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The Development of Visual-Tactual Perception of Objects: Amodal Relations Provide the Basis for Learning Arbitrary Relations

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Infants of 4 and 6 months were familiarized with an object visually and tactually and then tested for visual-tactual matching on the basis of amodal and arbitrary relations or arbitrary relations only (Experiment 1). Results indicated that both the 4- and the 6-month-olds were capable of matching when amodal information specifying the common shape of the visual and tactual stimulation was available during test. In contrast, only the 6-month-olds were capable of matching on the basis of arbitrary relations between the haptically experienced shape of the object and its color or pattern. A control study (Experiment 2) demonstrated that the 4-month-olds were, in fact, able to discriminate the colors or patterns used. Results were interpreted as consistent with findings in the area of audiovisual event perception, demonstrating a developmental lag between detection of amodal and arbitrary relations. Finally, Experiment 3 explored the basis for 6-month-olds' detection of the arbitrary relations in Experiment 1. Results demonstrated that when amodal information for shape was eliminated during familiarization, infants were no longer able to match on the basis of arbitrary relations. These findings are consistent with an invariant-detection view and suggest that amodal information can serve as a basis for learning about arbitrary relations.

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Young infants are adept perceivers of multimodal stimulation. For example, infants perceive redundancy across visual and tactile stimulation in the first month of life. After mouthing an object, 1-month-old infants can visually recognize its smooth or nubby texture (Meltzoff & Borton, 1979; Pecheux, Lepecq, & Salzarulo, 1988) and its rigid or flexible substance (Gibson & Walker, 1984). Infants of 2 to 3 months transfer shape information from the hands to the eyes (Streri, 1987), and 4-month-olds recognize motion patterns across touch and sight (Streri & Spelke, 1988). By 6 to 9 months, across different experimental settings and varied techniques, infants recognize complex shapes, textures, and substances across touch and sight (Bryant, Jones, Claxton, & Perkins, 1972; Bushnell, 1981, 1982; Rose, Gottfried, & Bridger, 1981; Ruff, 1976; Steele & Pederson, 1977; Streri & Pecheux, 1986; Wagner & Sakovits, 1986). Taken together, these findings demonstrate that crossmodal visual-tactual perception is functioning and rapidly developing soon after birth.

Parallel findings have been documented for early audiovisual perception. In a series of studies, Bahrick (1996, 2000) showed that by 3 weeks of age, infants detect the synchrony between sights and sounds of an object's impact, and by 6 weeks they detect the composition of the object (whether it is composed of a single, solid unit or of a group of smaller elements) on the basis of temporal information common to vision and audition. By 3 to 5 months of age, infants detect intermodal audiovisual relations specifying the changing distance, substance, rhythm, and tempo of an event (Bahrick, 1983, 1987, 1988; Lewkowicz, 1994; Pickens, 1994; Spelke, 1979; Walker-Andrews & Lennon, 1985). They also match faces and voices on the basis of affect, gender, and age of speaker (Bahrick, Netto, & Hernandez-Reif, 1998; Walker, 1982; Walker-Andrews, Bahrick, Raglioni, & Diaz, 1991) and on the basis of vowel sounds (Kuhl & Meltzoff, 1984). Thus, infants are capable perceivers of the redundancy across audible and visible stimulation. The properties just delineated, such as shape, texture, substance, changing distance, rhythm, and tempo, are amodal; that is, they are not specific to a particular sense modality. Rather, the same information is conveyed by two modalities. According to Gibson (1969), detection of these amodal relations is direct and requires little or no learning. Furthermore, when amodal information is presented concurrently in two sense modalities, it selectively recruits infant attention and facilitates processing of the redundant information (Bahrick & Lickliter, 2000).

Some properties of objects and events are, however, available to only one sense modality and are modality specific. For example, pitch and timber are aurally detected, color and brightness are visually detected, and temperature is haptically detected. Most events make both amodal and modality-specific properties available for perception. For example, the amodal rhythm of a bouncing ball may be detected, and at the same time the pitch of its sound and the color of its surface may be noticed. When we concurrently perceive two properties in different modalities that are not amodally related but occur together (e.g., pitch and color), we are detecting *arbitrary intermodal relations,* relations between properties in two sense modalities that do not predictably occur together in nature or across contexts. For example, the relation between the specific voice qualities and the appearance of a specific face of a given sex is arbitrary (e.g., Mary: soft, squeaky voice; Jane: loud, resonant voice). So is the relation between a verbal label and a particular object or between the texture of an object and its particular color and shape. These relations may change from one language or context to another.

Few studies have examined infants' intermodal perception of arbitrary relations. Spelke and Owsley (1979) found that by 3 months, infants could pair their mother's face with her voice and discriminate this relation from a female stranger's face and voice. By 6 months, infants showed learning and memory for arbitrary face–voice pairings of same-sex adult strangers (Hernandez-Reif, Cigales, & Lundy, 1994). In the visual-olfactory domain, 4-month-old infant girls showed learning of arbitrary object–odor pairs (Fernandez & Bahrick, 1994), and by 7 months, infants learned the relation between the color of a container and the taste of its contents (Reardon & Bushnell, 1988). Even newborns showed learning of the arbitrary relation between a distinctive spoken syllable and a particular color or shape when the two were united by amodal temporal information but not when temporal information was absent (Slater, 1999). Although few studies have examined infants' intermodal perception of arbitrary relations, even fewer have explored the basis for detecting these relations.

Bahrick (1992, 1994, 2000; Bahrick & Pickens, 1994) proposed that detection of intermodal relations emerges in order of increasing specificity, consistent with Gibson's (1969) differentiation view. From this view, detection of global (amodal) relations precedes and constrains detection of nested relations (e.g., arbitrary, modality-specific relations). Consistent with this hypothesis, Bahrick (1992, 1994) found that infants detected amodal relations developmentally prior to arbitrary relations in a given set of events. Specifically, 3-month-old infants detected the amodal synchrony and composition relations uniting the visible and audible impacts of an object hitting a surface; however, they did not detect the arbitrary relation between the pitch of the sound and the color or shape of the object until 7 months of age. These findings, along with a recent study on the perceptual basis of language development (Gogate & Bahrick, 1998), suggest that detection of amodal relations developmentally precedes detection of arbitrary relations in a given domain and may serve as the basis for learning arbitrary relations across modalities in early infancy.

Gogate and Bahrick (1998) demonstrated that infants learned arbitrary audiovisual relations in the presence of amodal information but not in its absence. Seven-month-old infants learned to match a vowel sound with an object when the movements of the object were synchronized with the speech sounds; however, matching did not occur when the object was still or was moved out of synchrony with the speech sounds. Apparently amodal synchrony facilitated learning the arbitrary relation between the speech sounds and appearance of the object at the age of 7 months. The primacy of infants' detection of amodal synchrony over other audiovisual relations and its importance for detecting those relations has also been documented in other studies (e.g., Bahrick, 1996, 2000; Lewkowicz, 1996; Slater, 1999).

Infants' detection of amodal relations prior to learning about arbitrary relations is adaptive (Bahrick & Pickens, 1994) in the sense that amodal relations are context-free, whereas arbitrary relations can vary from one context or event to another. Early detection of amodal relations focuses attention on context-free relations that can be generalized across events prior to learning about relations that vary from one context to the next. For example, an object that looks round will always feel round. An object that looks red, however, will only sometimes feel bumpy.

If amodal relations precede and constrain detection of arbitrary relations, then this developmental pattern should also be evident in the domain of visual-tactual functioning. The research reported here examined this issue by testing whether the developmental lag between the detection of audiovisual amodal and arbitrary relations found by Bahrick (1994) generalizes to the visual-tactual domain (Experiments 1 and 2). Moreover, Experiment 3 explores the learning process underlying the visual-tactual perception of arbitrary relations; it asks whether the presence of amodal information is important for detecting arbitrary relations.

EXPERIMENT 1: MATCHING ON THE BASIS OF AMODAL OR ARBITRARY RELATIONS

In the natural environment, once infants begin to reach for objects, they interact with them by coordinated visual and tactual exploration. This allows them to abstract amodal information uniting the visual and tactual experience, such as shape, size, and depth common to the touch and sight of an object. It also allows infants to abstract arbitrary relations uniting the visual and tactual experience, such as the relation between the felt shape of the object and its seen color and pattern.

In this experiment, infants were given the opportunity to concurrently explore an object haptically (below a bib) and visually (above a bib) in a familiarization phase similar to the method used by Bushnell (1982, 1986). This presentation, just like exploration in the natural environment, provided infants with the opportunity to detect amodal object properties, such as shape, size, and depth across touch and vision, as well as arbitrary tactual-visual relations, such as shape and color or pattern. Infants were then tested under one of two conditions to determine if they had (a) abstracted the amodal information for object shape or for the arbitrary relation between shape and color or pattern (amodal/arbitrary condition), or (b) abstracted the arbitrary relation between shape and color or pattern alone (arbitrary condition). Infants of 4 and 6 months were selected for this study because these two ages represent the typical time window from when deliberate reaching becomes evident (3–4 months) to when reaching is reliable (5–6 months; see Bower, 1974; Bruner, 1969; McDonnell, 1979). Consistent with the differentiation view and with recent findings by Bahrick (1992, 1994), it was expected that infants would show evidence of visual-tactual matching, even at the youngest age in the amodal/arbitrary condition, because, as in the natural environment, matching could be accomplished on the basis of amodal relations. In contrast, it was expected that matching would be more difficult when only arbitrary relations were available and thus would only be evident at the oldest age or not at all.

Method

Participants

Forty-eight infants, 24 of 4 months (12 boys and 12 girls), whose mean age was 127 days ($SD = 6.38$), and 24 of 6 months (12 boys and 12 girls), whose mean age was 187 days ($SD = 10.63$), participated. The data of 10 additional infants were rejected ($n = 3$ at 4 months and $n = 7$ at 6 months) for crying or excessive fussiness. The criteria for rejection included behaviors that continuously interfered with attention to task. The data of infants who fussed but continued to look or feel the objects with their hands were not rejected. In contrast, infants' data were rejected if they closed their eyes or looked away from the stimuli when crying for prolonged periods of time (e.g., during most or all of one trial) or were continuously squirming in an attempt to get out of the infant seat or pull the bib off. Typically, attempts were made to calm the fussy baby (including feeding or water breaks) before the test was aborted. All participants in this and the other experiments were healthy, full-term infants with no known sensory impairments. Across all participants, there were 38% White infants, 56% Hispanic, 3% African American, and 3% Asian American. Infants were recruited through the county's birth records department and came primarily from middle-class families.

Stimulus Materials

Two differently shaped three-dimensional objects, an eight-point star (6 cm wide × 6 cm long × 6 cm deep) and an ellipsoid (4.5 cm wide × 5.75 cm long × 3.5 cm deep), served as stimuli. Each was presented against a white background and subtended a visual angle of approximately 11°. The two shapes were selected because of their distinct visual and haptic characteristics: A star has only flat surfaces and angles, whereas an ellipsoid has only curves. The star was made of wood, and the ellipsoid (egg) was plastic and hollow. One member of each pair was painted purple with green polka dots, and the other yellow with horizontal, orange stripes. Two pairs resulted, one consisting of a purple and green egg and a yellow and orange star, and the other of a yellow and orange egg and a purple and green star (see Figure 1). A thin, black rod was attached to the back of each object for the purpose of presenting the objects to the infant. During all visual presentations, an experimenter moved the objects slowly in an arc-shaped trajectory by rotating the rods slightly and in an erratic temporal pattern. Furthermore, two posterboards (measuring approximately 30 cm wide × 22 cm long, each subtending a visual angle of approximately 35°) were constructed depicting the two color patterns (purple with green polka dots and yellow with orange stripes; see Figure 1). They, too, were moved up and down in an erratic temporal pattern during all visual presentations, traversing approximately 10 cm in each direction.

Apparatus

Infants were seated in an infant seat facing a white occluder (1.2 m high × 2.2 m long) approximately 30 cm away. They were fitted with a large white bib that was secured to the front of the occluder. The bib prevented infants from seeing objects placed in their hands, at the same time allowing them to explore the objects, one by touch under the bib and the other by sight above the bib.

Objects explored by touch were presented through a rectangular opening in the occluder approximately 20 cm below the bib, and the visual objects were displayed through a round opening or openings cut near the top of the occluder above the bib. Small peepholes positioned at the upper right and left sides of the occluder allowed observers to monitor infants' looking at stimuli during the familiarization and test phases (see Figure 2). Trained observers used small button boxes connected to a Rustrack event recorder to record both direction (right vs. left sides) and duration of infant looks at the visual presentations.

Procedure

Familiarization phase. Infants were first familiarized with both objects. The purpose of this phase was to provide infants with the opportunity to abstract amodal shape information and arbitrary shape and color pattern information from the two identical objects, one felt below the bib and one seen above the bib. Half of the infants in each age group were familiarized and tested with the purple-dotted egg and the yellow-striped star and the other half with the other combination.

Familiarization consisted of four trials, each 30 cumulative sec long, in which infants concurrently felt and viewed two identical versions of first one object and then the other in an alternating sequence. A cumulative looking criterion was used to ensure that all infants were familiarized with each object by touch and sight for at least 60 sec, because this trial length has been found in prior studies

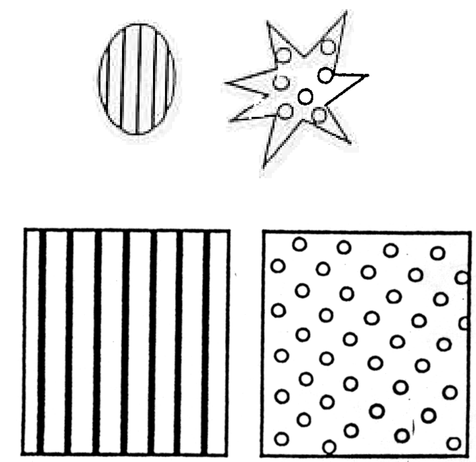

FIGURE 1 Three-dimensional objects and posterboards depicting distinctive color patterns used as stimuli in Experiment 1.

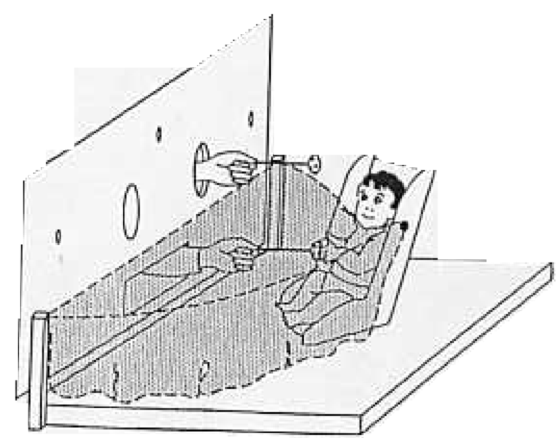

FIGURE 2 Apparatus showing visual-tactual familiarization phase for Experiment 1.

(Hernandez-Reif, 1994; Rose, Gottfried, & Bridger, 1981) to be effective in promoting abstraction of amodal properties. In each familiarization trial, infants were assisted by an adult to grasp, rub, and explore the object under the bib while they viewed an identically shaped object with a distinctive color pattern presented above the bib at a distance of approximately 30 cm from the infant. The order of object presentation alternated across the four trials (e.g., star, egg, star, egg). The object presented first (i.e., star or egg) was counterbalanced across participants within each age group. Two of the four trials were terminated when the infant accrued 30 cumulative sec of looking at the object above the bib regardless of the amount of time spent touching the object below the bib. The other two trials were terminated when the infant accrued 30 cumulative sec of touching the object below the bib regardless of the amount of looking to the object. The criterion (i.e., touching or looking) for the first trial was counterbalanced across participants.

Test phase. Half the infants in each age group were assigned to the amodal/arbitrary test condition and half to the arbitrary test condition. The amodal/arbitrary test assessed infants' ability to match the object in their hands with one of the visually presented objects on the basis of amodal shape information, arbitrary shape–color pattern relations, or both. (Note that the term *matching* is used loosely to mean abstracting and relating information across visual and tactual modalities. Evidence of matching is inferred when infants' looking during the test is influenced by what they have seen and touched earlier during familiarization.) The amodal/arbitrary test was comprised of four 20-sec trials. In each trial, infants viewed the star and the egg with their distinctive color patterns side by side above the bib while one of the two objects was presented for tactile exploration under the bib. The side on which the stimuli first appeared above the bib (e.g., the egg first on the left or on the right) was counterbalanced across participants and across the four test trials. Half of the infants received the star to explore under the bib for two consecutive trials, followed by the egg for the other two trials, and the other participants received the objects in the reverse order.

Because the visually presented egg and star differed in terms of shape and color pattern during the test phase (e.g., purple-dotted egg vs. yellow-striped star), infants could match the haptically explored object with the appropriate visual object on the basis of their common shape (amodal relations) or on the basis of the relation between the haptically experienced shape and the color pattern abstracted during familiarization (arbitrary relations).

The arbitrary test assessed infants' ability to relate the objects across touch and sight on the basis of the arbitrary relation between the tactually experienced shape and the visually experienced color pattern. The procedure was similar to that of the amodal/arbitrary condition in that infants haptically explored the egg in two trials and the star in two trials, all below the bib, and were required to match them to the stimuli above the bib. Thus, as in the amodal/arbitrary condition, only tactile shape could be used to differentiate the two objects below the bib. The test phase differed from that of the amodal/arbitrary condition, however, in that the two-dimensional posterboards depicting the distinctive color patterns were displayed above the bib (at a distance of approximately 43 cm from the infant) instead of the actual objects. This eliminated all amodal information common to touch and sight (i.e., shape, size, and depth) as a basis for matching during this test, leaving only the arbitrary tactual shape and visual color pattern relations.

The duration of infant looks to the objects or posterboards presented above the bib was recorded from behind the occluder by trained observers. To preclude experimenter bias, the observers were unaware of the lateral positions of the objects and posterboards above the bib and of the type of object (egg or star) in the infant's hand. The lateral positions of the two displays were counterbalanced as before.

Results

The Dependent Measure

The data from the test phase were expressed in terms of the proportion of total looking time (PTLT) infants spent looking at the visually presented object that matched the object in their hands. This measure was derived for each infant by calculating the amount of time spent looking at the matching object divided by the total amount of time spent looking at both visual stimuli on each trial. The proportions for the four trials were averaged to yield a single PTLT for each infant. Mean PTLTs were derived for the 4- and 6-month-olds. PTLTs significantly greater than .50 indicated a visual preference for the matching stimuli.

Interobserver Reliability

Interobserver reliability for the test phase was calculated on the basis of 31% (15/48) of the infants (21% for the amodal/arbitrary condition and 42% for the arbitrary condition). PTLTs to the matching stimuli during the test were computed independently for the primary and the secondary observers. These scores were then correlated. The average Pearson product–moment correlation was .94 (SD = .07), with mean correlations of .94 (SD = .06) for the amodal/arbitrary condition and .95 (SD = .09) for the arbitrary condition.

Preliminary Analyses

To determine whether the mean PTLTs differed as a function of the type of stimulus, a three-way analysis of variance (ANOVA) was conducted on PTLTs with age (4 months vs. 6 months), stimulus type (star or egg), and stimulus color pattern (purple dots or yellow stripes) as main factors. No significant main effects or interactions were found involving stimulus type or stimulus color pattern (all $ps > .05$). Thus, infant responses were not affected by the object type or color pattern of the stimuli during the test phase.

Additional analyses were conducted to check for side preferences using single sample t tests against the 50% chance level. New PTLTs were computed for this analysis, reflecting the PTLT to the visual display presented on the right side regardless of whether it matched the tactile display. These PTLTs were then averaged across groups to derive separate PTLTs for each age. Results indicated a significant right-side preference only for the 4-month-old infants in the arbitrary test condition ($M = .61$, $SD = .14$), $t(11) = 2.72$, $p = .02$; however, given that the lateral positions of the two objects were counterbalanced both across and within participants and that the matching stimulus occurred on the right side half the time, this would not preclude observing significant evidence of matching.

Main Analyses

The mean PTLTs to the matching displays are shown in Figure 3. To address the question of whether infants showed evidence of intermodal matching, single sample *t* tests were performed on the PTLTs against the chance value of .50 for infants of each age and each condition. As expected, evidence of visual-tactual matching was found at both ages, $t(11) = 2.71$, $p = .02$ at 4 months and $t(11) = 2.18$, $p = .052$ at 6 months in the amodal/arbitrary test condition. (Note that all reported *p* values are two-tailed even though the predictions are framed in terms of visual-tactual matching.) Thus, infants spent a significantly greater proportion of their total looking time viewing the object that matched the one in their hands when both amodal and arbitrary information were available as a basis for matching. In contrast, in the arbitrary test condition, infants showed significant evidence of matching at 6 months, $t(11) = 2.31$, $p = .041$, but no evidence of matching at 4 months, $t(11) = .35$, $p > .1$. Thus, when matching relied solely on arbitrary shape and color pattern information, 4-month-olds were no longer able to detect a relation between the tactually experienced object and the visual color pattern.

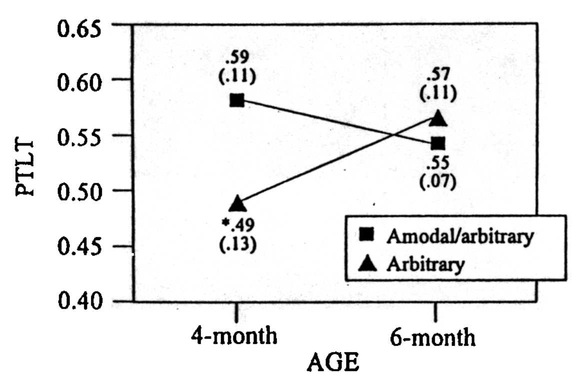

FIGURE 3 Mean proportions of total looking time (PTLT) to the matching stimuli (and *SDs*) as a function of the infant's age (4 months vs. 6 months) and test condition (amodal/arbitrary matching vs. arbitrary matching only).

Further analyses were conducted to compare the results across conditions and ages. A Cochran's C Homogeneity of Variance test and a Lilliefors test supported the assumption that the four groups came from populations with equal variances ($p > .05$) and that the data were approximately normally distributed (all $ps > .05$). To compare intermodal learning across the four groups, a 2 × 2 ANOVA was performed using age (4 months vs. 6 months) and test condition (amodal/arbitrary vs. arbitrary) as the between-subject factors and using PTLT as the dependent variable. This analysis yielded a significant Age × Condition interaction, $F(1, 44) = 3.98$, $p = .05$. A Dunnett *t* test revealed that the mean PTLT of the 4-month-old infants in the arbitrary test condition was significantly lower than the mean PTLT of the other three groups, $tD'(4, 44) = 3.57$, $p < .01$. Thus, at both 4 months and 6 months of age, infants displayed crossmodal matching on the basis of amodal shape relations, but only at 6 months was there evidence of learning the arbitrary shape–color pattern relations (see Figure 3).

Discussion

These findings provide evidence that 4- and 6-month-old infants are able to match a visible object with one they are feeling following familiarization with the appearance and tactile impression of the object. During familiarization, infants viewed the same three-dimensional object as they were feeling. This provided the opportunity for abstracting amodal information, such as shape, depth, and size, as well as arbitrary relations between the tactile impression of the object and its visual appearance, similar to exploration of objects in the infant's natural environment. Two types of test conditions assessed what infants had abstracted from the familiarization phase. The amodal/arbitrary test assessed detection of amodal shape information, arbitrary shape–color pattern relations, or both. (This test did not, however, test for detection of other amodal properties, such as size or depth, because the two tactile objects could be differentiated only on the basis of their shape during the test.) Infants at both 4 months and 6 months looked longer at the matching test object in the amodal/arbitrary test. In contrast, the arbitrary test assessed detection only of the arbitrary relation between the tactually experienced shape and the visually experienced color pattern. In this condition, only the 6-month-olds and not the 4-month-olds showed evidence of intermodal matching. Apparently detection of arbitrary relations emerged later than detection of amodal or amodal combined with arbitrary relations. It may be that matching on the basis of amodal properties is easier than matching on the basis of arbitrarily paired properties in part because amodal properties can be experienced in two modalities concurrently. In contrast, arbitrary relations must be learned, and matching on the basis of arbitrary relations requires memory for the relation between the information in two modalities.

Taken together, these findings suggest a developmental lag between the detection of amodal and arbitrary relations, a lag in which amodal information for shape is detected developmentally prior to arbitrary shape–color pattern relations. This lag is consistent with the lag observed by Bahrick (1992, 1994) in the domain of audiovisual perception. Detection of amodal relations appears to developmentally precede detection of arbitrary relations in a given domain. Bahrick (1992, 1994) reported that 3- and 5-month-olds abstracted amodal audiovisual relations (synchrony, composition) but that the arbitrary audiovisual relation between the pitch of the impact sounds and the colors and shapes of objects was not detected until 7 months. Similarly, in this study, amodal shape information was detected and matched across touch and sight at 4 and at 6 months, but arbitrary object–color pattern relations were detected only by the 6-month-olds. The visual-tactual matching on the basis of amodal shape information by 4 months of age is consistent with previous findings. Young infants have been reported to detect amodal information for a variety of object properties, including shape, size, and texture across sight and touch (Bryant et al., 1972; Kaye & Bower, 1994; Rose et al., 1981; Ruff, 1976; Steele & Pederson, 1977; Streri, 1987; Streri & Pecheux, 1986; Wagner & Sakovits, 1986); however, the finding that 6-month-old, but not 4-month-old, infants learned and remembered arbitrary object–color pattern relations across touch and sight has not been previously documented.

In the arbitrary test condition, the 6-month-olds demonstrated intermodal learning on the basis of familiarization that involved concurrent viewing and touching of identical three-dimensional objects. Bimodal familiarization provided amodal information for the common shape, size, and depth of the visual and tactual objects as well as information for the arbitrary relation between the object's tactual properties and its visual color pattern. Thus, intermodal learning about the arbitrary tactual-visual relations occurred in the presence of amodal information uniting the visual and tactual experiences. This is similar to the conditions under which arbitrary relations are detected in the natural environment when objects are viewed and touched concurrently. These findings raise the question, which is addressed by Experiment 3, of whether amodal information was important for abstraction of the arbitrary relations. In the area of audiovisual event perception, we have demonstrated that amodal relations do provide an important basis for early learning about arbitrary relations (Gogate & Bahrick, 1998; Gogate, Bahrick, & Watson, 2000).

Why might the 4-month-olds fail to detect the arbitrary but not the amodal visual-tactual relations? One possibility is that they did not visually discriminate between the two color patterns. They could have matched in the amodal/arbitrary condition on the basis of amodal shape information without being able to discriminate the color patterns of the objects and then failed to match in the arbitrary condition because color pattern discrimination was required for matching. This seems unlikely in light of previous research showing that by 2 months of age, if not earlier, infants readily distinguish hues and patterns (Adams, Maurer, & Davis, 1986; Bornstein, 1976b; Hamer, Alexander, & Teller, 1982; Packer, Hartman, & Teller, 1985; Teller, Peeples, & Sekel, 1978; Varner, Cook, Schneck, McDonald, & Teller, 1984) and display robust memory for colors (Bornstein, 1976a; Fagan, 1984). Nonetheless, Experiment 2 serves as a control to assess whether or not 4-month-old infants can in fact discriminate the two color patterns used.

EXPERIMENT 2: DISCRIMINATION OF COLOR PATTERN

This experiment tested 4-month-olds' ability to discriminate the color patterns presented in the arbitrary condition of Experiment 1. A novelty preference method (Fantz, 1964) was used. Infants were first visually familiarized with one of the color patterns and then presented with the familiar color pattern and a novel color pattern side by side. Infants were expected to show a preference for the novel color pattern if they discriminated the two.

Method

Participants

Twelve healthy, full-term 4-month-olds (7 boys and 5 girls), whose mean age was 127 days (*SD* = 10.6), were recruited from the same population of infants tested in Experiment 1. The data of one baby were rejected because his mother stated that one stimulus pattern closely resembled the wallpaper in the infant's bedroom.

Procedure

The posterboards displaying the distinctive color patterns used in Experiment 1 served as the stimuli for this experiment. The apparatus was identical to that described for Experiment 1 except that infants were not fitted with the bib.

Familiarization phase. Half of the participants were familiarized with the purple posterboard with green dots and the other half with the yellow posterboard with orange stripes. Familiarization consisted of two trials of one posterboard pattern. A familiarization trial ended when the infant accrued 30 cumulative sec of looking to the posterboard. This procedure ensured that by the end of familiarization, infants accumulated at least 1 full min of looking at the visual color pattern.

Novelty preference test. Following familiarization, the familiar and the novel posterboards were presented side by side for four 20-sec trials. The lateral positions of the two color patterns were counterbalanced across participants and across the four trials. Infants' looking responses to the familiar and the novel color patterns were recorded by trained observers who were unaware of which posterboard was familiar.

Results and Discussion

To determine whether 4-month-olds discriminated the familiar from the novel posterboard, the data from the test trials were expressed as a PTLT to the novel color pattern. This measure was derived for each infant by dividing the amount of time spent looking at the novel color pattern by the total looking time at both color patterns on each test trial. The individual proportions were then averaged across the four test trials to obtain a mean PTLT to the novel color pattern.

Preliminary Analyses

Interobserver reliability was calculated as before, on the basis of 4 of the 12 infants. A mean correlation of .86 ($SD = .18$) was obtained between the recordings of the primary and secondary observers.

Analyses were conducted to test for side bias and stimulus preferences. As in Experiment 1, right-looking PTLTs were computed and tested against the chance level of .50. This analysis revealed no side bias ($M = .48$, $SD = .25$), $t(11) = .22$, $p >$ .10. An ANOVA with pattern presented for familiarization as the between-subject factor (purple vs. yellow) revealed no main effect, $F(1, 10) = 2.39$, $p > .10$.

Main Analyses

The mean PTLT to novel stimulus was subjected to a single sample t test against the chance level of .50. The results revealed that infants spent significantly more time looking at the novel color pattern ($M = .59$, $SD = .11$), $t(11) = 2.24$, $p <$ .05, during the test. These findings are consistent with other studies showing that infants visually discriminate an array of stimuli by showing a preference for the more novel one (Bornstein, 1976b; Fagan, 1977, 1984; Fantz, 1964; Friedman, 1972; Rose, 1981).

In sum, the data showed that 4-month-olds discriminated between the two color patterns used in the arbitrary matching task of Experiment 1. This finding rules out the hypothesis that the 4-month-olds' failure to detect the visual-tactual arbitrary relations was due to an inability to distinguish between the purple-and-green-dotted and the yellow-and-orange-striped patterns.

EXPERIMENT 3: INTERMODAL LEARNING OF ARBITRARY SHAPE–COLOR PATTERN RELATIONS

On what basis might the 6-month-old infants have learned to relate the haptically experienced shape with the color pattern information in the arbitrary test condition of Experiment 1? During familiarization, infants felt a three-dimensional object of a distinctive shape and size beneath the bib and at the same time they saw the identical three-dimensional object with a distinctive color pattern above the bib. Infants may have related the haptically experienced object properties (shape, size, and depth) with the visually experienced properties (shape, size, depth, and color pattern) on the basis of contiguity, consistent with an association view. The visual and haptic information may have been perceived as related because they were experienced together. Then, during the test, which assessed matching on the basis of memory for the haptically experienced shape and visual color pattern, infants looked more at the color pattern that had previously been paired with the shape in their hands.

Alternatively, consistent with an invariant detection view and with recent findings of Bahrick (Bahrick, 1992, 1994; Gogate & Bahrick, 1998), the common shape detectable across vision and touch during familiarization may have served as an important basis for relating the haptic object properties and color pattern during testing. That is, infants may have abstracted amodal information during familiarization, and amodal information may serve as a basis for learning arbitrary associations. Bahrick (1992, 1994) argued that detection of amodal information guides and constrains detection of more specific, nested relations. According to this view, amodal relations are differentiated first and lead to differentiation of more specific relations. Arbitrary shape–color pattern relations are more specific than amodal relations because they are context-specific, whereas amodal relations (size, shape, and texture) are not. That is, objects that look angular always feel angular. Objects that look purple and green, however, only sometimes feel angular. If amodal relations provided the basis for learning the arbitrary relations and if amodal information was eliminated during familiarization, infants would no longer be able to detect the arbitrary shape–color pattern relations; however, for association on the basis of contiguity, the presence of amodal information during familiarization should have little effect on matching object shape with color pattern. Experiment 3 therefore assessed the role of amodal information in intermodal learning of arbitrary relations. It asked whether amodal information was necessary for learning arbitrary relations. Experiment 3 examined whether 6-month-olds would still show matching of arbitrary shape–color pattern relations if all amodal information (shape, size, and depth) common to the visual and haptic displays was eliminated during familiarization. Thus, the familiarization phase was modified by presenting the posterboards displaying the color patterns instead of the actual objects while infants haptically explored the two objects. The test phase was identical to that of the arbitrary test condition of Experiment 1.

Method

Participants

Twelve healthy, full-term 6-month-olds (7 boys and 5 girls), with a mean age of 186.2 days ($SD = 3.8$), participated. The data for 2 infants were rejected, one because of crying and another for falling asleep.

Procedure

The stimuli, apparatus, and procedures were identical to those described in Experiment 2 except for the familiarization phase. During familiarization, while haptically exploring (below the bib) an object of a distinctive shape (egg or star), the infant saw a distinctive color pattern displayed on the flat posterboard above the bib, rather than the actual object. Thus, the amodal properties of shape, size, and depth uniting the visual and tactile stimulations were eliminated as a basis for intermodal learning during familiarization.

Half of the participants were familiarized with the star by touch along with the purple-dotted posterboard and the egg by touch along with the yellow-striped posterboard, and the others were presented with the opposite combination. The arbitrary matching test was identical to that of Experiment 1. Following familiarization, the two posterboards were presented side by side while infants manipulated one object at a time (star or egg) under the bib. Because the tactile objects differed only in terms of shape, the test assessed learning of shape–color pattern relations, just as in Experiment 1. Intermodal learning was inferred if infants looked significantly more to the color pattern previously paired with the object they had in their hands.

Results and Discussion

PTLTs were calculated for each infant as before. For 4 of the 12 infants tested, a second observer recorded infant looking during the test. These PTLTs of the primary and secondary observers were subjected to a Pearson product–moment correlation, which averaged .90 ($SD = .17$).

Preliminary Analyses

A *t* test on the PTLT to the right, regardless of stimulus presentation, revealed no significant side preference ($M = .54$, $SD = .20$), $t(10) = .75, p > .10$. There was also no evidence of a stimulus preference, $F(1, 11) = 2.73, p = .13$.

Main Analyses

To assess whether intermodal learning of the arbitrary shape–color pattern relations occurred in the absence of amodal information about the object, the PTLT was subjected to a single sample *t* test against .50. In contrast with results of Experiment 1, this test revealed no evidence of intermodal matching of the arbitrary relations at 6 months ($M = .53$, $SD = .12$), $t(11) = .76, p > .10$. Thus, at 6 months, intermodal learning of arbitrary shape–color pattern relations was not evident when amodal information was eliminated as a basis for learning during familiarization.

GENERAL DISCUSSION

Both 4- and 6-month-old infants matched objects across touch and sight when amodal information for shape was provided during familiarization and test phases. They showed this matching after 60 sec of concurrent visual and tactual familiarization with two distinctive shapes, an egg and a star. Furthermore, 6-month-olds, but not 4-month-olds, learned the arbitrary relation between the haptically experienced shape of an object and its color pattern. After 60 sec of concurrent visual and tactual familiarization with objects of distinctive color patterns, the 6-month-olds matched the haptically perceived object to the appropriate color pattern depicted on posterboards. Experiment 2 indicated that the 4-month-olds' failure to detect the shape–color pattern relations was not due to an inability to discriminate the color patterns. These findings, together with Bahrick's (1992, 1994) findings in the domain of audiovisual perception, provide converging evidence for a developmental lag between the detection of amodal and arbitrary intersensory relations in a given domain.

How might this lag develop? When multimodal events provide both amodal and arbitrary relations, as most do, infants first differentiate the amodal relations. Amodal relations appear to be perceptually more salient. This salience directs and constrains further differentiation of nested relations. The developmental lag between detection of amodal and arbitrary relations may thus be a result of the young perceptual system's heightened sensitivity to intersensory redundancy (see Bahrick & Lickliter, 2000). If amodal relations are detected first and if they guide and constrain further perception, the nested arbitrary relations will receive less attention and may sometimes not be noticed in a given interaction. Given competing stimulation, attention may shift to other events before processing of nested relations occurs. Thus, the attentional salience of intersensory redundancy can lead to a processing priority for amodal relations and consequently to a developmental lag between detection of amodal versus arbitrary relations. The processing priority for amodal relations was illustrated in a recent study: Bahrick and Lickliter (2000) demonstrated that 5-month-olds could discriminate between two complex rhythms when the rhythms were presented audiovisually, providing intersensory redundancy for rhythm information; however, the infants were unable to discriminate between the rhythms when they were presented in one modality alone, either visually or acoustically. This attentional salience for redundantly specified object properties creates a developmental lag between detection of properties that can be specified redundantly and those that cannot. This lag may be adaptive because it can facilitate infants' learning of consistencies across modalities that occur irrespective of context and, in turn, facilitate appropriate generalizations. It can also minimize learning of relations that occur in some contexts but not others, thus minimizing nonveridical generalizations.

The results of Experiment 1 demonstrated that with a familiarization time of 60 sec, 4-month-olds detected amodal relations but showed no evidence of detecting arbitrary relations. The intersensory redundancy hypothesis described earlier would suggest that perhaps with longer familiarization time, arbitrary relations might be detected even by the 4-month-olds. After attending to the perceptually more salient amodal relations, attention may shift to nested arbitrary relations, similar to the patterns shown by 6-month-olds in the arbitrary test condition of Experiment 1. In fact, 2-month-olds, and even newborns, have been shown to detect some arbitrary associations in the context of amodal relations such as temporal synchrony (Morrongiello, Fenwick, & Nutley, 1998; Slater, 1999) or colocation (Morrongiello, Fenwick, & Chance, 1998).

If amodal relations are in fact perceptually more salient and guide and constrain detection of arbitrary relations, then when amodal relations are absent, it should be more difficult for infants to learn the arbitrary relations. Experiment 3 addressed this issue. It eliminated all amodal information during familiarization by presenting the tactual objects along with flat posterboards depicting the color pattern information instead of the actual objects depicting the color pattern (as in Experiment 1). Results revealed that amodal information for shape was important for 6-month-olds' learning of the arbitrary relations in Experiment 1. Detection of arbitrary relations between the haptically experienced shape of an object and the visually experienced color pattern was evident in the presence of amodal information (Experiment 1) but not in its absence (Experiment 3) at 6 months of age. Apparently the common shape across vision and touch was necessary for learning the arbitrary shape–color pattern relations in the 60-sec familiarization period. Infants' failure to show matching in Experiment 3 may also have been due to an inconsistency between the visual information for shape and size (large, flat posterboards) and the haptic information (smaller, three-dimensional objects). In any case, this also highlights the importance of common amodal information as a basis for relating arbitrary tactual-visual information. These findings are consistent with the view that intersensory redundancy is perceptually more salient and captures infant attention. Learning of arbitrary relations is more difficult in the absence of amodal relations (or in the presence of conflicting amodal information) that guide and constrain attention. This view is also supported by recent findings with newborns (Slater, 1999), where they, too, learned arbitrary associations (between a distinctive sound and a color or shape) in the presence, but not in the absence, of amodal information (temporal contingency). As suggested by the intersensory redundancy hypothesis (Bahrick & Lickliter, 2000), however, it is possible, with additional familiarization time, that the 6-month-olds in Experiment 3 would eventually learn the arbitrary relations, even when amodal relations were absent.

Thus, these findings reveal important information about the conditions for learning arbitrary relations in early infancy. They indicate that intermodal learning of arbitrary relations occurs most efficiently in the context of amodal relations. Six-month-olds were able to relate the haptically experienced shape with a distinctive color pattern only when amodal object information united their visual and tactual exploration. Association between a haptically experienced shape and a distinctive color pattern did not occur on the basis of contiguity in the absence of amodal information. Although not inconsistent with an integration–association view, these findings demonstrate that other processes guide and constrain the conditions under which association takes place. When amodal relations are available, they are perceptually salient and direct attentional selectivity. Consequently, they play a fundamental role in directing and constraining intermodal learning in early infancy.

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