The Official Journal of the International Society on Infant Studies
Infancy

Infancy, **15**(6), 636–649, 2010

ISSN: 1525-0008 print / 1532-7078 online
DOI: 10.1111/j.1532-7078.2009.00029.x

WILEY-BLACKWELL

Infants' Response to Pictures of Impossible Objects

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Previous work has shown that 4-month-olds can discriminate between two-dimensional (2D) depictions of structurally possible and impossible objects [S. M. Shuwairi (2009), *Journal of Experimental Child Psychology*, 104, 115; S. M. Shuwairi, M. K. Albert, & S. P. Johnson (2007), *Psychological Science*, 18, 303]. Here, we asked whether evidence of discrimination of possible and impossible pictures would also be revealed in infants' patterns of reaching and manual exploration. Nine-month-old infants were presented with realistic photograph displays of structurally possible and impossible cubes along with a series of perceptual controls, and engaged in more frequent manual exploration of pictures of impossible objects. In addition, the impossible cube display

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elicited significantly more social referencing and vocalizations than the possible cube and perceptual control displays. The increased manual gestures associated with the incoherent figure suggest that perceptual and manual action mechanisms are interrelated in early development. The infant's visual system extracts structural information contained in 2D images in analyzing the projected 3D configuration, and this information serves to control both the oculomotor and manual action systems.

The question of how we are able to perceive objects in the real world as coherent in three dimensions, and how we are able to use visual information to act appropriately on a variety of objects, has been a topic of interest in the fields of development and perception for decades. Impossible figures, such as the cube shown in Figure 1, have long intrigued a wide range of individuals, including artists and psychologists, and recent research has established that young infants share this interest (Shuwairi, Albert, and Johnson, 2007). Specifically, when shown cubes with possible intersections of elements versus cubes with an impossible one as in Figure 1, 4-month-old infants looked longer at the impossible object (Shuwairi, 2009; Shuwairi et al., 2007). Additional eye-tracking data revealed that 4-month-old infants showed longer dwell times and increased oculomotor activity for impossible relative to possible object displays (Shuwairi, 2008; Shuwairi & Johnson, 2006). Of most importance, they also engaged in active visual comparison of the *critical regions* in the impossible displays: those parts of the display containing overlapping edges that "defined" the images as impossible configurations in three-dimensional (3D) space. Differentiating between possible and impossible objects inherently requires that the visual system respond to a perceptual discrepancy in the apparent levels of depth and spatial relations among parts to infer global 3D structure. These findings are interesting and surprising because they revealed that infants as young as 4 months of age are sensitive to several depth cues (e.g., T- and Y-junctions) that are fundamental for perceiving shape. In addition, this work established that the ability to detect inconsistencies in global object structure is present early and that selective attention to particular visual information may guide young infants' oculomotor exploration of novel objects.

In the present study, we asked whether the perception of an impossible figure would also evoke increased manual exploration of these displays during a reaching task with older infants. Recent studies using a picture-grasping task with 9-month-olds have demonstrated that infants in this age group typically engage in manual investigation of depicted objects (DeLoache, Pierroutsakos, & Uttal, 2003; DeLoache, Pierroutsakos, Uttal,

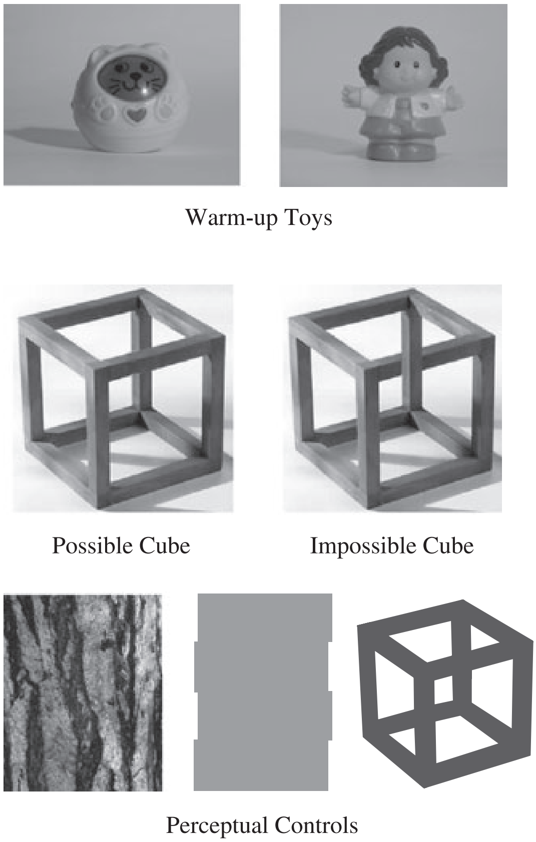

Figure 1 Schematic diagram of picture displays used as test stimuli.

Rosengren, & Gottlieb, 1998; Pierroutsakos & DeLoache, 2003; Yonas, Granrud, Chov, & Alexander, 2005). For example, when presented with a realistic photograph of an object, infants touch, rub, and sometimes even grasp at the depicted object. And, as the degree of realism decreases in the depicted objects (e.g., black and white photo versus line drawing), so too does the frequency of manual gestures initiated toward those displays (Pierroutsakos & DeLoache, 2003). This behavior does not reflect an inability to perceive the difference between depicted and real objects: When given a choice between a real object and a picture of it, infants virtually always reach for the real one (DeLoache et al., 1998). Rather, it appears that infants explore depicted objects because they are not fully certain about their nature.

Perceiving whether or not an object is graspable and within reach involves encoding spatial position coordinates and integrating visual features inherent to the object prior to performing a manual action. Coordinated reaching and object manipulation skills begin to surface around the age of 4 months, and young infants start reaching for graspable objects at about this time (Bertenthal, 1996; von Hofsten, 2004), even reaching in the dark for an object previously seen (Clifton, Perris, & McCall, 1999). Studies of visually guided reaching further reveal a rapid increase in sensitivity to pictorial depth information in static image displays. Between the ages of 5 and 7 months, infants show increased reaching to the nearer-appearing object in the display, which indicates that infants can perceive pictorial depth from information provided by linear perspective (Yonas, Cleaves, & Pettersen, 1978; Yonas, Elieff, & Arterberry, 2002), surface occlusion (Granrud & Yonas, 1984), surface illumination (Granrud, Yonas, & Opland, 1985), and cast shadows (Yonas & Granrud, 2006). Research of this variety has led to the belief that depth perception arises from increasing fine motor capabilities and experience with haptic exploration (Bushnell & Boudreau, 1993). Other studies show that infants modify their manual actions appropriately to register the features and functions of objects and surfaces they explore (e.g., pliable versus solid, smooth versus textured) (Bourgeois, Khawar, Neal, & Lockman, 2005; Palmer, 1989; Ruff, 1984). Infants' differential responses to such visual and haptic cues may be indicative of their expanding perception of various surfaces and objects.

Given that we already know that younger infants can visually discriminate between pictures of possible and impossible objects, we now ask whether the perception of anomalous pictorial information in the impossible figure would evoke a differential reaching response in 9-month-old infants. We reasoned that the degree to which infants manually explore depictions of possible versus impossible objects might provide an index of their interpretation of such displays. Accordingly, we measured differences in the number of manual behaviors attempted toward realistic photographic displays of possible and impossible cube stimuli that were rich in pictorial depth information (e.g., shading, shadows, texture, color, luminance, and interposition cues). If infants apply their investigative activities with equal frequency to both displays, then this would be interpreted as indiscriminate exploratory action. However, if infants initiate increased exploratory actions toward one of the displays relative to the other, this would be interpreted as evidence that the perceptual anomaly elicited differential reaching behavior between pictures of possible versus impossible objects.

METHOD

Participants

Infants were selected from a public database of new parents and were recruited by letters and telephone calls. The final sample consisted of 14 9-month-old infants (*M* age = 283 days, *SD* = 19.0; 7 boys, 7 girls). An additional four infants were observed but not included in the sample due to lack of attention or excessive fussiness. All infants were full-term with no known developmental difficulties.

Stimuli

The visual displays are shown in Figure 1. Each display was constructed by mounting a high-resolution color printout (measuring approximately 13 cm × 13 cm) onto white foam core board that measured approximately 21 cm × 28 cm. Velcro adhesive tape on the back of the board was used to secure each display to the tabletop in front of the infant in an effort to discourage the infants from trying to pick up the board.

The stimulus displays of primary interest were the realistic color photograph of a structurally possible wooden cube and that of an impossible cube. The image of the impossible wooden cube was created in Photoshop® (Adobe Systems, Inc., San Francisco, CA) by altering the local depth relations in a single overlapping bar junction. The color photograph displays of possible and impossible cubes were used previously in a visual discrimination task with 4-month-olds (Shuwairi et al., 2007). In addition, the stimuli included color photographs of two plastic toys, which served as "warm-up" displays to get infants interested in the task, as well as pictures of tree bark, gray patches, and a 2D hexagonal pattern composed of solid brown lines, which served as nonobject perceptual controls. The latter three stimuli served as nonobject pictorial control images for a comparison of manual response, following a procedure used by Yonas et al. (2005).

Procedure

Participants were seated in an infant chair secured to a testing table. Parents were seated in a chair immediately adjacent to the child and were instructed to keep their hands in their lap and not to initiate any gestures toward the display or interact with the child during the session. The experimenter was concealed behind a black curtain, only emerging to change displays. In addition, parents were instructed to remain neutral but equally attentive to each display that was presented to the child. Parents were not informed of the hypotheses or the nature of the visual displays prior to the testing session. A full debriefing took place after the session was completed.

On each trial, a display was secured to the tabletop directly in front of the infant. Infants were free to explore any part of the display, but they were prevented from picking it up. Infants viewed a total of seven displays presented individually. Each display remained available for a maximum of approximately 40 sec. The experiment always began with a color photograph of a real toy (e.g., either a kitten or a doll) as a "warm up" to engage the infants in the task as shown in Figure 1. Infants' responses to the initial "warm-up" displays were not included in final analyses. The experimental and control displays, shown in Figure 1, were presented in a pseudorandom order. For example, half of the participants viewed a sequence of displays in which the possible figure appeared before the impossible one in the series, and the other half viewed a sequence of displays in which the impossible cube was presented before the possible cube display. A photo of a real toy always preceded the displays of the possible and impossible cubes (i.e., the possible and impossible figures were never presented back to back in sequence). This was to control for the possibility of increased visual attention and/or interest generated by the warm-up displays toward the subsequent display. The three perceptual control displays were presented in randomized order immediately following the displays of primary interest in this experiment (i.e., the possible and impossible cubes).

Coding

All test sessions were recorded on digital video and were subsequently coded from videotapes for types of manual contact and deliberate behaviors directed toward exploring the picture displays (e.g., touching, grasping, rubbing, scratching, and patting). The scoring criteria were based on a modified hybrid version of the coding schemes used by DeLoache et al. (1998) and Yonas et al. (2005). A manual behavior was coded only if the infant was judged to be looking at the depicted object and his/her hand or fingers were in contact with the depicted object or within a 1.0 cm radius of the image. A behavior was considered to have ended when an infant looked away, initiated a different type of manual behavior, changed hands, or removed the hand (or hands). Uninterrupted repetitions of a given gesture type were counted as one instance of that categorical type of behavior. Thus, several uninterrupted repetitions of the same manual action were conservatively scored as a single behavior.

We evaluated the qualitative ("categorical") types of manual exploration behaviors as well as the total number of behavior changes initiated in sequence ("sequential") for each display. In the *Categorical* level of analysis, infants' manual gestures were classified as one of five gross categories of reaching behavior (e.g., touching, grasping, rubbing, scratching, or patting). These qualitatively different types of reaching behaviors were recorded and tallied for each display. At the categorical level, infants could potentially receive a score between 0 and 5 representing the number of qualitatively different types of manual gestures initiated toward each display. In the *Sequential* level of analysis, a finer grain assessment of successive actions was reviewed. The total quantity of gesture changes that occurred in sequence were recorded and tallied for each display. For example, if an infant was observed rubbing a picture display with one hand followed by tapping with both hands, followed by rubbing with one hand, then those manual behaviors would be recorded as two categorical gestures and three sequential gestures. For both measures of manual exploration, an *impossible preference score* was calculated for each infant by computing the total number of behaviors initiated toward the impossible cube divided by the sum of gestures initiated to both the possible and impossible cube displays. Preference scores were then compared with 50/50 chance.

We also documented the frequency of social referencing, vocalizations, and mouthing behaviors as independent and complementary measures of infants' differential responses toward each type of display. Social referencing was defined as an occurrence of the infant looking to the parent or the experimenter only *after* the child had initially visually inspected the display at least once. Instances of social referencing were logged each time the child referred back to the parent/experimenter after viewing and/or touching the stimulus display. Social referencing behavior has been a useful indicator of infants' perceptual judgments and impending actions during an ambiguous, uncertain situation involving novel or unusual stimuli (Klinnert, Emde, Butterfield, & Campos, 1986; Walden & Kim, 2005). Vocal utterances are thought to serve as a communicative mechanism in young infants that often accompany manual gestures, such as pointing and reaching, and may convey meaningful information in preverbal infants (Bernardis, Bello, Pettenati, Stefanini, & Gentilucci, 2008). Our tally of social referencing did not include instances of the child turning to the parent/experimenter during a display change, or if the parent or the experimenter initiated spoken communication to the child, both of which elicited the child's attention. We hypothesized that if infants detected the perceptual anomaly in the picture of the impossible cube, it might elicit an increased frequency of vocalizations and/or social referencing to the parent accompanying the child during the study.

Infants' responses were analyzed using a repeated-measures 2 (Sex) $\times$ 2 (Order: Possible versus Impossible First) $\times$ 3 (Display) analysis of variance (ANOVA). Preliminary analyses revealed no reliable differences in the extent of reaching, social referencing, vocalizations, or mouthing behaviors based on sex or stimulus order, $F(1, 10)$ = n.s., all p-values $> .25$, and no interactions, so these between-subjects factors were omitted from further analyses. Data points from the perceptual control displays (tree bark, gray patches, and brown lines) were collapsed into one within-subjects variable for comparison with the possible and impossible cube displays. In order to assure reliability of the experimenter's judgments, an independent observer who was blind to the hypotheses also coded manual gestures offline for 100% of the final sample. Pearson correlations between the experimenter's and the coder's judgments indicated strong interrater reliability for all measures (manual gestures $r = .90$, $p < .01$; sequential gestures $r = .92$, $p < .001$; social referencing $r = .89$, $p < .01$; vocal utterances $r = .80$, $p < .01$). All tests of statistical significance used an alpha level of .05, and all *t*-tests were two-tailed.

RESULTS

Categorical gestures

Results of a within-subjects ANOVA yielded a main effect of display, $F(2, 26) = 8.76$, $p < .001$, due to differences in mean quantity of categorical types of manual gestures across displays. Pairwise comparisons (with least squares differences [*LSD*]) revealed that the infants engaged in a greater number of different types of manual exploration toward the impossible cube relative to the possible cube display, $t(13) = 2.74$, $p < .001$, and the perceptual controls, $t(13) = 4.25$, $p < .02$, as shown in Figure 2a. The mean impossible preference score was .63, which differed significantly from chance, $t(13) = 2.48$, $p < .03$. Infants attempted an average of one additional different type of manual gesture toward the impossible cube display above that of the possible cube display and the perceptual controls. The pattern of increased manual exploration toward the impossible cube display was observed in nine of the 14 infants, with four infants responding equally to the two displays, and one with more reaching to the possible cube, $Z = 2.13$, $p = .03$. In contrast, there were no reliable differences in manual exploration of the picture of the possible cube versus the other control stimuli, $t(13) = .71$, $p = .489$.

Sequential gestures

Results of a within-subjects ANOVA yielded a main effect of display, $F(2, 26) = 15.71$, $p < .0001$, due to differences in mean number of manual actions produced in sequence to each of the displays. Pairwise comparisons (with *LSD*) suggested that the infants engaged in a reliably greater number

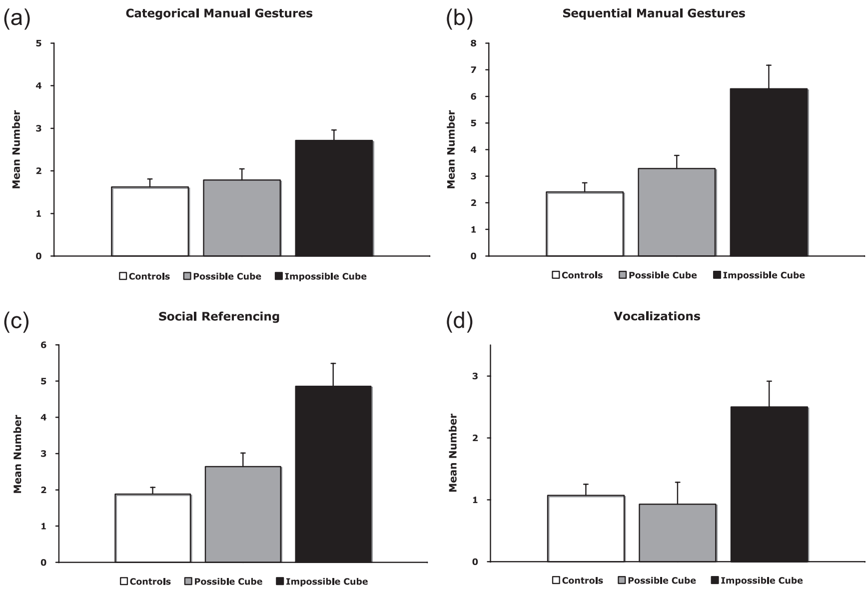

Figure 2 (a) Infants' initiate a greater number of qualitatively different reaching actions toward the impossible cube display relative to the possible cube and perceptual controls. (b) Infants' engage in a significantly greater number of sequential reaching actions toward the impossible cube display relative to the possible cube and perceptual controls. (c) Infants engage in a significantly greater amount of social referencing to their parent and to the experimenter during the impossible cube display relative to the possible cube and perceptual controls. (d) Infants made significantly more vocalizations during the impossible cube display relative to the possible cube and perceptual controls. Error bars represent the standard error of the mean.

of sequential manual gestures during the trial toward the impossible cube relative to the possible cube display, $t(13) = 4.29, p < .001$, and the perceptual controls, $t(13) = 4.05, p < .001$, as shown in Figure 2b. The mean impossible preference score was .68, which differed significantly from chance, $t(13) = 3.58, p < .003$. Infants attempted an average of three additional sequential actions toward the impossible cube display above that of the possible cube display. The pattern of greater manual exploration toward the impossible cube was observed in 12 of the 14 infants, with two engaging in more reaching to the possible cube, $Z = 3.01, p = .003$.

Social referencing

Results of a within-subjects ANOVA yielded a main effect of display, $F(2, 26) = 13.40, p < .0001$, due to differences in mean number of instances of social referencing occurring during each of the displays. Pairwise comparisons (with *LSD*) indicated that infants engaged in a reliably greater amount of social referencing overall to the caregiver and/or experimenter when presented with the impossible cube relative to the possible cube, $t(13) = 2.87$, $p < .01$, and the perceptual controls, $t(13) = 5.27$, $p < .001$, as shown in Figure 2c. The mean impossible preference score was .64, which differed significantly from chance, $t(13) = 2.58$, $p = .02$. On average, infants engaged in two additional instances of social referencing to the parent and/or experimenter during presentation of the impossible cube display above that of the possible cube display. This pattern of behavior was observed in 11 of the 14 infants, with two infants referencing equally and one infant referencing to a greater extent during the possible cube display, $Z = 2.45$, $p = .015$. Further analyses revealed that infants engaged in significantly more referencing behaviors toward the experimenter (relative to the mother) during the presentation of the impossible cube display, $t(13) = 3.47$, $p < .005$. However, there were no significant differences in the amount of referencing behaviors to the mother relative to the experimenter during the possible cube display ($p > .10$), and infants' first looks to either of the adults during both the possible and impossible cube displays did not differ from chance ($p > .25$).

Vocalizations

There was a main effect of display, $F(2, 26) = 8.57$, $p < .001$, due to differences in mean number of vocalizations emitted during each of the displays. Pairwise comparisons (with *LSD*) demonstrated that infants produced a greater number of vocalizations during the impossible cube display relative to the possible cube, $t(13) = 3.15$, $p < .01$, and the perceptual controls, $t(13) = 3.57$, $p < .001$, as shown in Figure 2d. The mean impossible preference score was .79, which differed significantly from chance, $t(13) = 3.92$, $p = .002$. Infants produced an average of approximately 1.5 additional vocalizations during the impossible cube display above that of the possible cube display and the perceptual controls. This pattern of behavior was consistent in 10 infants, with two infants vocalizing equally and two infants vocalizing more during the possible cube display, $Z = 2.72$, $p = .007$. By contrast, there were no reliable differences in vocalizations made during presentation of the possible cube versus the other perceptual control stimuli (all p-values $> .68$).

Mouthing

The frequency of infants' mouthing behavior toward each of the displays was also recorded. Interestingly, five infants engaged in mouthing behavior, but *only* toward the impossible cube display, $t(13) = 2.69$, $p < .02$, and they did *not* use oral exploration for any of the other displays. This pattern of behavior was consistent in five of the infants, and nine infants did not engage in any attempted mouthing behavior, $Z = 2.24$, $p = .02$.

DISCUSSION

We set out to examine the effects of a perceptual illusion on infants' manual exploration. Our initial question of whether 9-month-olds would respond differently to picture displays of possible and impossible cubes received a clear answer: Infants engaged in qualitatively similar types of reaching behaviors (e.g., touching, scratching, rubbing, and patting) toward the possible and impossible cubes as well as the nonobject pictorial control displays, but they directed a significantly greater number of these gestures toward the *impossible* object display. Thus, by 9 months of age, infants use the pictorial depth cue of interposition to guide manual investigation of 2D depictions of objects, and they behave differently in response to pictures of possible and impossible objects. Presumably, it was the detection of anomalous depth information that inspired greater visual attention and more persistent manual exploration of the pictures of impossible objects. Perhaps the impossible figure invoked increased interest and exploration because the infants found the unusual geometry so novel and unlike any other objects they had previously encountered in the world.

The impossible cube display also elicited a reliably higher frequency of social referencing to the parent and experimenter, as well as a significantly greater number of vocalizations relative to the possible cube and perceptual control displays. Increased referential looking to the mother (a trusted source) and to the experimenter (a friendly female stranger in close proximity) may be due to the infants' desire to gather applicable information about the unusual or ambiguous nature of the impossible cube stimulus. Other work has shown that when slightly older infants were presented with novel and unusual animated robotic toys, infants from multiple age groups (ranging from 12- to 18- and 24-month-olds) turned more often to visually reference the female experimenter who had previously provided an emotional message about the toy rather than their own mothers who were present in the room (Klinnert et al., 1986; Walden & Kim, 2005). This suggests that infants are visually referencing the adult with the appropriate advice and information pertaining to the visual stimulus or event at hand, rather than seeking emotional or physical comfort.

The observed increase in vocalizations accompanying the greater number of manual gestures toward the impossible cube may also be interpreted as the preverbal infants' means of communicating their interest in such a novel and unusual visual display. Recent work examining the spectral frequency of infants' babbling and utterances has shown that vocalizations may serve as a communicative mechanism co-occurring with pointing and reaching gestures, which together may convey meaning among preverbal infants (Bernardis et al., 2008). In addition to referencing the two adults in the test room, infants may have been trying to communicate their interest or curiosity in the depicted images.

Interestingly, we also observed mouthing in some of the infants as an exploratory behavior that occurred *only* with the impossible cube display. In addition to haptic exploration, infants between the ages of 6 and 9 months also rely on their mouths as a primary means of exploring the distinct features of objects, such as texture and shape (Ruff, 1984), although this particular behavior tends to wane by the end of the first year as infants expand their repertoire of manual exploration skills (McCall, 1974; Ruff, 1984). In addition to the increased manual exploration efforts among these infants, some also employed mouthing as a final means of determining what the object might be.

In our study, infants were more persistent in focusing their exploration and reaching activity on the *impossible* cube, and this was directly affected by the perception of the incompatible depth relations in the display. Other researchers have also shown that these types of manual exploration activities are purposeful in ascertaining features, properties, and functions of surfaces and objects, rather than random, haphazard, and indiscriminate motions (Bourgeois et al., 2005; Palmer, 1989; Ruff, 1984). As infants' fine motor skills improve toward the end of the first year, there is progressive increase in coordinated action and haptic exploration of objects, which simultaneously complements and enhances visual and other sensory input (McCall, 1974; Palmer, 1989).

Indeed, the manual action system was directly affected by the depiction of an impossible object. We observed differences in a variety of "whole body" behaviors ranging from more persistent manual gestures to increased social referencing, mouthing, and vocalizations toward the picture of an impossible cube. These responses are in accordance with the theory of embodied cognition (Thelen, 2000), which postulates that infants show a developmental continuity of perceptual response and subsequent bodily actions toward familiar and novel stimuli. The pattern of coordinated behaviors that we observed provides insight into infants' perceptual understanding of real 3D objects in the world. The infant's visual system extracts geometric information contained in 2D images in an attempt to analyze the projected 3D configuration, and this perceptual information serves to guide both oculomotor and manual action systems. Our findings provide important insights into the development of mechanisms for processing pictorial depth cues and extracting information about global 3D structure from pictures of objects.

ACKNOWLEDGMENTS

We thank Karen Adolph, Barry Cohen, Carl Granrud, Lisa Oakes, Paul Quinn, and Albert Yonas for helpful comments on this research. We also thank Lauren Clepper and Melissa Rozon for their assistance with scheduling and testing infants, and Lauren Kosinski for assistance with reliability coding. We are grateful for the contributions of all the parents and infants who participated in the research. This work was supported in part by the PSC-CUNY-40 and the George N. Shuster Fellowship to Sarah Shuwairi and by NIH grants R01-HD40432 and R01-HD48733 to Scott Johnson.

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