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Picture Perception in Infants: Generalization From Two-Dimensional to Three-Dimensional Displays

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Two experiments investigated 9-month-old infants' abilities to recognize the correspondence between an actual three-dimensional (3D) object and its two-dimensional (2D) representation, looking specifically at representations that did not literally depict the actual object: schematic line drawings. In Experiment 1, infants habituated to a line drawing of either a doll or a sheep and were then tested with the actual objects themselves. Infants habituated to the sheep drawing recovered to the unfamiliar but not the familiar object, showing a novelty preference. Infants habituated to the doll drawing, however, recovered to both familiar and unfamiliar objects, failing to show any preference between the two. In Experiment 2, infants habituated to the 3D objects and were then tested with the 2D line drawings. In this case, both groups of infants showed a preference only for the novel displays. Together these findings demonstrate that 9-month-old infants recognize the correspondence between 3D objects and their 2D representations, even when these representations are not literal copies of the objects themselves.

The ability to perceive two-dimensional (2D) representations of three-dimensional (3D) visual arrays is an essential part of our lives. Typically, perceivers are asked to make use of information contained in many 2D representations, including literal representations (e.g., photographs),

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symbolic representations (e.g., "danger" signs), and schematic representations (e.g., line drawings). Accordingly, exploring the perception of such 2D information is critical for understanding visual perception and development.

Developmental studies of the perception of 2D representations have proceeded along multiple avenues. One line has explored the development of basic perceptual abilities, such as form constancy (e.g., Bornstein, Krinsky, & Benasich, 1986; Caron, Caron, & Carlson, 1979) or perceptual organization (e.g., Ferroni, Valenza, Simion, & Umilta, 2000; Ghim, 1990; Kavšek & Yonas, 2006; Quinn & Bhatt, 2005). A second avenue has focused on infants' perception of structure from motion (e.g., Arterberry & Yonas, 2000; Johnson, Davidow, Hall-Haro, & Frank, 2008; Kellman, 1984; Soska & Johnson, 2008; Yonas, Arterberry, & Granrud, 1987), and a third line has investigated the symbolic nature of 2D information as a guide for search behavior (e.g., DeLoache, 1995; DeLoache, Kolstad, & Anderson, 1991; DeLoache & Pierroutsakos, 2003).

One characteristic common to these investigations is that perceivers generalize from the 2D representations of these studies to their actual 3D counterparts. This transference from 2D to 3D, however, is often taken for granted and virtually never examined on its own. Such an assumption is curious, given that transferring from 2D representations to 3D objects is not necessarily automatic. As an example, work on visual agnosia has identified patients who retain normal 2D percepts of representations but fail to generalize such representations to their 3D counterparts (Ratcliffe & Newcombe, 1982; Turnbull, Driver, & MacCarthy, 2004).

Studies of children's ability to transfer between 2D and 3D representations has demonstrated the perception of this relation by the second year (Daehler, Perlmutter, & Myers, 1976), and possibly even earlier in life (DeLoache, Strauss, & Maynard, 1979; Dirks & Gibson, 1977; Hochberg & Brooks, 1962; Rose, 1977). Investigating the recognition of 2D and 3D correspondences has also been explored by examining infants' and children's abilities to match video images to 3D objects (Krcmar, Grela, & Lin, 2007), to recognize video images of one's own limb movements (Schmuckler, 1996; Schmuckler & Fairhall, 2001; Schmuckler & Jewell, 2007), and has also been explored in children's use of video images as imitative models (e.g., Barr, Muentener, & Garcia, 2007; Hayne, Herbert, & Simcock, 2003).

Finally, infants' understanding of 2D to 3D relations has been explored using manual tasks (DeLoache & Pierroutsakos, 2003; DeLoache, Pierroutsakos, Uttal, Rosengran, & Gottlieb, 1998; Yonas, Granrud, Chov, & Alexander, 2005). DeLoache et al. (1998), for instance, demonstrated that 9-month-olds distinguished between 3D objects and 2D pictures of objects in that they reached for the real object first when presented with both simultaneously. However, infants in this study manually explored the pictures 40% of the time, with this exploration arguably demonstrating confusion between the objects and the pictures. In DeLoache and Pierroutsakos (2003), the degree of manual exploration was related to the realism of the pictures, with the most manual investigation directed toward colored photographs and the least directed toward black and white line drawings (but see Yonas et al., 2005).

The DeLoache and Pierroutsakos (2003) finding is especially intriguing, suggesting that the realism of the 2D representations influences generalization from 2D to 3D referents. It is important to note that one striking feature of this work is that this research has overwhelmingly employed literal, realistic 2D representations, such as photographs. Accordingly, it is unclear whether infants' generalizations are constrained by the degree of literal correspondence between 2D and 3D objects, although this possibility is supported by research demonstrating that the physical similarity between a symbol and its referent influences older children's symbolic comprehension (DeLoache, 1995; DeLoache et al., 1991; Jowkar-Baniani & Schmuckler, 2009, 2010; Simcock & DeLoache, 2006).

Given these findings, there is reason to wonder whether infants' abilities to generalize between 2D pictures and 3D referents would be influenced by the literal correspondence between the two. This question was explored by testing infants' abilities to generalize habituation from a nonliteral 2D representation to a 3D object.

EXPERIMENT 1: 2D LINE DRAWING TO 3D OBJECT RECOGNITION

Method

Participants

Twenty 9-month-old infants participated (*M* age = 9.9 months, *SD* = .71 months). This age group was chosen based on previous research (e.g., DeLoache & Pierroutsakos, 2003) in which 9-month-olds' 2D to 3D generalization was influenced by the realism of the 2D representation. All infants were recruited from the Greater Toronto area.

Materials: stimuli and apparatus

The stimuli employed in this study were a doll (approximately 20 cm × 28 cm) and a stuffed sheep (approximately 16.5 cm × 17.5 cm), along with their black and white line drawings as shown in Figure 1. The stimuli were presented to infants using a 103-cm tall metal stand. All infants participated while seated on a parent's lap, approximately 57 cm from the

Figure 1 A picture of the 3D doll and the 2D doll drawing (top), and a picture of the 3D sheep and the 2D sheep drawing (bottom); stimuli used in Experiments 1 and 2.

stand. A white cardboard screen (71 cm × 56 cm) was used to begin and end each trial.

The habituation procedure was run using a PowerMac G4, running Habit2000 (Apple Computer, Inc., Cupertino, CA) (Cohen, Atkinson, & Chaput, 2000). Visual fixations were recorded using a Sony Digital Handycam DCR-TRV 340 Video Camera (Sony Corporation, Japan).

Procedure

All infants participated in an infant-control habituation procedure (Horowitz, Paden, Bhana, & Self, 1972). Half of the infants were habituated to the line drawing of the doll, and half to the sheep drawing. Habituation criterion was based on half of the average looking time during the first three habituation trials, with habituation ending when the average looking on three trials was less than criterion, or until 20 habituation trials had occurred.

Test trials consisted of a familiar and an unfamiliar stimulus. For infants habituated to the sheep drawing, the 3D sheep was the familiar stimulus and the 3D doll was the unfamiliar stimulus. For infants habituated to the doll drawing, the 3D doll was the familiar stimulus and the 3D sheep was the unfamiliar stimulus. All infants received two repetitions of these stimuli, in an alternating sequence beginning with either the familiar or the unfamiliar stimulus.

Reliability

Reliability was calculated for all participants. Three indices assessed reliability. First, a coding was considered unreliable if the reliability measure changed the pattern of looking relative to the original; none of the codings showed this pattern. Second, the mean absolute difference between all pairs of codings for the total fixation time was calculated for each infant. None of the reliability codings exceeded a cutoff difference value of 2 sec (M = .62 sec, SD = .25 sec). Finally, correlations between the codings were calculated, looking for correlations $< .90$. The reliability codings for all but two infants were strongly correlated, r = .95–.99 ($p < .001$); the correlations for the two remaining infants were .88. Intraclass correlation coefficients (ICCs) between the codings were also calculated and were all significant, with ICCs in the acceptable range ($> .70$), ranging from .91 to .99 (ps $< .001$).

RESULTS

Initial analyses compared looking during habituation as a function of habituation stimulus. Four habituation variables were compared, using independent samples t-tests—the total looking time during habituation, the number of habituation trials, the averaged looking time across habituation, and the criterion for habituation. Table 1 presents the means and standard deviations for these variables, and summarizes the results of these analyses. Overall, the two groups did not differ in these parameters.

The principal analysis compared looking times to the test trials using a four-way analysis of variance (ANOVA), with the within-subjects variables of *Test Condition* (familiar versus unfamiliar) and *Repetition* (1 versus 2), and the between-subjects variables of *Habituation Stimulus* (sheep versus doll) and *Test Order* (familiar/unfamiliar versus unfamiliar/familiar). This

TABLE 1
Means (and *SD*) of Different Parameters During the Habituation Phase for the Two Groups of Infants

	Habituation criteria			
	Looking time (sec)			
Habituation group	*Total*	*Average*	*Number of trials*	*Criterion*
Experiment 1				
Sheep	34.1 (13.9)	4.7 (2.5)	8.0 (3.0)	8.9 (6.3)
Doll	34.9 (17.2)	5.7 (3.9)	6.8 (3.3)	10.3 (7.1)
$t(18)$	−.124	−.705	.840	−.479
Experiment 2				
Sheep	40.2 (13.9)	4.8 (1.6)	9.1 (3.7)	10.1 (4.0)
Doll	61.4 (19.4)	5.9 (2.4)	11.3 (4.3)	13.2 (6.7)
$t(26)$	−3.33*	−1.43	−1.47	−1.49

Note. $^*p < .01$.

analysis revealed a main effect for Test Condition, $F(1, 16) = 5.04$, $MSE = 255.97$, $p < .05$, $\eta_p^2 = .24$, with longer looking to the unfamiliar ($M = 10.4$, $SD = 7.8$) than the familiar stimuli ($M = 6.9$, $SD = 5.2$). There was also a significant interaction between Test Condition and Habituation Stimulus, $F(1, 16) = 7.21$, $MSE = 365.94$, $p < .05$, $\eta_p^2 = .311$. This interaction as shown in Figure 2 reveals that infants habituated to the sheep drawing discriminated between the familiar and the unfamiliar 3D objects, $t(9) = -4.50$, $p < .005$, whereas infants habituated to the doll drawing failed to discriminate between the 3D objects, $t(9) = .27$, *ns*.

Finally, novelty preference was assessed by comparing average looking times toward the familiar and unfamiliar test trials to the average looking times toward the final two habituation displays. For infants habituated to the sheep drawing, there was significant recovery to the unfamiliar 3D object, $t(9) = -3.47$, $p < .01$, but not to the familiar 3D object, $t(9) = -.83$, *ns*. For infants habituated to the doll drawing, there was significant recovery to both the unfamiliar 3D object, $t(9) = 2.56$, $p < .05$, and the familiar 3D object, $t(9) = 3.07$, $p < .05$.

DISCUSSION

Two findings emerge from this experiment. First, there is evidence that 9-month-olds generalize from a 2D line drawing of an object to the actual 3D object. This result converges with previous results demonstrating

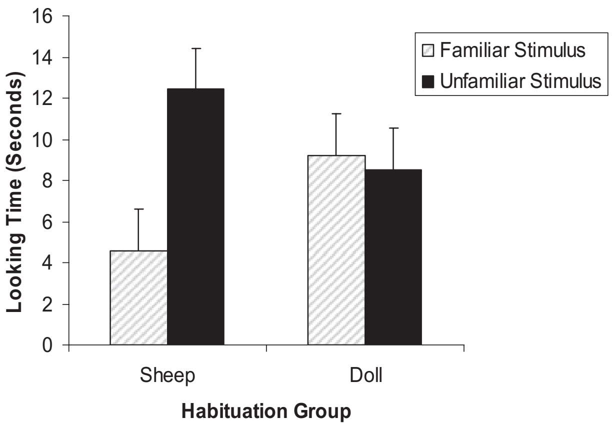

Figure 2 Infants' mean looking times (and standard errors) toward the familiar and unfamiliar stimuli as function of habituation group in Experiment 1.

that infants generalize from 2D photographs to 3D objects (DeLoache et al., 1979), and extends these findings by investigating 2D representations that were schematic, at best. Second, this study qualifies this first result in that infants did not generalize all 2D representations to their 3D counterparts. Instead, infants failed to recognize the correspondence between the line drawing of the doll and the actual doll, treating both 3D objects as unfamiliar.

Two interpretations for this finding exist. On the one hand, it is possible that infants do not have a generalized ability to recognize 2D to 3D correspondence, but instead only do so for certain stimuli. If true, this shifts the emphasis of future work onto the question of delineating those stimulus features that enable such recognition. On the other hand, it is possible that infants' recovery to the 3D doll and sheep following habituation to the doll drawing resulted from two simultaneous, independent processes. First, it might be that infants found the 3D doll itself highly salient and thus responded strongly to this stimulus, regardless of its similarity to the habituation stimulus. Second, infants' response to the 3D sheep could have been driven by a novelty effect arising from the habituation process. In fact there are reasons for why the 3D doll might have been of special interest to infants, including a general preference for dolls, that the doll was multi-colored, that it had a recognizable human face, and so on. Hence, it is of importance to determine whether the group differences in this study stemmed from differential 2D to 3D recognition across objects or were due to a general interest in the doll per se.

EXPERIMENT 2: 3D OBJECT TO 2D LINE DRAWING RECOGNITION

Experiment 2 examined whether infants' failure to transfer habituation from a doll drawing to a 3D doll was due to a special interest in dolls. The simplest procedure to examine this hypothesis involves reversing the order of generalization from habituation. If there is a high baseline interest in a 3D doll, relative to a 3D sheep, this difference should be eliminated by habituating infants to the 3D objects, and then testing with the 2D drawings. Moreover, convergent evidence for a preexisting difference in initial interest to a doll over a sheep might emerge through differential patterns of habituation to the two objects.

Method

Participants

Twenty-eight 9-month-old infants participated in this study (*M* age = 9.8 months, *SD* = 1.1 months). Seven additional infants were also tested, but four were excluded due to fussiness and three due to technical errors.

Stimuli, apparatus, and procedure

The stimuli and apparatus used in this experiment were identical to that of Experiment 1. The only procedural difference was that the 3D objects were used for habituation and the line drawings were the test stimuli.

Reliability

Reliability coding was calculated for all but two participants, employing the same indices used in Experiment 1. Reliability codings did not show a reverse pattern of looking time for any infants, none of the reliability codings exceeded a mean absolute difference score of 2 sec ($M = 1.05$ sec, $SD = .41$ sec), and codings for all but one infant were strongly correlated, $r = .90$–$.99$ ($p < .001$). The correlation for the one remaining infant was .82. Intraclass correlations were again calculated, and revealed significant ICCs in the acceptable range ($> .70$), ranging from .72 to .99 (ps $< .005$).

RESULTS

Initial analyses compared looking during habituation as a function of habituation stimulus; Table 1 presents the relevant information regarding these analyses. Overall, there was a significant difference between the groups in total looking toward the habituation stimuli, $t(26) = -3.33$, $p < .01$. None of the remaining measures differed significantly.

The principal analysis investigated looking times to the test trials using a four-way ANOVA with the same variables as in Experiment 1. The only significant result was a main effect of Test Condition, $F(1, 24) = 6.63$, $MSE = 89.82$, $p < .05$, $\eta_p^2 = .22$, with longer looking to the unfamiliar ($M = 4.5$, $SD = 3.2$) than the familiar stimuli ($M = 2.7$, $SD = 1.7$). Most importantly, and in contrast with Experiment 1, there was no interaction between Test Condition and Habituation Stimulus, $F(1, 24) = .21$, $MSE = 2.80$, *ns*. For comparison, this interaction appears in Figure 3. Tests of recovery toward the test displays found marginal recovery to the unfamiliar line drawing, $t(27) = -1.72$, $p = .096$, but not to the familiar line drawing, $t(27) = -.83$, *ns*.

DISCUSSION

Confirming Experiment 1, this study demonstrated that 9-month-olds recognize the correspondence between a 3D object and a nonliteral 2D counterpart. Moreover, this study provided a potential explanation for the asymmetry of Experiment 1. By reversing the direction of generalization from 3D to 2D, this study confirmed that this differential generalization was due to a greater baseline interest in the 3D doll, relative to the 3D sheep, a

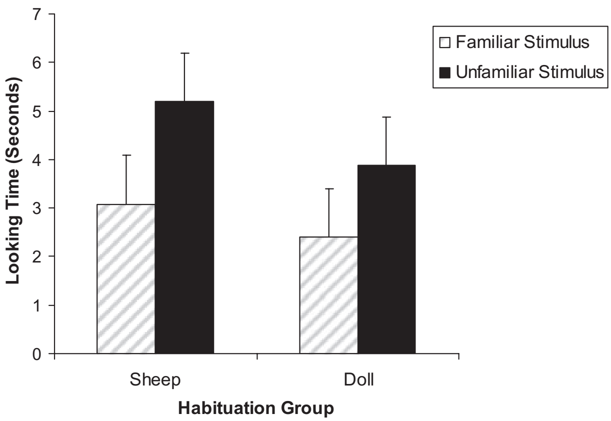

Figure 3 Infants' mean looking times (and standard errors) toward the familiar and unfamiliar stimuli as function of habituation group in Experiment 2.

result that is also supported by the greater total looking time toward the doll than the sheep during habituation. This finding does provide reassurance that 2D to 3D recognition is not overwhelmingly stimulus dependent, but instead could represent a more general ability of infants at this age.

GENERAL DISCUSSION

The current studies demonstrate that infants at 9 months recognize the correspondences between 2D representations of objects and the actual 3D objects, even when these 2D representations are fairly abstract. Of course, this conclusion must be tempered by realizing that only two objects and their corresponding two line drawings were tested in this project. Accordingly, it would be heartening to demonstrate that the current findings hold when tested across a larger group of 2D and 3D objects.

It is also important to note that the observed ability of 9-month-olds in generalizing from 3D objects to their 2D line drawings might be quite fragile at this age. As previously mentioned, DeLoache and Pierroutsakos (2003) showed that although infants almost always reached for the real object first, they nevertheless manually explored the photographs 40% of the time. Thus, it is also quite possible that age-related changes exist with respect to infants' ability to generalize information across dimensions.

Nevertheless, these results do replicate and extend earlier research on this topic (e.g., DeLoache et al., 1979; Dirks & Gibson, 1977; Rose, 1977), and are in line with theoretical arguments that picture perception can be conceived of as responding to common, invariant information for object recognition that is available across 2D and 3D representations (Gibson, 1971).

Before considering the implications of these findings, it is important to address limitations to these results. One such limitation is that rather than truly understanding the 2D to 3D relations of these displays, infants were instead simply responding to some low-level perceptual attribute that underlies similarity between 2D and 3D displays. It is instructive to note that the sheep and doll stimuli did differ in their relative sizes, with the doll approximately twice the size of the sheep.

Although possible, it seems improbable that something like size similarity is the determining factor in these studies. In this case, hypothesizing generalization based on size correspondence does not explain the asymmetry in the findings of Experiment 1. Given that the size similarity between the habituation stimulus and the familiar test display was equally present for both doll and sheep stimuli, it is difficult to understand why this similarity would only be operative for one of the two objects. In fact, this unexpected disparity in response between the two habituation stimuli is ironically one of the most compelling pieces of evidence that infants in these studies truly were responding to the content of these displays, and not to some low-level perceptual variable, such as relative sizes, shapes, and so on. Any argument based on low-level factors would have difficulty explaining this asymmetry.

Another potential limitation to these findings involves our implicit assumption that the 2D line drawings truly represented displays portraying pictorial information of a "lesser" degree of realism than, say, a 2D photograph of the objects. In contrast to arguments based on low-level features, this idea could explain the asymmetry of Experiment 1, in that the divergent novelty patterns of this study could have arisen if the doll and sheep drawings differed in their respective degrees of realism.

Unfortunately, assessing this limitation is difficult because there is no preexisting metric to determine the level of schematic relatedness between the 2D line drawings in these studies and their actual 3D counterparts. In an attempt to address this concern, a control study was conducted in which adults rated the realism of varying pictorial representations of the doll and sheep, relative to the 3D objects.[1] The central findings of this study demonstrated two critical points. First, the line drawings were indeed perceived by observers as representing less realistic displays than the actual 3D objects themselves, a result that confirms our initial assumptions. Second, there was no difference in the perceived degree of abstractness between the sheep and the doll line drawings, thus eliminating alternative explanations for the asymmetry of Experiment 1.

Accepting, then, that these findings do indicate that infants of this age recognize the correspondence of 2D representations and 3D objects, the next obvious issue involves the information that enables this transfer between 2D and 3D representations. Based on the stimuli of this study, it is clear that

[1]Ten adult university students rated the realism, on a 1 (not at all realistic) to 10 (very realistic) scale, of color photographs, black and white photographs, and the line drawings of the doll and sheep stimuli, with reference to the 3D stimuli. These observers saw all six stimuli, and indicated their ratings on a response sheet. These ratings were analyzed in a two-way ANOVA, with within-subject factors of *Stimulus* (doll versus sheep) and *Representation* (line drawing, black and white photograph, and color photograph). This analysis revealed a main affect of Stimulus, $F(1, 9) = 12.85$, $MSE = 6.67$, $p < .01$, $\eta_p^2 = .588$, and Representation, $F(2, 18) = 77.53$, $MSE = 108.12$, $p < .001$, $\eta_p^2 = .896$, but no interaction between the two, $F(2, 18) = .81$, *ns*. Pair-wise comparisons indicated that adults perceived color photographs ($M = 8.55$, $SD = 1.18$) as more realistic representations than black and white photographs ($M = 6.25$, $SD = 6.25$), $t(9) = 7.23$, $p < .001$, and line drawings ($M = 3.9$, $SD = 1.88$), $t(9) = 11.20$, $p < .001$. The black and white photographs were perceived as more realistic than line drawings $t(9) = 6.18$, $p < .001$. Most importantly, there were no differences in realism between the doll line drawing ($M = 4.0$, $SD = 2.05$) and the sheep line drawing ($M = 3.8$, $SD = 2.04$), $t(9) = .39$, *ns*.

neither color information nor gray-scale variation are crucial for recognizing 2D and 3D correspondence. Similarly, it seems that shadow information is not critical for this recognition, a finding that contrasts with research on the importance of shadow information in object recognition (e.g., Cavanagh & Kennedy, 2000; Cavanagh & Leclerc, 1989; Kennedy & Bai, 2004; Kersten, Knill, Mamassian, & Bülthoff, 1996). By contrast, these drawings did contain significant outer contour information, and were seen from the same general orientation across the 2D and 3D presentations.

In terms of orientation, it is not clear what impact this factor had in these studies, given that previous work on object and picture perception is equivocal as to the importance of such information in infancy. Specifically, there is a wealth of evidence demonstrating that infants can both discriminate changes in object orientation (e.g., Atkinson, Hood, Wattam-Bell, & Anker, 1988; Bornstein, Gross, & Wolf, 1978; Bornstein et al., 1986; Kraebel & Gerhardstein, 2006; Stankiewicz, 2003; Watson, Johnson, Hill, & Troje, 2005), and can generalize across multiple views and orientations of a single object (Bower, 1966; Caron et al., 1979; Cook & Birch, 1984; Day & McKenzie, 1973; Slater, 2000; Slater & Morison, 1987).

As for contour information, it seems intuitively obvious that contour was one of the principle means by which infants apprehended 2D and 3D correspondence; after all, the line drawings were initially defined by the presence of contour information. With regards to importance of contour information, it is notable that researchers have highlighted the importance of edge information and points of curvature as critical for object decomposition and shape perception in adults (Attneave, 1954; Biederman, 1987; Feldman & Singh, 2005; Hoffman & Richards, 1984; Marr & Nirshihara, 1978) and in infants (Bhatt, Hayden, Reed, Bertin, & Joseph, 2006; Colombo, Frick, Ryther, & Gifford, 1996; Frick & Colombo, 1996; Salapatek, 1968, 1975; Yonas & Arterberry, 1994). Future work might thus profit by systematically manipulating the different types of contour information and assessing the impact of such information on 2D to 3D recognition.

These findings also have implications outside the realm of picture perception. Probably the most significant implication stems from the explanation proposed in Experiment 1 for the differential 2D to 3D transfer. Based on the argument presented earlier, when both novelty and baseline interest drove infants' looking to a single display, infants showed a great deal of interest in that display. By contrast, when novelty and baseline interest worked against one another, infants showed only moderate interest in both displays, and when neither novelty nor baseline interest drove looking, infants showed little interest in these display. Characterized in this fashion, there are clearly multiple factors driving infants' looking in a habituation paradigm, an idea that is illuminating for theoretical models of infant habituation (Gilmore & Thomas, 2002; Schafer & Mareschal, 2001; Schöner & Thelen, 2006; Simon, 1998; Sirois & Mareschal, 2002, 2004; Thomson & Spencer, 1996). Surprisingly, such models have typically failed to take into account initial baseline interest, and more importantly variation in such interest, toward the test trials as an explicit parameter in their predictions. This oversight is curious, in that researchers do, periodically, point out differences in baseline preferences for certain displays (e.g., Kavšek & Yonas, 2006). It is likely that such effects are widespread throughout the developmental literature, often relegated to the status of unexplainable interactions involving habituation group, test trial order, or some combination of similar variables.

In sum, the current project has enabled a window into infants' ability to transfer information between 2D and 3D representations, providing some insight as to the critical information for object recognition across these differing representations, and has also highlighted an often overlooked factor when considering the actual paradigm employed to assess infant discrimination. Clearly, though, this work raises as many questions as it answers; exploring these new avenues of inquiry will presumably lead to even more detailed understandings of infant perceptual recognition.

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