ball and a red ball, successively, for 60 s each prior to an individuation task involving those same objects. The infants who engaged in multimodal exploration of the objects, examining each ball visually and tactilely during the preexposure trials, subsequently used the color information to individuate the objects 1 month earlier, at 10.5 months, than infants who did not. However, another group of infants who received visual-only experience with the objects prior to test failed to attend to color information to individuate the objects. These results suggest that infants needed multisensory experience, and not simply extra visual experience, with the objects for color priming to occur.

Why does visual and tactile exploration, and not visual exploration alone, lead to greater sensitivity to color information? Visual and tactile exploration provides infants with the opportunity to

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experience the same information in more than one modality (e.g., shape encoded tactilely and visually) and to link information across modalities (e.g., link color encoded visually to shape encoded visually and tactilely). Some researchers have proposed that information available concurrently to two or more senses, because it is invariant and redundant, captures and focuses infants' attention (Bahrick & Lickliter, 2003; Slater, Quinn, Brown, & Hayes, 1999; see also Bahrick, 2004, for a review).

Bahrick and her colleagues (Bahrick & Lickliter, 2000, 2003; Bahrick, Lickliter, & Flom, 2004) have proposed a conceptual model of intermodal processing, the *intersensory redundancy hypothesis*, that focuses on the importance of detecting amodal relations within the context of physical events. Two components of this model are most relevant here. First, amodal relations are detected prior to modality-specific relations. That is, when exploring and interacting with objects, infants attend first to information that is presented redundantly and in temporal synchrony across the senses and then to unimodal information. Second, the detection of amodal relations guides and constrains learning about modality-specific information. That is, the extent to which infants attend to modality-specific information depends on whether they have identified amodal object properties. When infants are provided object information via a single modality (i.e., vision), they have difficulty identifying amodal relations, which, in turn, prevents integration of modality-specific information into their object representation. There are a number of studies that support this proposal and demonstrate that multisensory presentation of amodal information, such as shape, facilitates processing of modality-specific object information, such as color and pattern (Bahrick, 1992, 1994; Hernandez-Reif & Bahrick, 2001).

What remain unspecified are details about the nature and development of multisensory priming in infants. For example, once young infants begin to engage in simultaneous visual and tactile exploration of objects, do they demonstrate multisensory priming? What role do attentional and motor factors play in the priming process? Under what conditions is multisensory priming most effective? Can infants be primed to attend to other surface features, such as pattern, or is multisensory priming limited to color information? The purpose of the present research was to enhance our understanding of multisensory priming by addressing these questions. First, we investigated whether multisensory priming is specific to color or whether infants can be primed to attend to another object surface feature, pattern. Second, we investigated the extent to which multisensory priming is observed in younger infants, who may be less skilled at multisensory exploration. Finally, we investigated the direct effect of motor development (i.e., postural control and object manipulation behaviors) on infants' ability to benefit from multisensory priming. There is evidence that postural strength and sitting ability can influence both object exploration and object processing (Bertenthal & von Hofsten, 1998; Fallang, Saugstad, & Hadders-Algra, 2000; Gabbard, Santos, & Goncalves, 2007; Out, van Soest, Savelsbergh, & Hopkins, 1998; Rochat, 1992; Rochat & Senders, 1991; Soska, Adolph, & Johnson, 2010; Thelen & Spencer, 1998). Given that infants begin the transition to self-supported sitting between 4 and 7 months of age, leaving the hands free for two-handed exploration of objects (Piper & Darrah, 1994), we might expect to see a relation between sitting ability, multisensory exploration, and object individuation during this time. In summary, in the present research we investigated the extent to which multisensory experiences could prime infants 4.5–6.5 months of age to attend to pattern differences in an object individuation task and the role that postural support plays in this process.

Experiment 1

To assess the extent to which multisensory experience can prime young infants to use pattern information to individuate objects, it is necessary first to determine the earliest age at which infants spontaneously use pattern information as a basis for object individuation. In previous studies, infants used pattern differences by 7.5 months, but failed to do so at 4.5 months (Wilcox, 1999); therefore, in Experiment 1 we assessed the ability of 5.5- and 6.5-month-old infants to use pattern differences in an object individuation task. The narrow-screen task of Wilcox and Baillargeon (1998a, 1998b) was used here. In this task, infants are presented with a test event in which two featurally distinct objects (e.g., a dotted ball and a striped ball) emerge successively on opposite sides of a screen that is either too narrow or sufficiently wide to hide both objects simultaneously. If infants perceive the different-features event as involving two distinct objects and recognize that both objects can fit behind the wide but not the narrow screen, then they should find the narrow- but not the wide-screen event unexpected. Hence, longer looking to narrow- than to wide-screen events is taken as evidence for object individuation, an interpretation supported by data obtained in other tasks (McCurry, Wilcox, & Woods, 2009; Wilcox & Baillargeon, 1998a; Wilcox & Chapa, 2002; Wilcox & Schweinle, 2002; for a review, see Wilcox & Woods, 2009).

Method

Participants. Participants were 16 healthy, full-term 5.5-month-old infants (eight boys) (M = 5 months, 18 days; range = 5 months, 9 days to 5 months, 29 days) and 16 6.5-month-old infants (seven boys) (M = 6 months, and 16 days; range = 6 months, 0 days to 6 months, 27 days). Parents reported their infants race/ethnicity as Caucasian (n= 26), Hispanic (n = 3), Asian (n = 1), or Black (n = 2). Five additional infants were tested but eliminated from analyses due to procedural problems. Eight infants were pseudo randomly assigned to one of the four conditions formed by crossing age (5 or 6 months) with test event (narrow or wide screen).

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 a parent's lap facing an opening 51 cm high and 93 cm wide in the front wall of the apparatus. The floor and inner side walls in the apparatus were painted a cream color, and the back wall was covered with lightly patterned contact paper. On the floor of the apparatus lay a platform 1.5 cm high, 60 cm wide, and 19 cm deep. Embedded in the center of the platform was a bilevel device (12.7 cm wide and 13 cm deep) composed of an upper and lower shelf 16 cm apart that allowed the experimenter to surreptitiously exchange the two objects as they lay hidden behind a screen.

The balls used in the familiarization and test events were 10.25 cm in diameter and made of Styrofoam. Each ball was painted green and approximated the hue of 2.5G 5/10 of the Munsell matte collection (Munsell, 2005). One ball was painted with yellow, blue, and red stripes. The other ball was painted with yellow, blue, and red dots. Each ball was attached to a clear Plexiglas base with a 16-cm handle that protruded through a small gap between the back wall and floor of the apparatus; the gap was masked by cream-colored fringe.

The screen used in the familiarization trials was 41 cm high and 30 cm wide and made of yellow matte board (see Figure 1a). The narrow-test screen was 41 cm high and 17 cm wide, and the wide-test screen was 33 cm high and 30 cm wide (see Figure 1b and c). Test screens were made of blue cardboard and decorated with small gold stars, thereby differing from the familiarization screen in color, pattern, and overall size. The screens were mounted on a wooden stand that was centered in front of the platform.

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 stood at an angle on either side of the apparatus and isolated the infants from the experimental room. In addition to room lighting, a 20-watt fluorescent bulb was affixed to the inside wall of the apparatus.

Events. Each experimental session included familiarization and test events (see Figure 1). The experimenter followed a script, using a metronome that ticked softly once per second. Infants first saw a familiarization event that began with the dotted ball resting at the left end of the platform and the striped ball rested on the lower shelf of the bilevel. The numbers in parentheses in the next paragraph indicate the time taken to produce the actions described.

Each familiarization began with the dotted ball sitting at the left end of the platform. When the computer signaled that the infant had looked at the ball for 1 cumulative s, the ball paused for 1 s more and then moved right behind the screen. Once it reached the upper shelf of the bilevel (2 s), the experimenter lifted the bilevel until its lower shelf was level with the platform (1 s); the striped ball emerged from behind the screen and moved to the right edge of the platform (2 s). This sequence was then seen in reverse. When in motion, the balls moved at a rate of 12 cm per s. The entire 12-s event sequence was repeated continuously until the trial ended. After familiarization trials, infants saw a test event appropriate for their condition. The narrow- and wide-screen events were identical to the familiarization event except that the famil-

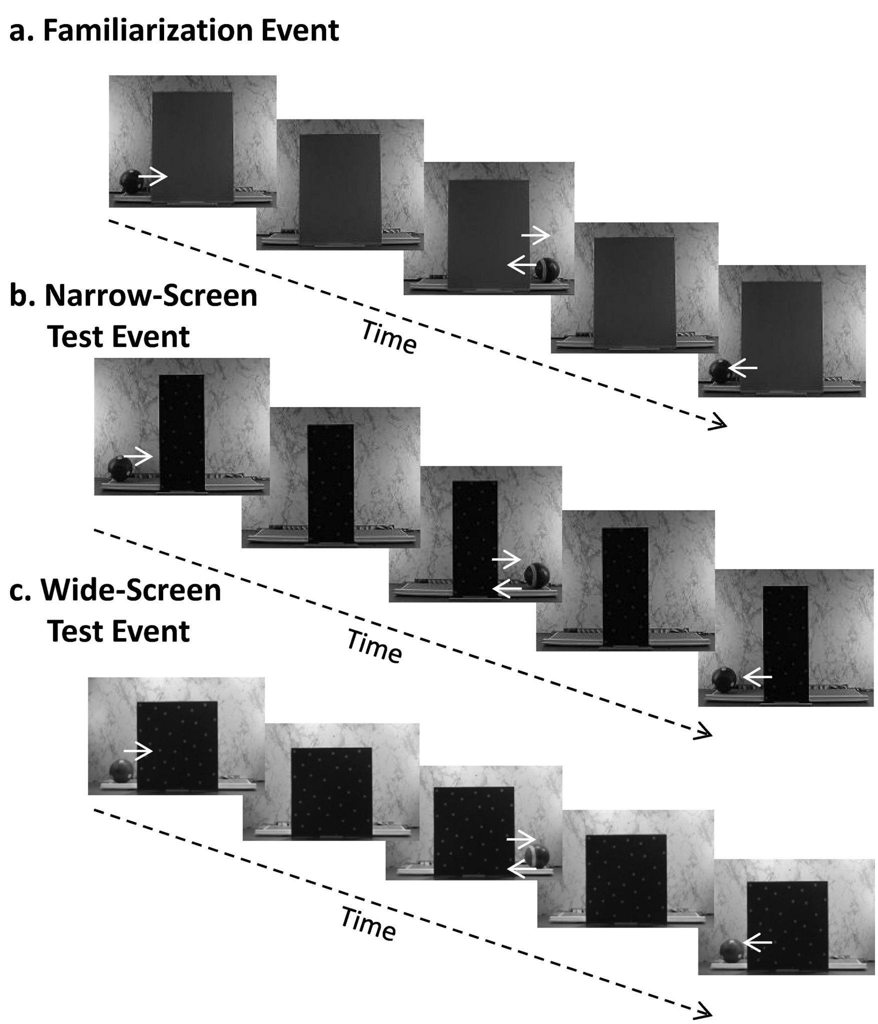

Figure 1. The familiarization event (a), and narrow- (b), and wide-screen (c) test events of Experiments 1 through 3. All infants saw the same familiarization event. Half the infants saw the narrow-screen test event, and half saw the wide-screen test event.

iarization screen was replaced with the narrow- or wide-test screen, respectively.

Procedure. Each infant sat on a parent's lap facing the opening in the front of the apparatus, approximately 80 cm from the objects. First, infants saw the familiarization event on six successive trials. Each trial ended when the infant (a) looked away for 2 consecutive s after having looked for at least 12 s or (b) looked for 60 cumulative s without having looked away for 2 consecutive s. Following familiarization, infants saw a test event appropriate for their condition on four successive trials. Each trial ended when the infant (a) looked away for 2 consecutive s after having looked for at least 6 s or (b) looked for 60 cumulative s without having looked away for 2 consecutive s.

Infants' looking behavior was monitored by two observers. Each observer held a button connected to a computer and depressed the button when the infant was attending to the events. The looking times from the primary observer determined when each trial ended and were used in analyses. Interobserver agreement for 31 infants (for one infant, only one observer was present) was calculated for each trial on the basis of the number of intervals in which the computer registered agreement compared with the total number of intervals in the trial. Agreement averaged 93% per test trial per infant.

Results and Discussion

Preliminary analysis. In this and the following experiments, we averaged infants' looking times during the four test trials and first examined data for outliers, then, for violations of normality and homogeneity of variance. In Experiment 1, we identified one outlier and adjusted the score to the mean score. We also detected heterogeneity of variance in Experiment 1; therefore, we adjusted data using a square-root transformation. Analysis of subsequent experiments revealed no such irregularities.

We then analyzed scores by means of a $2 \times 2 \times 2$ analysis of variance (ANOVA), with age (5.5 or 6.5 months), screen size (narrow or wide), and sex (male or female) as between-subjects factors. In this and the following experiments, no significant interactions of sex were revealed (all $ps > .05$), so we collapsed the data for all subsequent analyses.

Familiarization trials. We averaged infants' looking times during the six familiarization trials (see Figure 2) analyzed them by means of a 2×2 ANOVA, with age (5.5 or 6.5 months) and screen size (narrow or wide) as between-subjects factors. The main effects of age, $F(1, 28) = 0.02$, $p = .89$, and screen, $F(1, 28) = 0.79$, $p = .38$, were not significant, nor was the Age $\times$ Screen interaction, $F(1, 28) = 0.02$, $p = .89$. Infants' looking in the four conditions during the familiarization trials did not reliably differ (5 months, narrow $M = 38.65$, $SD = 10.77$; 5 months, wide screen $M = 34.65$, $SD = 12.94$; 6 months, narrow screen $M = 37.52$, $SD = 8.96$; 6 months, wide screen $M = 34.65$, $SD = 11.52$).

Test trials. We analyzed infant's mean looking time scores by means of a 2×2 ANOVA, with age (5.5 or 6.5 months) and screen size (narrow or wide) as between-subjects factors. No significant main effects were found for age, $F(1, 28) = 0.08$, $p = .78$, or screen, $F(1, 28) = 0.03$, $p = .87$. The Age $\times$ Screen interaction was also not significant, $F(1, 28) = 2.29$, $p = .14$. These results indicate that infants' looking during the test trials did not differ significantly (see Figure 2) (5.5 months, narrow $M = 19.06$, $SD = 6.60$; 5.5 months, wide screen $M = 26.86$, $SD = 14.23$; 6.5 months, narrow screen $M = 24.93$, $SD = 7.08$; 6.5 months, wide screen $M = 20.56$, $SD = 7.62$).[1]

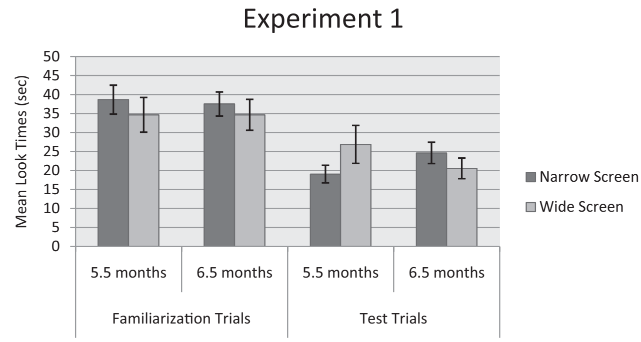

Figure 2. Mean looking times (in seconds, with standard error bars) of infants looking during the familiarization and test events of Experiment 1. Test scores are shown prior to transformation to allow comparison across experiments.

These results revealed that both 5.5- and 6.5-month-old infants looked about equally at the narrow- and wide-screen events, suggesting that the infants failed to use the pattern difference as an indication that two objects were involved in the event. These results suggest that infants did not spontaneously use the pattern difference to individuate objects at 5.5 or 6.5 months. In contrast, at 7.5 months, infants successfully used these same pattern differences when individuating objects (Wilcox, 1999).

Experiment 2

Once we established that 5.5- and 6.5-month-old infants did not use this pattern difference to individuate objects, we next investigated whether same-age infants could be primed by multisensory experiences to attend to pattern information. The multisensory priming procedure and the test procedure from Wilcox et al. (2007) was used with one exception: The dotted and striped balls of Experiment 1 replaced the green and red ball used in Wilcox et al. (2007).

Our hypothesis was that the 6.5-month-olds, but not the 5.5-month-olds, would individuate the objects following multisensory priming. This outcome would be consistent with the results of Wilcox et al. (2007) in which infants benefited from multisensory priming 1 month, but not 2 months, prior to the age at which they used the object feature in the absence of priming.

Method

Participants. Participants were 16 healthy, full-term 5.5-month-old (eight boys) ($M = 5$ months, 15 days; range $= 5$ months, 1 day to 5 months, 29 days) and 16 6.5-month-old infants (eight boys) ($M = 6$ months, and 17 days; range $= 6$ months, 0

[1] Means and standard deviations are reported prior to transformation to allow comparison of looking time across experiments. After transformation, mean and standard deviations are as follows: 5.5 months, narrow $M = 4.31$, $SD = 0.73$; 5.5 months, wide screen $M = 4.90$, $SD = 1.46$; 6.5 months, narrow screen $M = 4.94$, $SD = 0.76$; 6.5 months, wide screen $M = 4.67$, $SD = 0.85$.

days to 6 months, 28 days). Parents reported their infants' race/ethnicity as Caucasian ($n = 27$), Hispanic ($n = 1$), Asian ($n = 1$), or of mixed race ($n = 3$). Four additional infants were tested but eliminated from analyses due to fussiness ($n = 2$) and to the inability of the primary observer to determine the infant's gaze ($n = 2$). Eight infants were pseudo randomly assigned to one of the four conditions formed by crossing age (5.5 or 6.5 months) with test event (narrow or wide screen).

Apparatus, stimuli, events, and procedure. The apparatus, stimuli, events, and procedure were identical to that of Experiment 1 with one exception: Prior to the individuation task, infants in Experiment 2 were given two 60-s preexposure trials in a room separate from the familiarization- and test-event room. During the preexposure trials, infants sat on the floor near or in front of their parent. If the infant had difficulty sitting without aid, the parent helped the infant sit by gently holding the infant at the torso from behind. No other sitting support was provided (see Figure 3a).

In the first preexposure trial, the experimenter presented the infant a dotted ball and encouraged the infant to look at and touch the ball. The ball was identical to the dotted ball seen during familiarization and test events except that this ball did not have a handle. If the infant dropped, threw, or rolled the ball out of reach, the experimenter retrieved the ball and returned it to the infant. The second preexposure trial was identical to the first, except that the experimenter offered the infant the striped ball. The balls were presented successively, with approximately 30 s between appearances. The balls were never seen together. Infants were video recorded during the preexposure trials, and these videos were later examined to assess the extent to which the infants were able to sit unassisted during object manipulation.

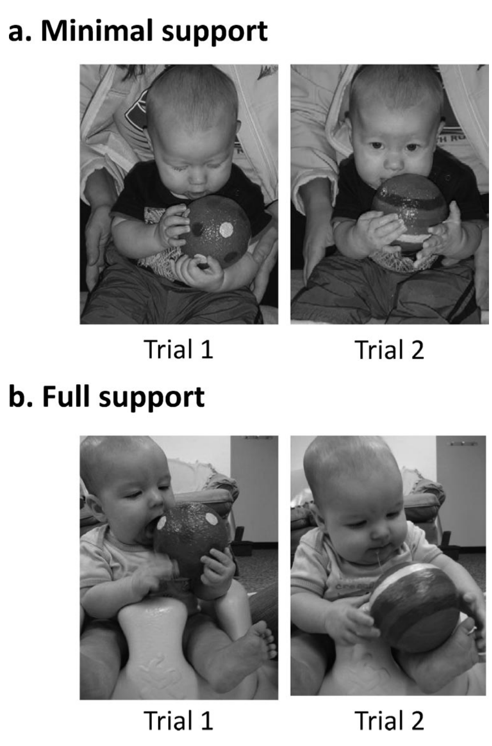

Figure 3. Infants unable to sit alone in Experiments 2 and 3 received either minimal posture support from a parent (a) or were fully supported in an infant seat (b) during the preexposure trials. The mother of the infant appearing in these photographs gave signed consent for the infant's likeness to be published in this article.

Following the preexposure trials, parents and infants were escorted to the testing room where they saw the familiarization and test events appropriate for their condition. Interobserver agreement was calculated for 30 infants and averaged 91% per test trial per infant.

Results and Discussion

Familiarization trials. We averaged infants' mean looking times and analyzed them by means of a 2×2 ANOVA, with age (5.5 or 6.5 months) and screen size (narrow or wide) as between-subjects factors. Neither the main effects of age, $F(1, 28) = 0.65$, $p = .43$, nor of screen, $F(1, 28) = 3.62$, $p = .07$, were significant, nor was their interaction, $F(1, 28) = 0.00$, $p = .99$. Infants' looking to the six familiarization trials in each of the four conditions did not significantly differ (see Figure 4) (5.5 months, narrow screen, $M = 38.23$, $SD = 8.73$; 5.5 months, wide screen, $M = 30.82$, $SD = 14.69$; 6.5 months, narrow screen, $M = 41.30$, $SD = 9.87$; 6.5 months, wide screen, $M = 33.99$, $SD = 9.40$).

Test trials. We analyzed infants' mean look times during the test trials (see Figure 4) in the same manner as familiarization trials. The main effects of age, $F(1, 28) = 0.07$, $p = .79$, and screen, $F(1, 28) = 1.93$, $p = .18$, were not significant. The Age $\times$ Screen interaction, however, was significant, $F(1, 28) = 4.34$, $p = .04$, $\eta_p^2 = .13$. Planned comparisons indicated that 5.5-month-olds looked about equally to the narrow- and wide-screen test events, $F(1, 14) = 0.20$, $p = .66$ (5.5 months, narrow screen, $M = 21.62$, $SD = 6.28$; 5.5 months, wide screen, $M = 24.20$, $SD = 15.00$). In contrast, the 6.5-month-olds looked significantly longer to the narrow- than wide-screen event, $F(1, 14) = 7.57$, $p = .02$, $\eta_p^2 = .35$ (6.5 months, narrow screen, $M = 30.32$, $SD = 8.43$; 6.5 months, wide screen, $M = 17.45$, $SD = 10.19$). These results indicate that the 6.5- but not the 5.5-month-olds benefited from multisensory priming and individuated the objects on the basis of the pattern differences.

Preexposure behaviors. We suspect that infants' ability to benefit from multisensory priming was driven by differences in infants' object exploration behaviors. To assess this possibility, we coded three exploratory behaviors—looking, haptic touch, and mouthing—from video recordings of the preexposure trials using The Observer XT 8.0® behavioral coding software by Noldus (2008). We calculated the duration in seconds of total looking to touching or mouthing the object during each of the two preexposure trials and obtained an average score for each infant. Intercoder reliability was calculated and averaged 91% for looking (25 of the 32 infants), 95% for touching (30 infants), and 100% for mouthing (30 infants).

To determine whether 5.5- and 6.5-month-olds differed in their object exploration behaviors, we analyzed mean duration scores using a multivariate analysis of variance (MANOVA), with age (5.5 months or 6.5 months) as the independent variable and looking, touching, and mouthing as dependent variables. The overall MANOVA was not significant, $F(3, 28) = 2.16$, $p = .12$, nor were the between-subjects effects (all ps $> .05$). The 5.5-month-olds and 6.5-month-olds looked at (5.5 months, $M = 42.83$, $SD = 13.28$; 6.5 months, $M = 35.63$, $SD = 11.88$), touched (5.5 months, *M* = 35.71, *SD* = 11.88; 6.5 months, *M* = 41.22, *SD* = 7.80), and mouthed (5.5 months, *M* = 7.93, *SD* = 8.24; 6.5 months, *M* = 6.59, *SD* = 6.22) the objects during the preexposure trials about the same amount of time (see Figure 5).[2]

We also examined the duration of time infants looked at the objects while simultaneously touching the objects during preexposure trials. We obtained scores for simultaneous look and touch by calculating the amount of time that each infant's looking and touching scores occurred at the same time; therefore, we analyzed them separately from total look and touch durations. Because there are age-related changes in infants' ability to manipulate objects, we expected that the 6.5-month-olds would spend more time in multisensory contact with the object. Scores were averaged across the two preexposure trials and analyzed by means of a one-tailed *t* test. Contrary to our expectations, results indicated no significant differences, $t(30) = 1.24$, $p = .23$ (5.5 months, *M* = 27.64, *SD* = 11.04; 6.5 months, *M* = 23.03, *SD* = 9.75) (see Figure 5). Together, these results indicate that there are no differences in the duration of looking, touching, mouthing, or simultaneous looking and touching of the objects.

Cumulatively, these results revealed no differences in the manipulation behaviors of the 5.5- and 6.5-month-old infants. Given previous studies in which age-related differences in infants' ability to grasp and manipulate objects were obtained (Eppler, 1995; Gabbard et al., 2007; Rochat, 1989; Spencer, Vereijken, Deidrich, & Thelen, 2000), we found these results surprising. However, the objects used here were relatively large, thus limiting the type of manipulations afforded to infants and potentially masking typical age-related variations in infants' manipulation abilities.

If 5.5- and 6.5-month-olds explored the objects for the same length of time, then why did the 6.5-month-olds succeed at the individuation task, whereas the 5.5-month-olds did not? It is possible that there are subtle differences in infants' exploratory behaviors that were not captured by our measures. However, given the detail with which exploratory behaviors were coded (see the Results section and Footnote 2), we believe it more likely that other factors influenced the effectiveness of infants' multisensory experience. One such possibility is sitting ability.

Sitting ability and multisensory exploration. Because the procedure used during the preexposure trials required infants to sit up during object exploration, and the ability to sit upright first emerges during the age period we assessed (i.e., 5–7 months; Piper & Darrah, 1994), we evaluated infants' ability to sit unsupported. Our reasoning is that developmental changes in postural control have the potential to profoundly influence the information infants' receive during visual-haptic object exploration. First, postural development and the ability to sit upright are intricately linked to infants' ability to effectively reach for, grasp, and manipulate objects (Bertenthal & von Hofsten, 1998; Gabbard et al., 2007; Rochat, 1989, 1992; Rochat & Goubet, 1995; Rochat & Senders, 1991; Thelen & Spencer, 1998). These object-manipulation skills have, in turn, been linked to infants' perception of and action on objects (Needham, 2000; Needham, Barrett, & Peterman, 2002; Soska et al., 2010). In addition, the ability to sit upright requires attention to head, trunk, and pelvic stabilization, as well as to leg

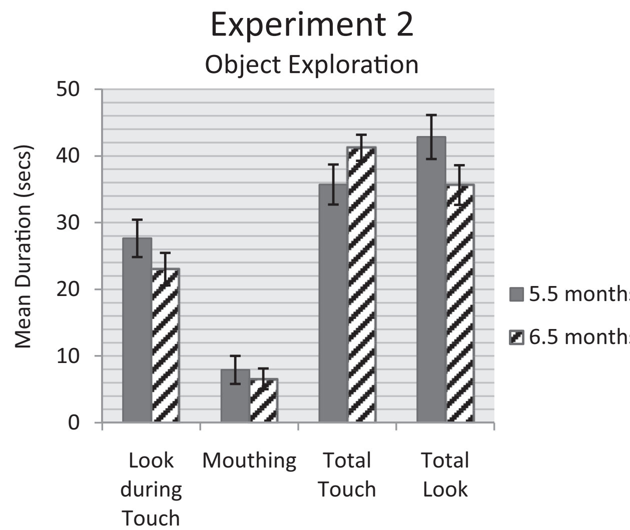

Figure 5. Mean duration of infants' object exploration behaviors (in seconds, with standard error bars) as a function of age during the two preexposure trials of Experiment 2.

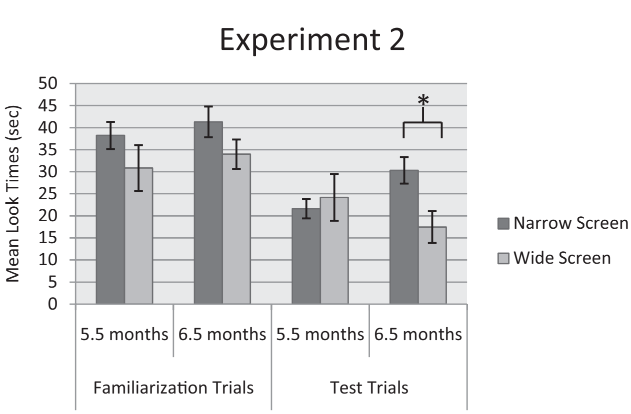

Figure 4. Infants' mean looking times (in seconds, with standard error bars) during the familiarization and test events of Experiment 2 as a function of age and screen size. Asterisks represent significance at $\alpha < .05$.

[2] We were concerned that the null results obtained with the preexposure data could be attributed to lack of sensitivity in our coding of exploratory behaviors. Hence, a more detailed analysis of touch behaviors was initiated. Infants' *active touch*—the duration of time in seconds spent scratching, tapping, or rubbing the object—and *palming*—the duration of time spent grasping or resting hands on the object, were coded separately. We chose this distinction to evaluate the effect of known age differences in infants' ability to grasp objects (Eppler, 1995; Gabbard et al., 2007; Spencer, Vereijken, Deidrich, & Thelen, 2000) separately from other touch behaviors. Intercoder reliability averaged 93%. Average duration times were analyzed by means of a MANOVA, with age (5.5 or 6.5 months) as the independent variable. Analyses indicated no significant between-group differences in active touching, $F(1, 30) = 0.36$, $p = .55$ (5.5 months, *M* = 6.63, *SD* = 10.69; 6.5 months, *M* = 8.78, *SD* = 9.45), nor in palming, $F(1, 30) = 1.46$, $p = .24$ (5.5 months, *M* = 25.59, *SD* = 10.83; 6.5 months, *M* = 30.38, *SD* = 11.53). Similar analyses were conducted to compare active touch and palming for those 5.5-month-olds who sat supported and those who did not (Experiment 3). Between-subject effects were not significant for active touch, $F(1, 30) = 0.45$, $p = .51$ (supported, *M* = 6.22, *SD* = 6.88; unsupported, *M* = 4.79, *SD* = 5.12), nor for palming, $F(1, 30) = 3.49$, $p = .07$ (supported, *M* = 33.83, *SD* = 12.45; unsupported, *M* = 26.54, *SD* = 9.41).

muscles for balance (Harbourne & Stergiou, 2003; Hedberg, Carlberg, Forssberg, & Hadders-Algra, 2005). Therefore, attention to maintaining a sitting position could draw attention away from the object and toward muscle coordination and balance.

Two independent coders used the Sit subscale of the Motor Assessment of the Developing Infant (Piper & Darrah, 1994) to determine sitting ability from video recordings of the preexposure trials. Item 8, Sitting Without Arm Support (1), was chosen as the critical level needed to promote multisensory exploration because it is the level of sitting at which infants are first able to sit alone well enough to allow proficient object manipulation. Of the 32 infants, 14 passed Item 8 (interrater reliability = 94%). The other 18 infants could not sit alone well enough to remain hands-free. Eleven of the 16 6.5-month-olds were able to sit unsupported, whereas only three of the 16 5.5-month-olds were able to sit unsupported. The association between age (5.5 or 6.5 months) to sitting ability (passing Item 8 or not) was significant, $\chi^2(1) = 10.20$, $p = .001$. These results suggest that infants' ability to sit unsupported may explain, in part, why the 6.5-month-olds benefited from the preexposure trials, whereas the 5.5-month-olds did not. However, with age as a confounding factor, it is difficult to identify the effects of sitting ability, alone, on multisensory priming. Therefore, in Experiment 3 we compared 5.5-month-olds who explored the objects with minimal support to same-age infants who explored the objects while fully supported. This allowed us to directly test the influence of being able to sit up on object exploration and pattern priming.

Experiment 3

In Experiment 3, 5.5-month-olds identified as nonsitters were tested using the same procedure as Experiment 2 except that half were provided full postural support during the preexposure trials. We expected that when provided full support during multisensory exploration, nonsitters would attend to pattern information and successfully individuate the objects based on the pattern differences.

An additional group of younger infants was included to assess potential age-related differences in performance. Previous studies investigating 4.5-month-olds' use of pattern differences to individuate objects has revealed that under highly supportive conditions, even very young infants have the capacity to use pattern information when individuating objects (Wilcox & Chapa, 2004; Wilcox et al., 2010). Therefore, it is possible that providing the multisensory object exploration experience with posture support will help 4.5-month-olds to successfully use pattern differences to individuate objects.

Method

Participants. Participants were 32 5.5-month-old healthy, full-term infants (15 boys), all identified as nonsitters (supported, $M = 5$ months, and 14 days; range = 5 months, 1 day to 5 months, 29 days; unsupported, $M = 5$ months, and 13 days; range = 5 months, 1 day to 5 months, 26 days). Eight infants were pseudo randomly assigned to one of four conditions formed by crossing sitting support (supported or unsupported) with screen size (narrow or wide). An additional 16 4.5-month-olds (10 boys) ($M = 4$ months, 14 days; range = 4 months, 3 days to 4 months, 26 days) were tested with full support. Eight infants were pseudo randomly assigned to either the narrow- or wide-screen condition. Parents reported their infants' race/ethnicity as Caucasian ($n = 36$), Hispanic ($n = 6$), Black American, ($n = 1$), Asian ($n = 1$), American Indian ($n = 1$), or of mixed race ($n = 2$). One parent did not report race/ethnicity. Nine additional infants were tested but eliminated from analyses due to fussiness ($n = 3$), the inability of the primary observer to determine gaze ($n = 5$), and failure to look at or touch the object during the preexposure phase ($n = 2$).

Apparatus, stimuli, events, and procedure. The apparatus, stimuli, events, and procedure were identical to that of Experiment 2 with two exceptions. First, rather than assessing sitting ability from videos, infants' sitting ability was assessed prior to the preexposure trials. All 48 infants were classified as nonsitters (i.e., failed to pass Item 8), with interrater reliability averaging 100%. Second, during the two preexposure trials, half the 5.5-month-olds and all of the 4.5-month-olds sat in a car seat or a Bumbo™ seat, which fully supported their body and enabled them to maintain an upright sitting position (see Figure 3b).[3] Interobserver agreement during familiarization and test trials was calculated for 42 infants and averaged 91% per test trial per infant.

Results and Discussion

Familiarization trials. We averaged infants' mean looking times during familiarization trials and analyzed them by means of a 3 × 2 ANOVA, with infant group (5.5 months supported, 5.5 months unsupported, or 4.5 months supported) and screen size (narrow or wide) as between-subjects factors. Results revealed neither significant main effects of group, $F(1, 42) = 0.34$, $p = .71$, nor of screen size, $F(1, 42) = 3.00$, $p = .09$, nor of a Group × Screen size interaction, $F(1, 42) = 0.10$, $p = .91$. Thus, infants' looking to the six familiarization trials in each of the six conditions did not significantly differ (5.5 months supported, narrow screen, $M = 36.03$, $SD = 9.21$; 5.5 months supported, wide screen, $M = 42.70$, $SD = 12.54$; 5.5 months unsupported, narrow screen, $M = 36.32$, $SD = 8.74$; 5.5 months unsupported, wide screen, $M = 41.53$, $SD = 8.17$; 4.5 months supported, narrow screen, $M = 34.82$, $SD = 11.17$; 4.5 months supported, wide screen, $M = 38.32$, $SD = 11.02$) (see Figure 6).

Test trials. We averaged and analyzed mean looking times (see Figure 6) in the same way as familiarization trials. Analysis revealed no significant main effects of group, $F(1, 42) = 2.20$, $p = .12$, or screen, $F(1, 42) = 0.001$, $p = .98$. However, the Group × Screen interaction was significant, $F(1, 42) = 3.80$, $p = .03$, $\eta_p^2 = .15$. Planned comparisons indicated that whereas the 5.5-month-olds who sat supported looked longer to the narrow- ($M = 35.03$, $SD = 11.71$) than to the wide-screen event ($M = 22.74$, $SD = 9.00$), $F(1, 14) = 5.54$, $p = .03$, $\eta_p^2 = .28$, the 5.5-month-olds who sat without support looked about equally to the two events, $F(1, 14) = 2.31$, $p = .15$ (5.5 months unsupported, narrow screen, $M = 19.13$, $SD = 4.15$; 5.5 months unsupported, wide screen, $M =$

[3] Because subtle differences in infants' body position when sitting semisupine relative to upright has the potential to affect the quality of visual and haptic exploration (e.g., Lefèvre, 2002; Out et al., 1998; van der Fits, Klip, van Eykern, & Hadders-Algra, 1999), the car seat was positioned in a way to allow infants' to sit fully upright while still being fully supported.

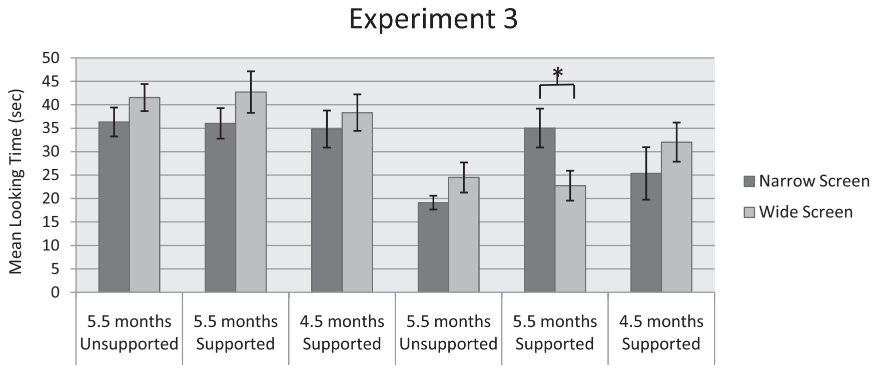

Figure 6. Mean looking times (in seconds, with standard error bars) during the familiarization and test events of 5.5-month-olds who sat unsupported and 5.5- and 4.5-month-olds who sat fully supported in Experiment 3. Asterisks represent significance at $\alpha < .05$.

24.49, $SD = 9.07$) as did the 4.5-month-olds who sat supported (4.5 months supported, narrow screen, $M = 25.36$, $SD = 15.84$; 4.5 months supported, wide screen, $M = 32.03$, $SD = 11.79$), $F(1, 14) = 0.91$, $p = .36$. These results suggest that 5.5-month-olds who received full posture support during preexposure exploration used the pattern differences to individuate the objects. In contrast, 5.5-month-olds who did not receive full support failed to use the pattern differences to individuate the objects following multisensory exploration. Furthermore, the 4.5-month-old infants did not use the pattern differences to individuate the objects following multisensory exploration even when provided full support. In summary, receiving full posture support significantly enhanced the degree to which the 5.5-month-old infants benefited from the multisensory priming experience, but did not provide the same benefit to 4.5-month-olds.

Preexposure behaviors. Because infants are typically better able to manipulate objects when provided sitting support, we expected the posture-supported infants to spend more time exploring the objects. However, given that the 4.5-month-olds did not benefit from multisensory experience, whereas the 5.5-month-olds did, we reasoned that despite the additional support provided by the infant seat, the 4.5-month-olds may have been unable to effectively explore the objects. To assess these hypotheses, we compared the exploration behaviors (i.e., touching, looking, mouthing) of the 5.5-month-olds who sat in a seat with the 5.5-month-olds who were not provided this support and with the 4.5-month-olds who were provided support. We calculated intercoder reliability, and it averaged 89% for looking (43 of the 48 infants), 95% for touching (43 infants), and 99% for mouthing (41 infants). Mean duration and standard errors for each behavior are reported in Figure 7.

We analyzed results by means of a MANOVA, with infant group (5.5 months supported, 5.5 months unsupported, and 4.5 months supported) as the between-subjects factor and duration of

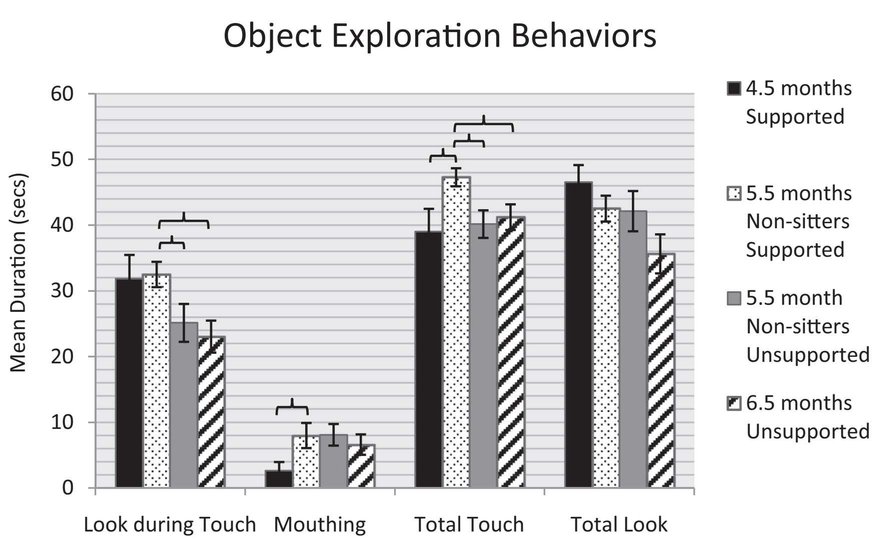

Figure 7. Mean durations (in seconds, with standard error bars) of infants' object exploration behaviors during the preexposure trials of the 6.5-month-olds from Experiment 2 and 4.5- and 5.5-month-olds from Experiment 3, separated by age, sitting ability, and level of posture support. Brackets denote statistically significant comparisons ($\alpha < .05$).

looking, touching, and mouthing the object as dependent variables. The overall MANOVA was significant, $F(6, 88) = 3.16$, $p = .007$, $\eta_p^2 = .18$. Between-subjects effects were found for duration of touching, $F(2, 45) = 3.31$, $p = .04$, $\eta_p^2 = .13$, and mouthing the objects, $F(2, 45) = 3.60$, $p = .03$, $\eta_p^2 = .14$, but not for duration of looking at the objects, $F(2, 45) = 0.88$, $p = .42$, suggesting that infants looked at the objects about equally across conditions (5.5 months supported, $M = 42.52$, $SD = 7.88$; 5.5 months unsupported, $M = 42.13$, $SD = 12.25$; 4.5 months supported, $M = 46.53$, $SD = 10.48$).

Because the 5.5-month-olds who sat supported successfully individuated the objects following the preexposure period, our primary interest was in the exploration of behaviors of those infants compared with the other infants. Planned comparisons indicated that the 5.5-month-olds who sat supported touched the objects for a longer duration of time than the 5.5-month-olds who were not supported, $F(1, 30) = 8.08$, $p = .008$, $\eta_p^2 = .21$, and the 4.5-month-olds who were also supported, $F(1, 30) = 4.96$, $p = .03$, $\eta_p^2 = .14$ (5.5 months supported, $M = 47.29$, $SD = 5.50$; 5.5 months unsupported, $M = 40.16$, $SD = 8.40$; 4.5 months supported, $M = 39.05$, $SD = 13.75$). The supported 5.5-month-olds mouthed the objects significantly longer than the 4.5-month-olds, $F(1, 30) = 5.32$, $p = .03$, $\eta_p^2 = .15$, but for about the same duration as the unsupported 5.5-month-olds, $F(1, 30) = 0.002$, $p = .97$ (5.5 months supported, $M = 7.97$, $SD = 7.65$; 5.5 months unsupported, $M = 8.08$, $SD = 6.58$; 4.5 months supported, $M = 2.64$, $SD = 5.20$). We also expected the posture-supported infants to spend more time in multisensory exploration than the unsupported infants. To test this hypothesis, the duration of time the infants spent simultaneously touching and looking at the objects was compared. The supported 5.5-month-olds ($M = 32.49$, $SD = 7.72$) spent significantly more time engaged in multisensory exploration than the unsupported infants ($M = 25.12$, $SD = 11.54$), $t(30) = 2.12$, $p = .02$ (one-tailed), $\eta_p^2 = .13$ (see Figure 7). In contrast, no significant differences were found when compared with the 4.5-month-olds, $t(30) = 0.16$, $p = .44$ (one-tailed) (4.5 months, $M = 31.83$, $SD = 14.55$).

Together, these results indicate that providing the 5.5-month-old infants with sitting support resulted in significantly greater durations of touching, and simultaneous looking and touching when compared with same-age infants who did not receive sitting support. Furthermore, the supported 5.5-month-olds differed from the supported 4.5-month-olds only in the duration of touching and mouthing, with the 5.5-month-olds engaged in these behaviors longer than the 4.5-month-olds. Despite these highly supportive conditions and the fact that the 4.5- and 5.5-month-olds who sat supported demonstrated similar durations of multisensory experience, the younger infants failed to attend to pattern when individuating the objects. There are a number of potential reasons for their failure, and these are discussed in the General Discussion section.

Because both the 5.5-month-olds who sat supported and 6.5-month-olds from Experiment 2 who sat unsupported successfully individuated the objects based on pattern differences, we were also interested in determining whether their object explorations were similar in duration. A MANOVA assessed group differences in looking, touching, and mouthing behaviors, $F(1, 28) = 2.91$, $p = .05$. Between-subjects analysis revealed that the supported 5.5-month-olds ($M = 47.29$, $SD = 5.50$) touched longer than the 6.5-month-olds ($M = 41.22$, $SD = 7.80$), $F(1, 30) = 6.48$, $p = .02$, $\eta_p^2 = .18$. No between-subjects differences were obtained in mean looking and mouthing behaviors (both $ps > .05$). Further analysis revealed that the 5.5-month-olds who sat supported simultaneously looked and touched ($M = 32.49$, $SD = 7.72$) significantly longer than the 6.5-month-old infants ($M = 23.03$, $SD = 9.95$), $t(30) = 3.00$, $p = .003$ (one-tailed), $\eta_p^2 = .23$ (see Figure 7). Similar results were obtained even when the analyses included only the 6.5-month-olds who were able to sit alone. These results are interesting, particularly when compared with the null results of Experiment 2 in which 6.5- and 5.5-month-old infants who sat unsupported showed no differences in object exploration times. When infants sat unsupported, their object exploration behaviors were highly similar, yet only the 6.5-month-olds were primed to attend to pattern. The younger infants failed to benefit from the preexposure trials. Once supported, however, the 5.5-month-old infants were able to maintain contact with the objects longer than both same-age infants who sat unsupported and the 6.5-month-olds (as indicated by touch, and simultaneous look and touch times). These findings suggest that the 5.5-month-olds needed more time to explore the objects for priming to occur compared with the 6.5-month-olds.

General Discussion

There is now a great deal of evidence that infants can be primed, through select experiences, to attend to surface features at younger ages than they do so spontaneously. In the present research, we investigated whether infants' younger than 7.5 months, who typically do not use pattern differences as the basis for individuating objects, could be led to do so when first allowed multisensory exploration of the objects. In three experiments, infants were presented with two different patterned objects (a dotted ball and a striped ball) to explore, one at a time, prior to an object individuation task involving those two objects. Infants aged 4.5–6.5 months, who varied in their ability to sit unsupported, were tested under different support conditions. Infants' object exploration behaviors during the preexposure trial and performance on the object individuation task were examined. Collectively, the outcomes of these experiments reveal an intriguing relation between postural support, object manipulation, and object individuation.

Postural Support, Multisensory Exploration, and Pattern Priming

Several important findings emerged. First, following preexposure trials, in which infants looked at, touched, and mouthed the balls, 6.5-month-olds, but not 5.5-month-olds, successfully individuated the different-patterned objects. (Without preexposure trials, neither group individuated the objects.) Data analysis revealed, however, that the two groups differed not only in their capacity to be primed to use the pattern difference as the basis for individuating the objects but also in their capacity to sit upright unsupported. Whereas most of the 6.5-month-olds could sit unsupported, most of the 5.5-month-olds could not sit unsupported. Interestingly, the 6.5- and 5.5-month-olds did not differ significantly in the duration of time in which they looked at, touched, or mouthed the objects, nor in the duration of time they engaged in multisensory (simultaneous touching and looking) behaviors.

In order to tease apart the effect of age (maturation and experience) on object exploration and subsequent priming, 5.5-month-olds were assessed using the same procedure with one important modification: They were placed in an infant seat that provided full postural support during the preexposure trials. Given evidence, from a wide range of tasks and domains of functioning, that postural strength and sitting ability influence object exploration and processing (Bertenthal & von Hofsten, 1998; Fallang et al., 2000; Gabbard et al., 2007; Out et al., 1998; Rochat, 1992; Rochat & Senders, 1991; Soska et al., 2010; Thelen & Spencer, 1998), we were not surprised to find that this manipulation positively influenced both object manipulation behaviors and pattern priming. Under these more supportive conditions, 5.5-month-olds now individuated the different-patterned objects. They also spent significantly more time touching the objects and engaged in significantly more simultaneous looking and touching during the preexposure trials. In summary, 5.5-month-olds who were fully supported spent more time in multisensory exploration and were more likely to individuate the objects than 5.5-month-olds who were not fully supported.

Interestingly, the posture-supported 5.5-month-olds also touched, and simultaneously looked at and touched, the objects longer than the 6.5-month-olds, who sat unsupported and successfully individuated the objects. These results suggest that the addition of postural support enabled the younger infants to spend more time with the objects in direct multisensory contact than both their unsupported same-age peers and the older 6.5-month-old infants. In doing so, the younger infants gained extra exposure to the objects—time that was necessary for them at 5.5 months to sufficiently attend to and process the pattern information for later use during the object individuation task. The older infants, in contrast, did not require the additional exploration time to succeed in the same task. These results are consistent with other studies showing that additional object exploration time and improved exploration skills enhance object processing and, importantly, attention to object features (Eppler, 1995; Perone, Madole, Ross-Sheehy, Carey, & Oakes, 2008).

In contrast to the positive findings obtained with the 5.5-month-olds, preexposure trials did not prime 4.5-month-olds to use pattern differences, even when they were given full posture support and even though they demonstrated multisensory (simultaneous looking and touching) times comparable to those of the 5.5-month-olds who sat supported. Perhaps if the 4.5-month-olds were given longer preexposure trials and they spent more time engaged in simultaneous visual and tactile exploration of the objects, behaviors that are indicative of successful priming, then they would be more likely to identify pattern as important to the individuation process. Another possibility is that the quality, and not the quantity, of younger infants' exploration experience prohibits successful multisensory priming. Perhaps younger infants would be more likely to benefit from multisensory exploration and attend to pattern features if an adult helped them manipulate the object during the preexposure trials or if they were given practice or training in sitting up and exploring objects at the same time. Previous studies support the idea that these kinds of experiences can facilitate multisensory exploration (Hadders-Algra, Brogren, & Forssberg, 1996; Lobo & Galloway, 2008), and a test of these hypotheses is presently underway.

Multisensory Exploration as a Priming Mechanism

The color priming results reported by Wilcox et al. (2007) together with the pattern priming results reported here provide a more comprehensive picture of multisensory priming, its benefits, and its limitations. First, collectively these studies reveal that the effects of multisensory priming are not specific to one feature property or age group. Using the same basic procedure, infants aged 10.5 months can be primed to attend to color information, and infants 5.5 and 6.5 months can be primed to attend to pattern information. Multisensory exploration appears to be a general priming mechanism that can be used with different aged infants to enhance sensitivity to different surface features, as long as the conditions under which it is applied are appropriate to the motor abilities of the infants tested. Because infants of almost all ages engage in some form of manual exploration on a daily basis, such a mechanism is quite useful for learning about objects, as it can be adapted to the exploratory skill level of the infant.

Second, the pattern priming results inform our interpretation of color priming results reported by Wilcox et al. (2007). In Wilcox et al. (2007), infants aged 9.5 and 10.5 months were allowed multisensory exploration of a green and a red ball, successively, and then their capacity to individuate on the basis of this color difference was tested. Whereas 10.5-month-olds benefited from the multisensory experience, the 9.5-month-olds did not. On the basis of preexposure data indicating that the exploratory behaviors of the two age groups did not differ reliably, one interpretation Wilcox et al. offered for the test results was that the two groups differed in their capacity to make use of the information gathered during the preexposure trials. The assumption was made that because the two groups engaged in the same type and amount of exploratory behavior, they gathered the same information during the preexposure trials. The present results suggest a slightly different interpretation. It is possible that 9.5-month-olds simply needed to engage in multisensory exploration longer than 10.5-month-olds before shifting their attention to color features. This is similar to 5.5-month-olds who needed to engage in multisensory exploration longer than 6.5-month-olds before shifting their attention to pattern features.

Finally, the two sets of studies provide a unified picture as to the importance of multisensory, visual, and tactile exploration to feature priming. The intersensory redundancy hypothesis, described previously, maintains that infants are more sensitive to amodal (e.g., shape, size, substance) than modality-specific (e.g., color, pattern, luminance) properties of objects because amodal properties are experienced redundantly and in temporal synchrony across the senses. Engaging in multisensory exploration of objects provides infants with the opportunity to encode amodal object properties and facilitates the formation of multimodal object representations. Once multimodal representations are formed, attention is then directed toward unimodal object properties. In Wilcox et al. (2007), 10.5-month-olds were primed to attend to color features only when they were allowed visual and tactile exploration of the objects. If they were allowed to look at but not touch the objects in the preexposure trials, they did not demonstrate increased sensitivity to color features. In the present studies, the main difference between the 5.5-month-olds who individuated the objects and those who did not, other than the amount of posture support they were provided, was the amount of multisensory exploration in which they engaged. The 5.5-month-olds who individuated the objects (Experiment 3) engaged in more simultaneous visual and tactile exploration, but not more visual exploration, of the objects during the preexposure trials than those who failed to individuate the objects.

Concluding Comments

The studies reported herein are significant in three ways. First, this study provides converging evidence that multisensory exploration is an effective method for priming infants to use surface features (e.g., color or pattern) as a basis for object individuation at an earlier age than they would use these features spontaneously. Second, this study is the first to demonstrate that priming during multisensory exploration can enhance the ability of infants as young as 5.5 months to attend to featural information in an object individuation task. Finally, these results indicate that the object information infants are able to access during multisensory exploration is constrained by their motor development, specifically the ability to sit independently. Cumulatively, these studies add to a growing body of literature demonstrating that perceptual and cognitive development are dependent on and intricately linked with the physical and motor capacities of infants (e.g., Bertenthal, Campos, & Barrett, 1984; Bertenthal, Campos, & Kermoian, 1994; Bushnell & Boudreau, 1993; Herbert, Gross, & Hayne, 2007; Needham, 2000; Needham et al., 2002; Perone et al., 2008; Piaget, 1954; Rakison & Woodward, 2008; Soska et al., 2010; Thelen, Schöner, Scheier, & Smith, 2001).

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