INFANCY, *12*(1), 105–118

Infants' Reactions to Object Collision on Hit and Miss Trajectories

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This experiment investigated the impact of the path of approach of an object, from head on versus from the side, and the type of imminent contact with that object, a hit versus a miss, on young infants' perceptions of object looming. Consistent with earlier studies, we found that 4- to 5-month-old infants do indeed discriminate hits versus misses. We also found a novel result regarding the path of the approaching object. The discrimination of hits from misses was modified by whether or not the approaching objects passed in front of the infants' faces; objects crossing the line of sight evoked more frequent defensive reactions than objects that did not cross the line of sight, regardless of whether or not such objects were on a collision course. These findings are discussed within the context of the development of visually guided locomotion and linear versus nonlinear paths of translation through the world.

Perceiving depth is critical for surviving in the three-dimensional world. For example, depth perception plays a fundamental role in visually guided locomotion (Cutting, Vishton, & Braren, 1995; Kingsnorth & Schmuckler, 2000; Schmuckler, 1993, 1995, 1996), allowing one to navigate through a cluttered environment. As such, understanding how we perceive depth is a prerequisite to understanding how we can function in the world.

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Of the various types of depth information available to perceivers, one of the most important involves the kinetic information arising from object movement or movement of an observer. In fact, sensitivity to kinetic information for depth develops quite early, with even very young infants responsive to expansion and contraction patterns specifying approach and withdrawal (Ball & Tronick, 1971; Bower, Broughton, & Moore, 1970; Kayed & van der Meer, 2000; Náñez, 1988; Pettersen, Yonas, & Fisch, 1980; Schmuckler & Li, 1998; Shirai, Kanazawa, & Yamaguchi, 2004; Yonas, 1981; Yonas et al., 1977; Yonas, Pettersen, & Lockman, 1979), and accretion and deletion patterns that specify object and surface depth, and three-dimensional object shape (Arterberry, 1992; Arterberry, Craton, & Yonas, 1993; Arterberry & Yonas, 1988, 2000; Granrud et al., 1984; Kaufmann, Stucki, & Kaufmann-Hayoz, 1985; Schmuckler & Li, 1998; Schmuckler & Proffitt, 1994; Yonas, Arterberry, & Granrud, 1987; Yonas & Granrud, 1985).

Research on optical expansion and contraction patterns has focussed on perceiving looming (e.g., Gibson, 1950; Regan & Vincent, 1995; Schiff, 1965; Schiff, Caviness, & Gibson, 1962; Schiff & Detwiler, 1979) or time-to-contact (e.g., Beverley & Regan, 1979; DeLucia, 1991, 2004; DeLucia & Warren, 1994; Gray & Regan, 2000; Johansson, 1964; Lee, 1976; Regan & Beverley, 1978; Regan & Hamstra, 1993; Todd, 1981). *Looming* refers to the optical expansion of visual information as an object and observer near one another, whereas *time-to-contact,* or tau, specifies the mathematical relation between the anticipated time of contact with an object and the rate of change within the visual array (for a review, see Hecht & Savelsbergh, 2004).

Studies have, to date, demonstrated that young infants are sensitive to looming information, with infants showing avoidance or defensive behaviors such as blinking (e.g., Ball & Tronick, 1971; Náñez, 1988; Náñez & Yonas, 1994; Pettersen et al., 1980; Schmuckler & Li, 1998; Yonas, 1981; Yonas et al., 1979), backward head pressure (e.g., Ball & Tronick, 1971; Bower et al., 1970; Carroll & Gibson, 1981; Yonas et al., 1979), and widening of the eyes and defensive arm raising (e.g., Ball & Tronick, 1971; Bower et al., 1970).

Studies have also looked at infants' sensitivity to specific components of looming information, investigating, for instance, infants' dissociation of expansion from contraction patterns (Bower et al., 1970; Náñez, 1988; Shirai et al., 2004) and the functional implications of the looming displays (Carroll & Gibson, 1981; Schmuckler & Li, 1998), such as the distinction between an approaching object (which indicates upcoming contact) and an approaching aperture (which implicates upcoming passage through the aperture).

Still other work has looked at discriminating between objects approaching on a hit versus a miss path. Yonas et al. (1977) found that 4- to 6-month-old and 8- to 9-month-old infants responded more to looming displays containing symmetrical expansions (suggesting object collision) than asymmetrical expansions (implying a miss path).[1] Similarly, Ball and Tronick (1971), using both a shadow casting apparatus and a real object, found that symmetrical expansions (hit paths) led to stronger avoidance responses than asymmetrical expansions (miss paths). Together, this research convincingly demonstrates that infants within the first 6 months dissociate objects on a collision versus a noncollision course, displaying defensive or nondefensive reactions, accordingly.

One limitation to the studies of Ball and Tronick (1971) and Yonas et al. (1977) is that these studies equated the path of approach with the consequences of object approach. Specifically, symmetrical expansions indicated objects on a hit path, whereas asymmetrical expansions specified objects on a miss path. Unfortunately, asymmetrical expansion is ambiguous in that it specifies both an object on a miss path and an object approaching from the side of a forward-facing infant on either a hit or miss path. Accordingly, it is unclear whether the observed decreased looming reactions to the object are due to the nature of the imminent contact (hit vs. miss), the path of approach (front vs. side), or both. The goal of this study was to disentangle these factors.

METHOD

Participants

Twenty-four (16 female) 4- to 5-month old infants (*M* age = 19.3 weeks, *SD* = 2.1) participated in this experiment. The data from an additional 13 infants (7 male) were excluded due to fussiness ($n = 7$), being born more than 2 weeks premature ($n = 2$), experimenter error ($n = 1$), and technical difficulties ($n = 3$). All infants were recruited from the demographically diverse community of Scarborough, Ontario, and received a toy and certificate for participating.

Apparatus and Materials

The experiment was conducted in a 2.3 m × 2.4 m orange curtained room, illuminated by ceiling overhead lights, and employed a specially built looming apparatus consisting of a 127-cm track and pulley system that manually moved a looming object toward and away from the infant. The looming object, which was an orange

[1]In fact, there are multiple problems with the terms *symmetrical* and *asymmetrical* relative to this situation. Technically, expansions and contractions are only symmetrical or asymmetrical with respect to a fixed reference (either in the world or on the approaching object), and assuming no head or eye movements by observers (clearly a problematic assumption with infant participants). As such, it would have been better to characterize these conditions as those requiring eye movements versus those not requiring eye movements. Regardless, to maintain consistency with the earlier research on this topic, we have chosen to retain the original (albeit flawed) terminology of symmetrical versus asymmetrical.

and black soccer ball, was attached to a pole suspended from the track that could be adjusted to eye level. Attached to one end of the track was a movable 145-cm vertical post.

Infants were strapped into a car seat positioned 1 m from the opposite end of the pulley, in front of the movable post. Directly in front of the infant seat was a plexiglass barrier, 98 cm wide × 33 cm high. This barrier functioned as a safety precaution for infants and to block any air pressure changes that might accompany object movement. On approach trials, the object began away from infants, and traveled 83.8 cm, in about 3 sec, for a looming velocity of 27.9 cm/sec, to stop between 22.86 and 35.56 cm away from the infant, depending on the specific experimental condition (see later). For withdrawal trials the object began in front of the infant and traveled the same distance over the same time period to stop at the far end of the apparatus. Although the looming velocities employed in this study are slightly faster (by roughly 10 cm/sec) than those used by Ball and Tronick (1971) and Yonas et al. (1977), research by Náñez (1988) indicates that even wide variations in looming velocity (from 6–48 cm/sec) do not modify looming reactions. The experimental session was recorded using a Sony DCR-TRV340 video camera.

Conditions and Design

The three within-subjects variables of this experiment are summarized schematically in Figure 1. The first variable was path of approach, with the object approaching infants from head on for a forward-facing infant (i.e., center approach), from the infant's left (i.e., left approach), or from the infant's right (i.e., right approach). The center angle of left and right approach was about ±21° relative to the center approach. The second variable was type of contact, which could be a hit, a miss to the left, or a miss to the right of the infant. Assuming a hit has an angle of contact of 0º, miss trials deviated by about ±12.5º. The third variable was direction of movement. On approach movements, the object came toward the infant, whereas in withdrawal movements, the object moved away from the infant. Together, one approach and one withdrawal were considered a trial.

Because of the plexiglass screen in front of infants' faces, the stopping position of the object varied as a function of the two experimental conditions just described. Accordingly, and as alluded to earlier, the distance between the infants' face and the center of the final object position similarly varied. This variation is indicated in Figure 1 by the fact that terminus of each arrow is a different distance away from the circle representing the infant. One consequence of this variation is that the visual angle subtended by the looming object when it was near the infant varied slightly with condition. For the center approach condition, the visual angles for the miss left, hit, and miss right conditions were 28.6°, 33.7°, and 28.6°, respectively. For the right approach conditions, the visual angles for the miss left, hit, and miss right conditions were 26.6°, 28.6°, and 23.3°, respectively. For the left approach

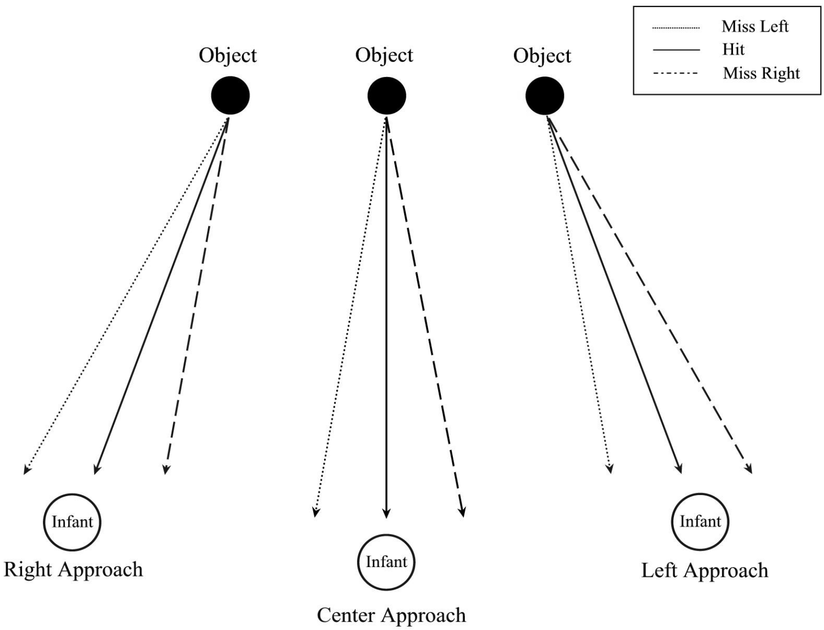

FIGURE 1 Schematic representation of the path of approach and type of contact variables.

conditions the visual angles for these three different object contacts were 23.3°, 28.6°, and 26.6°, respectively.

Path of approach was blocked and counterbalanced across infants, with infants receiving the conditions in one of three possible orders. Within each block, infants received a random order of 10 hits, 5 misses to the left, and 5 misses to the right. A research assistant moved the vertical post after each trial to vary type of contact. Direction of movement was counterbalanced, with half of the infants receiving either an approach or withdrawal movement first. In total, 20 trials for three paths of approach produced an experimental session of 60 trials, which lasted approximately 40 min.

Procedure

After being briefed about the experimental procedure, parents helped secure their children into the infant seat, and then watched the session on a monitor in an adjacent room. Trials were performed sequentially, with little delay unless infants began to cry or to slouch, at which point the block was paused to either soothe infants or readjust their position. There was a 1- to 2-min break between blocks to reposition the infant seat and the looming apparatus. Following the experimental session, parents were debriefed about the purposes of the study.[2]

Coding and Reliability

Using the video recordings, a trained observer coded reactions to approach and withdrawal movements as either an eye blink, no response, or not attending. To qualify as a response, an eye blink must have occurred within a 2-sec window surrounding the end of the movement (e.g., approximately 1 sec before the movement ended and 1 sec after the movement). Not attending trials, which accounted for about 1% of all responses, were excluded from analysis. A second coder provided interrater reliability for a randomly selected 20% of the sample. Cohen's kappa was calculated for each infant in this sample, and ranged from .67 to 1.00, with a mean of .84 (SD = .11). Kappa values over .75 indicate excellent reliability (Fleiss, 1981).

RESULTS

Data were analyzed using a 3 (path of approach: center vs. left vs. right) × 3 (type of contact: hit vs. miss right vs. miss left) × 2 (direction of movement: approach vs. withdrawal) within-subjects analysis of variance (ANOVA), with percent blinking as the dependent variable. The only significant main effect was for direction of movement, $F(1, 23) = 8.46$, $MSE = .08$, $p = .01$, $\eta^2_p = .269$, with blinking for approach trials ($M = 14.0$, $SE = .08$) greater than blinking for withdrawal trials ($M = 6.2$, $SE = .08$). The only significant two-way interaction was between path of approach and type of contact, $F(4, 92) = 2.55$, $MSE = .01$, $p < .05$, $\eta^2_p = .100$. This effect is qualified, however, by the three-way interaction among path of approach, type of contact, and direction of movement, which was marginally significant, $F(4, 92) = 2.36$, $MSE = .01$, $p < .06$, $\eta^2_p = .093$.

Given the significant main effect of direction of movement and the marginally significant three-way interaction, subsequent analyses examined path of approach and type of contact for approach and withdrawal trials separately. The data for withdrawal trials appears in Figure 2, and reveals only a significant main effect for path of approach, $F(2, 46) = 3.23$, $MSE = .01$, $p < .05$, $\eta^2_p = .123$, with right ap-

[2]On reflection, having an experimental session that was 40 min, including up to 60 trials seems a rather long study for such young infants, raising the issue of possible fatigue effects in responding. Although not presented formally, a series of analyses were conducted to examine the possibility of such fatigue effects. Specifically, a series of ANOVAs were run in which infants' looming reactions were examined as a function of increasing experimental block (ignoring the specific experimental condition), with these ANOVAs failing to find any consistent pattern of responding that could be interpreted as fatigue effects (i.e., decreased responding across the experimental blocks).

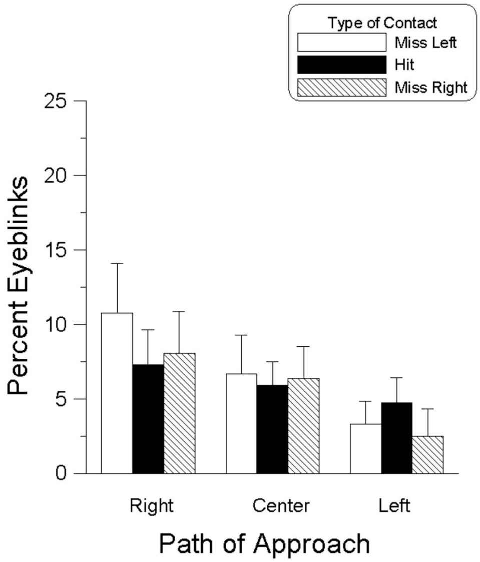

FIGURE 2 Percent eye blinking for withdrawal trials, as a function of the path of approach and type of contact variables.

proaches (M = 8.3, SE = 2.1) larger than center approaches (M = 6.3, SE = 1.3) which were larger than left approaches (M = 3.5, SE = 1.2).

The data for the approach trials, which appear in Figure 3, show a significant interaction between path of approach and type of contact, $F(4, 92) = 3.40$, MSE = .01, $p < .01$, $\eta^2_p = .129$. Subsequent comparison for this effect revealed a marginally significant trend for greater responses to hits in the center approach (M = 23.0, SE = .04) than the average of hits in the side approaches (M = 14.6, SE = .04), $t(23) = 1.99$, $p < .06$. Thus, for objects on a collision course, infants tended to respond more to objects beginning their approach from directly in front compared with objects beginning their journey from the side. Additional comparisons for the center approaches revealed that responses to hits were significantly greater than misses to the left (M = 11.7, SE = .03), $t(23) = 2.40$, $p < .05$, and misses to the right (M = 9.2, SE = .03), $t(23) = 3.30$, $p < .01$. Thus, for objects beginning directly in front, infants blinked more to collisions than noncollisions.

Finally, Figure 3 also suggests that for side-approaching objects there is a systematic effect depending on whether the object crosses in front of an infant. Specifically, for right approaches, misses to the left of the infant produce stronger responses than do misses to the right; similarly, for left approaches, misses to the right produce stronger reactions than misses to the left. To examine this possibility, the average response to the uncrossed misses (misses to the right in the right approach condition and misses to the left in the left approach condition) was com-

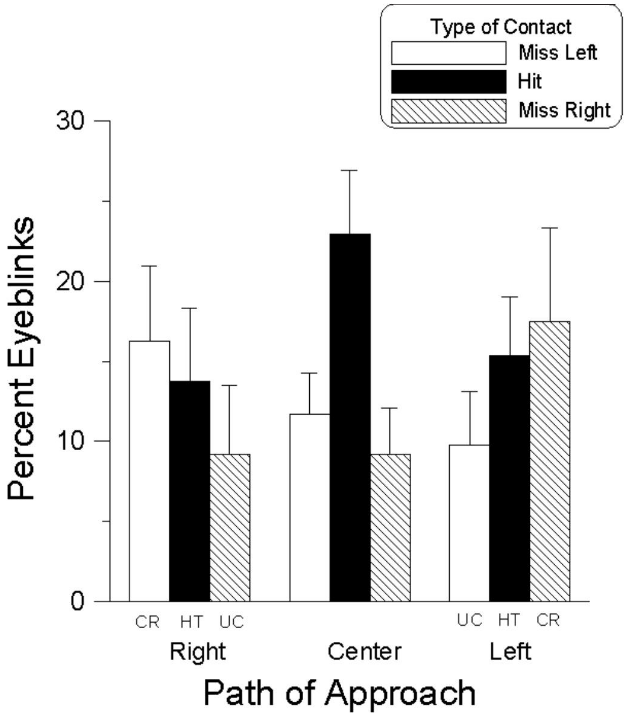

FIGURE 3 Percent eye blinking for approach trials, as a function of the path of approach and type of contact variables. "CR" refers to crossed misses, "HT" refers to hits, and "UC" refers to uncrossed misses, respectively.

pared to response to crossed misses (misses to the left in the right approach condition and misses to the right in the left approach condition). Crossed misses (M = 16.9, SE = .05) produced greater responses than uncrossed misses (M = 9.5, SE = .03), $t(23) = -2.19$, $p < .05$. Finally, a comparison of crossed misses versus hits versus uncrossed misses revealed a significant linear trend across these conditions, $F(1, 23) = 4.78$, $MSE = .03$, $p < .05$, $\eta^2_p = .172$, suggesting that reactions to the looming object grew systematically as the object increasingly crossed the line of sight.

DISCUSSION

In general, this work replicates the classic findings of Ball and Tronick (1971) and Yonas et al. (1977), demonstrating that symmetrically expanding objects on a collision path are responded to more strongly than asymmetrical noncollisions. Extending these earlier findings, this study also demonstrates that the path of approach of an object, head on versus from the side, does indeed influence perceptions of impending collision, as seen by the difference between center and side approach hits. Finally, this study found that for side approaches, objects crossing in front of infants produced stronger reactions than objects that did not cross infants, regardless of their being on a collision path.

Of these findings, clearly the most unexpected result is the fact that side-approaching objects crossing the infant's line of sight produced greater looming reactions than side-approaching objects that did not cross the line of sight, and that generally, looming reactions increased as the object crossed the infants' line of sight. What makes this result so interesting, of course, is that this linear effect essentially ignores whether or not the object was, ultimately, on a hit or miss path with the infant. This result, then, implies that infants cannot discriminate asymmetrical hits from asymmetrical misses; rather, true discrimination of hits versus misses needs to be indicated by symmetrical versus asymmetrical expansions.

Why are infants unable to discriminate hits from misses for side-approaching objects, and thus respond more to objects crossing the line of sight? Although truly satisfactory answers to these questions are not forthcoming, there are some possibilities that can be entertained (and in some cases dismissed). For instance, one (relatively uninteresting) explanation involves the possibility that even adults would be unable to consistently correctly identify hits from misses in the side approach conditions. Although this is not truly an explanation for infants' behavior per se, if adults had trouble dissociating hits from misses in side approaches, and produced comparable responses to the infants in this study, then the infant data might be reinterpreted as an accurate response to what is clearly inadequate information for determining hits from misses. To check this possibility, a comparison study with adults using the same looming apparatus and experimental conditions was conducted.[3] Using verbal responses of upcoming contact as the response measure, this study revealed that adults were 100% accurate in their abilities to discriminate hits from misses in all approach conditions. Thus, there is clearly adequate information for adults to allow for hit versus miss discrimination.

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[3]Eight adult observers were placed in the looming apparatus (with the plexiglass screen in front of them), seated on a small stool in a comparable position to the location of the infant seat. These observers were run in the same three paths of approach conditions, using the same counterbalancing orders as the infant study. In the two side approach conditions, the adults were seated such that their bodies faced forward (mimicking the infants' position when restrained in the car seat), but were told they could move their heads in any fashion they wished. In each approach condition adults received 20 randomly ordered types of contact trials (10 hits, 5 misses to the left, and 5 misses to the right); withdrawal trials were not included in this study. After the looming object stopped in front of the screen, adults were asked to say whether or not the looming object would have hit them had it continued. Adults' yes or no responses were recorded by the experimenter operating the looming apparatus

Another possible explanation for the finding of greater responses to crossed relative to uncrossed misses involves changes in the end state visual angle of the looming object across the conditions. Along these lines, maybe infants simply responded more to those conditions in which the retinal expansion patterns produced larger visual angles. In fact, a closer look at the visual angles supports this argument somewhat, in that the condition producing the strongest response (center approach hits) also had the largest final visual angle (33.69°), and the fact that the crossed misses had larger visual angles (26.56°) than the uncrossed misses (23.20°). Unfortunately, undermining this argument is the fact that crossed misses did not produce larger visual angles than actual hits (28.61°), meaning that the visual angle data do not, in fact, capture the linear increase in responding across the uncrossed misses, hits, and crossed misses conditions. Regardless, even though not fully consistent, a proposed relation between visual angle and looming response cannot be fully dismissed, in that the relation might be more along the lines of some (as yet undetermined) critical level of visual angle necessary for inducing looming reactions, rather than a strict linear increase. Future work might explore this question by looming objects of different sizes to infants, and observing their variation in reaction (if any) to such manipulations.

A third possible explanation for the differential looming response as a function of crossed versus uncrossed misses is that infants misperceived the distances to the moving objects or their sizes.[4] Consider an object starting from a position to the right of the infant and moving on a path that will miss the infant on the left (crossed or contralateral miss). This produced more defensive reactions than an object starting from the same position and approaching on a path that would hit the infant, and this in turn produced more defensive reactions than an object starting from the same position and moving on a path that missed the infant on his or her right (uncrossed or ipsilateral miss). Monocularly, any starting position and any linear motion of the object is consistent with an infinite number of objects, starting distances, and object speeds. All of these have in common the fact that they are related simply by a scale factor. For example, an object of diameter d starting at a distance l from the infant's eye and moving contralaterally at a speed v will produce precisely the same optical flow pattern as an object of half the diameter, $0.5d$, starting from a position half as far away, $0.5l$, and moving at half the velocity, $0.5v$. Without additional information regarding either the actual size of the ball or its actual starting distance, the monocular optic flow is completely ambiguous. Now if the distance to the object were to be underestimated substantially, it is possible that an object moving on a contralateral path missing the infant could be perceived as moving on a hit path. The data are internally consistent with the possibility that infants underperceived the distance or absolute size of the object because the magni-

[4]We thank Martin S. Banks for suggesting this possibility and for helpful discussions on this point.

tudes of their defensive reactions fell from a high on contralateral miss trials, through hit trials, to a low on ipsilateral miss trials. Binocular information could be used to disambiguate distance or size, but we have no way of determining whether infants used such information to solve the scale problem inherent in optic flow.

Along with these implications, there are also a variety of potential limitations to this work. Probably the most important issue in this regard involves infants' head orientations, in that it could be argued that if infants simply turned their heads in the side conditions, the distinction between the center and side approaches disappears. In fact, our own (informal) analyses of the videotaped sessions suggests that, by and large, infants did just this—they turned their heads to watch the approaching objects. Although potentially worrisome, we feel that head turning is ultimately not a critical concern given that even if object expansions were not asymmetrical themselves, the occlusion and disocclusion of the background behind the looming object remains asymmetric. Additionally, even with head turning, the infant's body and the room orientation instantiate a reference frame that retains the center–side distinction. Indeed, body orientation is a powerful indicator of the direction in which an observer is assumed oriented (e.g., Cutting & Readinger, 2002; Cutting, Readinger, & Wang, 2002; Cutting & Wang, 2000; Cutting, Wang, Flückiger, & Baumberger, 1999; Readinger, Chatziastros, Cunningham, Bülthoff, & Cutting, 2002). Finally, if infants were fixating the side-approaching objects directly, they should have then become identical to the center approaches, thus producing no differences between the conditions. The fact that we observed divergent results for side approaches thus demonstrates that infants were not treating these conditions equivalently.

Finally, these findings underscore a host of intriguing directions for future research. For instance, one potentially important distinction between the crossed and uncrossed misses of the side approaches is that in the crossed misses the object literally passes in front of infants' faces at the end of its trajectory, whereas in the uncrossed misses it does not ever really appear in front of infants at any time during its traverse. Such observations highlight the potential importance of at least two factors in the perception of looming: the time frame in which an object veers either into or out of a path of potential contact, and whether looming reactions vary depending on the point of contact with the observer's body. On this first topic, the primary question involves when along an object's trajectory it must deviate from collision to noncollision (or vice versa) for observers to detect and respond appropriately to this change. This question, of course, borders on the perception of nonlinear object approach, a topic that is just beginning to be broached with adults (e.g., Kerzel, Hecht, & Kim, 2001). In terms of the second topic, the primary issue involves whether there is something special about imminent contact with an infant's face, as opposed to another part of the body. From a functional view, the consequences of collision with the body are critical enough such that perceivers should wish to avoid such contacts, although it is questionable whether our dependent measure (blinking) would make much sense for an object on a collision path with the infants' torso, as opposed to the face.

In conclusion, this study found that both the type of object expansion and the type of contact with approaching objects influenced infants' perceptions of looming. Investigating such questions speaks to infants' abilities to learn to navigate the three-dimensional environment, and hopefully sheds light on processes involved in visually guided locomotion.

ACKNOWLEDGMENTS

This research was supported by a grant from the Natural Sciences and Engineering Research Council of Canada to Mark A. Schmuckler. The data from this study were collected in partial fulfillment of the requirements for the MA degree for Lisa M. Collimore. We would like to thank James Cutting, Peter Vishton, and three anonymous reviewers for their comments on previous drafts of this article.

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