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YOUNG INFANTS' SENSITIVITY TO MOVEMENT INFORMATION SPECIFYING SOCIAL CAUSALITY

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Adults and 3- to 6-month-old infants were tested for their visual preference for two different dynamic displays presented simultaneously on two side-by-side computer monitors. Each display consisted of a pair of colored discs moving either independently (the independent display) or in systematic interaction (the "chase" display), never actually contacting one another. Except for the relative spatio-temporal dependence of the discs' movements, all dynamic parameters on the two displays were controlled and maintained equal. Analysis of looking behavior showed that adults as well as infants looked differentially at the displays. Patterns of preference depended on age. For the infants who completed the experiment, there was a significant transition from more looking at the chase to more looking at the independent display as a function of age. Adults as well as the older, attentive infants, showed enhanced visual attention to the independent display. These results provide first evidence of young infants' sensitivity to movement information specifying social causality for adult observers.

Social-cognitive abilities develop dramatically by the end of the first year. Around age 9 to 12 months, infants start to engage in episodes of joint attention (Tomasello,

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1995), demonstrate intentionally communicative gestures (Bates, Camaioni, & Volterra, 1975), and engage in imitative learning (Meltzoff, 1988). The emergence of such social-cognitive abilities has been taken to herald infants' first understanding that other people behave intentionally. However, it is as yet unclear what the precursors of such understanding are. When do infants begin to be sensitive to information specifying intentional action, and how does this sensitivity develop? The general aim of the present research was to capture *precursors* of perceived intentionality, and in particular to document the early detection of perceptual information from which a theory of mind (i.e., an intentional stance and the detection of rational action in others) can eventually develop.

In adults there is a robust, if not compulsive inclination to perceive meaningful functional links in the motion of even abstract objects. Over fifty years ago, Heider and Simmel (1944) presented a short (two and half minute) motion picture of three moving geometrical figures to college students, asking them to describe and interpret what they saw. In the movie, the figures moved in and out of a rectangle, a section of which opened and closed like a door. Heider and Simmel reported that participants interpreted the picture with great uniformity in terms of a series of motivated actions performed by animate beings. They interpreted the moving geometric figures as persons, with specific personality traits, interacting, and expressing particular needs. These attributions depended on the characteristics of each of the figures' movement configurations, their relative proximity, and the relative temporal contingency between their motions. Phenomenal social events and social attribution are thus shown to depend on particular dynamic stimulus configurations.

Michotte (1963) demonstrated that causal links, too, are systematically perceived in the context of particular sequential movements of two geometric figures. Michotte showed that the precise timing and velocity of two squares moving in a display determined the perceiver's impression of whether one caused the other to move, by either entraining it or launching it. In general, the intuition of causal events depends on specific motion information that specifies dynamic links among moving entities. Michotte also showed that phenomenal causality was systematically accompanied by impressions of "activity" of each object moving in the display. The objects were reliably perceived as "doing" something: going toward, withdrawing from, hitting, or running away. Thus, Michotte demonstrated that the perception of both causality and activity depends on precise dynamic stimulus configurations.

As shown in the pionneering work of Heider and Simmel (1944), impressions accompanying the perception of particular animated displays are not limited to phenomenal causality and activity, but also to the reliable impression of specific social events and of social causality. This impression is construed as the detection of particular patterns of interaction at a distance (with no necessary physical contact) between self-propelled entities. Two studies have further specified the spatio-temporal determinants of perceived social and causal events using animated abstract displays. Basili (1976) investigated the responses of adult observers to different computer-generated films in which two discs chased each other in different, controlled ways. Conditions were compared in which the two discs' movements were temporally contingent and/or spatially related, or moved randomly in relation to one another. Basili found that a perceived interaction between the discs was linked to the degree of both the temporal contingency of the discs' movements and the relative congruence of their spatial trajectories. Basili's findings indicate that specific variations in the spatio-temporal contingencies between the movements of two abstract objects determine the perception of particular patterns of social interaction.

More recently, Dittrich and Lea (1994) studied adults' perception of intentional motion in an array of letters moving on a computer screen. These letters (distractors) moved randomly on the screen, except for one that was oriented towards one of the distractors. In various experiments varying the kinematics of the letters, the task of the participant was to detect the one letter that did not move randomly, but rather moved systematically towards another. Dittrich and Lea confirmed that perceived intentionality and social events among abstract, self-propelled entities depended on precise spatial and temporal features of the dynamic display such as the directness of the movement trajectory or the speed advantage of one dynamic element over another. Thus, overall, this collection of studies demonstrates that at least in adults, physical causality, social causality, and phenomenal activity, are all perceived and eventually interpreted on the basis of specific movement information.

In relation to development, the question of the origins of an attunement to movement information which specifies for adults intentional and motivated social interactions in abstract dynamic displays remains open. When do infants start to pick up spatio-temporal cues used by adults in their perception of social events? In particular, when do they start to discriminate movement information that, for adults, specifies social events and intentional action? Furthermore, how do they develop such discriminative ability? While there is yet no direct answer to these questions, numerous infant studies have investigated related phenomena, including the sensitivity to movement information, the perception of physical causality, physical and biological motion, the discrimination between animate and inanimate objects.

In general, studies demonstrated the existence of an early ability to detect motion information that is used by infants to perceive objects (Kellman & Spelke, 1983; Slater, Morison, Town, & Rose, 1985). Based on an habituation/dishabituation paradigm, researchers have tested young infants' perception of causality in relation to the kind of abstract dynamic events studied by Michotte (Leslie, 1984). Although there are different theoretical interpretations of the early development of perceived physical causality, it is now well established that at least by the end of the first year, infants are sensitive to information in abstract events that are perceived by adults to be causal interactions. Infants are reported to discriminate such information by 12 months (Oakes & Cohen, 1990), and perhaps as early as 6 months (Leslie & Keeble, 1987). The present research is an extension of existing works on the perception of causality in infancy, exploring the early sensitivity to causal events that do not entail any collision or physical contact.

Recent studies suggest that there is an early ability to detect the specific movement patterns of biological entities and to discriminate animate from inanimate objects. When presented with point light displays, 3- and 5-month-old infants have been shown to discriminate the canonical biological movement of a person from a perturbed spatial and temporal patterning of the same person's point-lights (Bertenthal, Proffitt, Kramer, & Spetner, 1987; Proffitt & Bertenthal, 1990). In an intriguing follow-up study, Bertenthal and Pinto (1993) reported that whereas 5-month-old infants discriminated between perturbed and non-perturbed point-light displays of a moving person, they did not do so in relation to non-familiar displays, such as a moving spider. These results are interpreted as evidence of an early stored knowledge of the human form and how it moves (Bertenthal, 1993). Furthermore, studies have indicated that already by 2 months of age infants start to express a basic categorical distinction between animate and inanimate motions (for a review, see Legerstee, 1992). Studies also have shown that early imitation is dependent on whether the modeled action is performed by an animated object or a person (Meltzoff & Moore, 1995). In addition, recent investigations have suggested that by 6 months infants perceive and understand that physical causality among inanimate objects entails physical contact (i.e., no action at a distance), but interactions among people do not (Woodward, Phillips, & Spelke, 1993; Spelke et al., 1995).

Thus, very young infants appear to differentiate animate and inanimate objects. They appear sensitive to relative motions as shown by the studies on physical causality and biological motions. As of yet, it is unclear when infants start to show detection of and attunement to movement information that specifies social events and intentionality for adults. However, a few studies have recently started to address this question directly. Using video displays of abstract objects in motion, Dasser, Ubaek, and Premack (1989) provided evidence of a sensitivity to intentional events by preschool children. In habituation-dishabituation tests, 3- to 5-year-old children differentiated between intentional and non-intentional (desynchronized) movement patterns of two balls. Premack (1990) interpreted these results as evidence of an early propensity to infer changes of internal state, social goals, and social reciprocity from the perception of moving physical entities. In studies of related abilities by much younger children, Poulin-Dubois and Shultz (1990) compared groups of 8- and 14-month-old infants in their visual habituation to dynamic causal events involving either a person or an inanimate object as the agent. Their observations suggest that only the group of 14-month-olds showed signs of a discrimination between the causal powers of social and nonsocial agents.

Finally, Gergely, Nádasdy, Csibra, and Bíró (1995) reported that 12-month-old infants perceive the behavior of objects moving on a video screen as performing rational action. The infants were habituated to a display of a ball gaining momentum, jumping over an obstacle, and approaching another ball. In post-habituation trials, the obstacle was removed and the first ball either went straight to the other ball (rational, new action) or jumped towards it (non-rational, old action). Infants at this age dishabituated significantly more to the non-rational old action compared to the new one. The authors concluded that infants discriminated these two outcomes by taking a rational stance, evaluating the rationality of the agent's goal-directed action. Interestingly, a follow-up study replicated these results with 12- and 9-, but not 6-month-old infants (Gergely, Csibra, Bíró, & Koós, 1994).

Considering that by 9 months infants appear to show first signs of an intentional/rational stance, questions remain regarding what prepares infants to take this stance. One question is whether infants younger than 9 months already have developed an ability to detect and discriminate perceptual information that they will eventually interpret as specifying social events and intentionality. One possibility is that younger infants develop a sensitivity to such information, prior to actually using it in the context of the social-cognitive abilities and the intentional stance that emerge by the end of the first year.

The present research was designed to explore precursor perceptual abilities that might allow infants eventually to recognize intentional actions. The rationale was that in order for the infant to take the intentional stance, first he or she had to develop a particular sensitivity and attunement to dynamic perceptual information that specifies social and intentional events for adults. We tested 3- to 6-month-old infants for their visual preference for two different dynamic displays showing abstract objects that adults perceive as interacting either intentionally or randomly. Both displays were presented to the infant simultaneously on two computer monitors placed side by side. Each display consisted of a pair of colored discs moving either independently (*independent display*) or in systematic interaction (*chase display*), never actually contacting one another.

The chase display was meant to specify an intentional, social event. In the independent display, the movements of the discs were random. In the chase display, one disc (the chaser) systematically approached the other (the chasee) at a constant velocity. When the chaser came close to the chasee, the latter accelerated away from it until it reached a "relax" distance (i.e., minimum distance in pixels, see stimuli below), at which point it returned to normal speed. Except for the relative spatio-temporal dependence of the discs' movements, all dynamic parameters of the two displays were controlled and maintained equal.

METHOD

Participants

Forty-six healthy, full-term infants (24 boys and 22 girls) were tested and included in the analyzed sample. Twenty-two (14 boys and 8 girls) were 3- to 4-month-olds (mean age = 4 months, 3 days; range = 3 months, 5 days to 4 months, 25 days; *SD* = 14.0 days); 24 (10 boys and 14 girls) were 5- to 6-month-olds (mean age = 5 months, 19 days; range = 5 months, 0 days to 6 months, 29 days; *SD* = 19.4 days). Twenty additional infants were tested but not included in the final sample either due to procedural error or because these infants did not look at the display for at least one third of the *first* trial presentation (i.e., 1 min of total gazing). Out of these twenty infants, thirteen were 3- to 4-month-olds (2 were excluded due to procedural error and 11 were excluded because they looked at the display for less than the criterion of one third of the first test trial), and seven were 5- to 6-month-olds (4 were excluded due to procedural error and 3 were excluded because they looked at the display for less than the one-third criterion). This one-third criterion was chosen to ensure that infants had enough time to explore and compare the two events. This criterion was based in part on pilot observations with adults placed in front of the two computer displays. These pilot participants were instructed to compare and depict the two displays. It took them on average approximately one minute of observation before they felt confident with their response. The infants were recruited from a subject pool consisting of over 500 infants born in various maternity hospitals of the Greater Atlanta, Georgia area.

In addition to the group of infants, 10 adults were also tested. These participants were Emory University undergraduate and graduate students (5 males, 5 females), unaware of the aim and rationale of the study. One additional adult was tested but her data were not included in the final results due to procedural error.

Stimuli

Participants were presented simultaneously with two computerized dynamic events, each displayed on one of two 15" computer monitors placed side by side. Each event consisted of a blue and a red disc constantly moving around the whole surface of the screen (which had a white background) and never touching one another. The red disc was 1.7 cm in diameter and the blue disc was 1.4 cm in diameter. In one event, the independent event, the two discs moved in relative independence from one another. In the other, the dependent ("Chase") event, the discs moved in relative spatio-temporal dependence. These events were both generated on-line by a computer program, therefore not prerecorded and replayed. This program determined the starting position of each disc on the screen and the exact parameters of their respective movements based on a random number generator running on the computer's clock. The parameters of the two events are precisely described below:

- *Dependent ("Chase") Event.* In this event, the movements of the two discs depended spatio-temporally on one another, moving in a "chase" type interaction. The red disc (chaser) was programmed to move constantly closer (reduce its absolute distance) to the blue disc (the chasee) without following its path (i.e., it was "heat-seeking," rather than "path-following").

The chaser moved at a constant velocity of 80 pixels/sec, and the chasee had a cruising velocity of 60 pixels/sec (except during its intermittent bouts of accelerations). Because the chaser was not path following, it managed to catch up frequently with the chasee. When the chaser came to the critically close ("panic") distance of 95 pixels, the chasee was programmed to accelerate away from the chaser at a maximum velocity of 200 pixels/sec until it reached a predetermined "relax" distance of 225 pixels from the chaser. When this relax distance was reached, the chasee recovered its 60 pixels/sec cruising velocity until the next "panic." Such sequences occurred approximately 8 times (+ or -1) per minute. This event sequence was repeated throughout each 3-min trial, such that the chase sequence took place an equal number of times and covered all locations on the white background of the computer screen for each trial. The parameters controlled by the program are described in detail in Table 1.

- *Independent Event.* In this event, the red and blue discs (see above) moved on the screen in the same fashion but in relative independence from one another. Again, the discs never came into contact with one another. Intermittently, the blue disc accelerated from its 60 pixels/sec cruising velocity to a 200 pixels/sec maximum velocity *independently* of the red disc's proximity (the red disc moved at a constant velocity of 80 pixels/sec, as in the other display). As in the chase event, acceleration sequences of the blue disc occurred approximately 8 (+ or − 1) times per minute and were of the same average duration and displacement, spanning the same average area of the screen. The average relative distance between the two discs across both events was also comparable. In both events, the red disc never came closer than 60 pixels to the blue disc. Note that this distance is different from the 95 pixel "panic" distance of the dependent "chase" event for comparability and to eliminate potential confounding variables (i.e., to maintain a comparable average distance between the two discs across events, see below). In other words, the minimum distance in the independent event had to be smaller than the minimum distance in the chase event in order that the average distance between the discs could be held constant across events.

Because we were interested in whether infants could discriminate between the chase versus the independent movements of the discs, we systematically controlled the spatial-temporal inter-dependence of the discs as the only difference between the two displays. To ensure that the only difference between the events was the relative dependence between the two discs' movements, the parameters listed in Table 1 (i.e., the discs' size, color, velocity, distance, turning angles and probability of the turning rate) were precisely set. Before running participants, a series of tests and measurements was performed to eliminate potentially confounding variables. The average distance between the two discs in either event was measured by videotaping the computer screen

Table 1. Parameter Settings for the Experimental Stimuli for each Condition (Chase and Independent).

Condition	Parameter	Blue Circle	Red Circle
A. Chase			
	Size	40 pixels	45 pixels
	Velocity	60 pixels/sec	80 pixels/sec
	Maximum velocity attained during periods of accelerations	200 pixels/sec	N/A
	Turning angle	45°, deterministic	90°, probabilistic
	Turning probability	15%	8%
	Panic distance	95 pixels	N/A
	Relax distance	225 pixels	N/A
	Avoid distance	N/A	N/A
B. Independent			
	Size	40 pixels	45 pixels
	Velocity	60 pixels/sec	80 pixels/sec
	Maximum velocity attained during periods of accelerations	200 pixels/sec	N/A
	Turning angle	45°, deterministic	90°, probabilistic
	Turning probability	15%	8%
	Panic distance	N/A	N/A
	Relax distance	N/A	N/A
	Avoid distance	N/A	60 pixels

from a fixed distance for several 3-min runs of the event. Upon playback of the videotape, still frames of the event were randomly selected at 5 to 15 sec intervals. Still frames were sampled in this manner in order to ensure that all possible distances between the two discs in the event were represented by their actual measurements. Using a Sony video graphic printer (UP-860), the selected still frames were printed and distances between the center of each disc were measured in centimeters. A measure of the number of accelerations per minute of the blue disc for each event was obtained by two independent coders who watched 10 live runs of these events and measured the frequency and duration of accelerations, using a computerized event recorder. Average percent agreement between coders for all measures was above 98%. The average distance between the two discs and the average frequency of accelerations displayed by the blue disc over the course of the 3-minute running time (a trial) were measured for each event and adjusted until no significant differences were found. The average distance of the discs, the frequency and duration of accelerations in each event were statistically compared using *t*-tests and again, adjusted until no significant differences were found between the two events.

In short, compared to the independent event, the dependent (chase) event varied *only* in terms of the spatio-temporal contingency between the two discs. Otherwise, the events were not significantly different, displaying comparable dynamic visual stimulation (i.e., amount of movement, characteristics of the moving discs, brightness, color, span of motion, displacement on the screen, and frequency of individual movement changes).

Apparatus

Participants were seated facing the two color high-resolution computer monitors (Apple Macintosh IIsi's). Infants sat on a parent's lap and adults sat on a chair. The computer monitors were placed just above the participant's eye-level, resting on a table. One meter separated the subject from each of the monitors. The monitors were 25 cm apart, angled 60 degrees inward toward the subject. An infrared camera (Panasonic WV-CD810) placed in the space between the two monitors was used to provide a close-up video recording of the subject's face for later measurement of preferential looking. Both computer monitors and the camera lens were surrounded by a black foamcore frame providing an even backdrop that hid the supporting equipment.

Procedure and Design

Infants. Participants were placed in front of the two screens which, at first, displayed a blue color background. Parents were blindfolded to ensure that they did not bias their infant's attention in any way. They were instructed to sit quietly and not interfere during the test, unless necessary. The lights were turned off to capture the participant's attention towards the computer screen and avoid other visual distractions. The infrared camera was set to record the participant's gazing behavior in low light. In a first calibration phase, one of two experimenters (E1) stood behind the participant, out of sight, and shook a rattle attached to a stick, first in between the 2 monitors, then in front of the right monitor, back to the center, in front of the left monitor, and finally back to the center. This phase was used for later gauging individual participants' gaze orientation towards either the left or right monitor.

Immediately following calibration and while the rattle continued to be shaken in between the two monitors, actual testing started. Both events were started simultaneously by another experimenter (E2), who sat behind the participant and clicked two computer mice at the same time, each of which was connected to one of the computers. Upon clicking the mice, both screens continued to display a blue background for 5 sec before the appearance of the dynamic stimuli (blue and red discs on a white background) on the screens. At that point, E1 removed the rattle from the center of the display.

A complete design for the infant participants consisted of two 3-min trial presentations of both events simultaneously with a short 5-sec inter-trial presentation time. The side of the dependent (chase) event during the first 3-min trial presentation was counterbalanced among participants of each age group. During the second trial presentation, the side of the events was switched for half of the infants in each age group. E1 shook the rattle in between the two monitors during the 5 second trial inter-presentation time and at the end of the second trial. The end of a trial presentation was signaled by a return to the blue background on the screen.

Adults. Adults were brought into the lab and told that they would watch two computer monitors displaying moving colorful discs. They were informed prior to testing that they would be asked questions about the displayed events after they ended. Participants were seated in front of the apparatus described above. The procedure for the calibration and test phases was identical to those described for the group of infants, with a few exceptions: Because pilot observations indicated that adults often showed boredom when viewing the displayed events for longer periods of time, test trials lasted one minute each instead of three. Similar to the infant group, both events were presented side by side. Each adult participant was shown two one-minute test trials separated by a 5-second blue screen interval. Half of the participants were presented with the independent event to their right for the first test trial, and half with the dependent ("chase") event. The location of each event was changed across the two trial presentations. As for the group of infants (see above), participants were videotaped for later assessments of their visual attention. Following the two 1-minute trials, participants were asked to respond to a short written questionnaire pertaining to the two events. During this post-test interview, the displays were turned on so that the participant could freely refer to them as they responded. In this post-test interview, participants were asked to describe concisely what they saw in the two events. In addition, they were asked to rate the two events by putting a mark on a continuous subjective scale (18 cm-long line), between positive (very much) and negative (not at all) values. This subjective assessment was made regarding the following questions for each event separately: a) to what extent the motions of the discs affect one another? b) to what extent the two discs interact with one another? c) How interesting is the event?

Scoring and Dependent Measures

The video recording of the infrared camera providing a close-up of the subject's face was scored by two independent coders using a computerized event recorder with multiple input channels running on the computer's clock. Coders activated two channels to score participants' looking. These two channels were controlled by predetermined keys on the computer's keyboard, one corresponding to looking to the right computer monitor in the display and the other to the left one. Coders watched the recording of the infant's face on the video tape running in real time, pressing the key corresponding to the monitor at which the infant was looking. No key was pressed when the subject was not looking at either monitor (looking away from the display).

Based on the print-outs of the simultaneous records entered from both channels of the event recorder (1 second was equal to 1 cm on the printout), coders measured:

1. *Looking Duration*: the absolute number of seconds the infant spent looking at each monitor for each minute separately and for the entire duration of each trial presentation,
2. *First Gaze Duration*: the duration (in seconds) of the first gaze towards each monitor for each trial presentation,
3. *Number of Looks*: the number of individual, separate looks towards each monitor,
4. *Look Duration*: the average duration (in seconds) of looks at each monitor (computed as the number of seconds looking at the monitor divided by the number of looks at that monitor), and
5. *Number of Gaze Switches*: the frequency of "switches," or gaze alternation from one monitor to the other, as a measure of the amount of comparison of the two events. Gaze alternation was considered a "switch" only when the switching of gaze orientation from one screen to the other occurred within a 1-sec interval.

Two coders independently coded the videotapes of 8 infants (total of fourteen 3-min trial presentations). The unit of analysis for all measures of duration (measures 1, 2, and 4 described above) was made in seconds, rounded up to the nearest second. Observed frequencies were compared for reliability regarding the other measures (measures 3 and 5 described above). For all 5 measures, between-coders reliability tests yielded Pearson's product moment correlation's greater than .96.

In addition to the visual behavior during the two test presentations of the events, we analyzed the content of each adult participant's responses to the short post-test written questionnaire and compared their subjective assessments of the two events by measuring the distance of their marks from the beginning of the line.

RESULTS

For clarity of presentation, results obtained with adult and infant participants are presented separately.

Adults

Overall, adults tended to spend more time looking at the independent event compared to the dependent ("chase") event in the course of the two 1-minute trial presentations (see Table 2).

A 2 (trial) X 2 (event) analysis of variance (ANOVA) comparing the number of seconds spent looking at each event (looking duration) yielded a close to significant event main effect ($F(1, 9) = 4.08$, $p < .07$, see Table 2). No significant trial by event interaction was found. A 2 (trial) X 2 (event) ANOVA on the average duration of individual looks also revealed a close to significant event main effect ($F(1, 9) = 4.54$, $p < .06$, see Table 2) and no significant trial by event interaction. Non-parametric statistics confirmed these results, showing that out of the

Table 2. Group of adult participants ($N = 10$): Means and standard deviations for Looking Duration in seconds (LD), First Gaze Duration in seconds (FGD), Frequency of Looks (FL), and Average Look Duration (ALD) for each condition: chase (CH) and Independent (IND) in both trial presentations.

	LD		FGD		FL		ALD	
	CH	IND	CH	IND	CH	IND	CH	IND
A. Trial 1								
M	28.7	34.6	1.7	1.5	20.3	20.6	1.5	1.9
sd	5.5	3.9	.8	1.7	7.5	6.8	.4	.6
B. Trial 2								
M	30.2	32.3	1.1	1.7	20.0	19.8	1.8	2.0
sd	6.1	5.7	.8	1.6	7.1	7.0	1.1	1.1

10 adult participants, 8 looked on average longer at the independent event and 9 showed longer average duration of individual looks at the independent event compared to the dependent ("chase") event ($p < .05$ for both binomial tests). ANOVAs yielded no significant differences regarding first look duration or the absolute frequency of looks at each event (see Table 2).

Based on the post-test interviews, all (10 out of 10) participants spontaneously described the dependent event as a *chase* whereas there was no systematic agreement among participants in their description of the independent event. A comparison of their mark on the subjective scale between positive ("very much") and negative ("not at all") values, showed that 8 of the 10 participants rated the dependent "chase" event as displaying greater interaction and greater mutual influence. In other words, the marking of these participants was closer to the "very much" value for the dependent compared to the independent event in relation to the question of the relative interaction and the extent to which the movement of the two discs affected one another. Interestingly, participants reported that the independent event was inherently more interesting than the chase event. Four participants volunteered that they quickly detected the regularities of the chase event and then focused more of their attention towards the independent event in an attempt to further explore a possible link between the movements of the disks on the display.

Infants

Out of the 46 infants included in the analysis, 25 (twelve of the 3- to 4-month-olds and thirteen of the 5- to 6-month-olds) completed the original design of two 3-min trial presentations. Twenty one infants (ten 3-month-olds and eleven 5-month-olds) met the minimum criterion of one third looking during the first trial presentation, but did not meet this criterion during the second trial presentation (see rationale in Participants section). First, we analyzed the data of all infants ($N = 46$) for the first 3-min trial presentation only, entering as a variable whether they terminated after one trial presentation (Group I or "Incomplete") or eventually completed the entire experiment (i.e. both the first and second trial presentations: Group C or "Complete"). Group was considered as a factor based on the assumption that each group comprised infants with different levels of attention, who expressed contrasting visual engagement in the computer displays.

The general aim of this first analysis was to investigate potential attentional and engagement differences between these two groups of infants. We performed a 2 (age) X 2 (group) X 3 (minute) X 2 (event) mixed design ANOVA on the looking duration measure. This analysis yielded a significant group main effect ($F(1, 42) = 10.96$, $p < .002$) and a significant group-by-minute interaction ($F(2, 84) = 4.08$, $p < .02$). These results are based on the fact that Group C infants were on the whole visually more attentive to the display (i.e., they looked longer in absolute seconds regardless of which events they preferred) compared to the Group I infants. The significant group-by-minute interaction rests on the fact that only the Group I infants showed a decrease of visual attention to the displays as a function of the three minutes of presentation (means for each minute were, respectively, 18.5, 14.5, and 14.1 sec). In contrast, Group C infants did not show a decline of visual attention to the displays in the first 3-min presentation (means for each minute were, respectively, 19.5, 20.8, and 20.1 sec). Finally, the only other significant effect from this analysis was a significant three-way interaction of age, group, and event ($F(1,42)$ 9.26, $p < .004$). Figure 1 illustrates this latter interaction. The graphs in Figure 1 show different overall patterns of preferential looking to the Chase and Independent events, depending on both the age and the group of infants.

To untangle these results, we considered the two groups of infants (Group C and Group I) in separate analyses. These separate analyses were justified considering that other dependent measures within the same global ANOVA design revealed marked contrasts between the two groups of infants. In particular, an ANOVA on the measure of first gaze duration (length of infants' first look at each display) yielded a significant main effect of group *only* ($F(1, 42) = 4.15$, $p < .047$), and no significant interactions. Again, Group C had a markedly greater average first gaze duration at either display (24.8 sec) compared to Group I (8.8 sec). Finally, an ANOVA regarding the measure of infants' average look duration (average length of individual looks to the display), yielded a significant group main effect ($F(1, 42) = 5.50$, $p < .023$). Specifically, Group C had a significantly greater average look duration at either display (15.1 sec) compared to Group I (5.9 sec).

These results confirmed that each group of infants demonstrated an overall differential visual engagement towards the display. In comparison to Group I, Group C demonstrated significantly greater sustained attention to the display as documented by both global (overall looking) and more specific measures of visual attention (first gaze and average look duration). The separate analyses of each group of infants were further justified based on the fact that these groups did not differ significantly in terms of age ($F(1, 44) < 1$, $p = .67$). The mean age of the younger group of infants was 119.4 days ($SD = 13.92$) for Group I, and

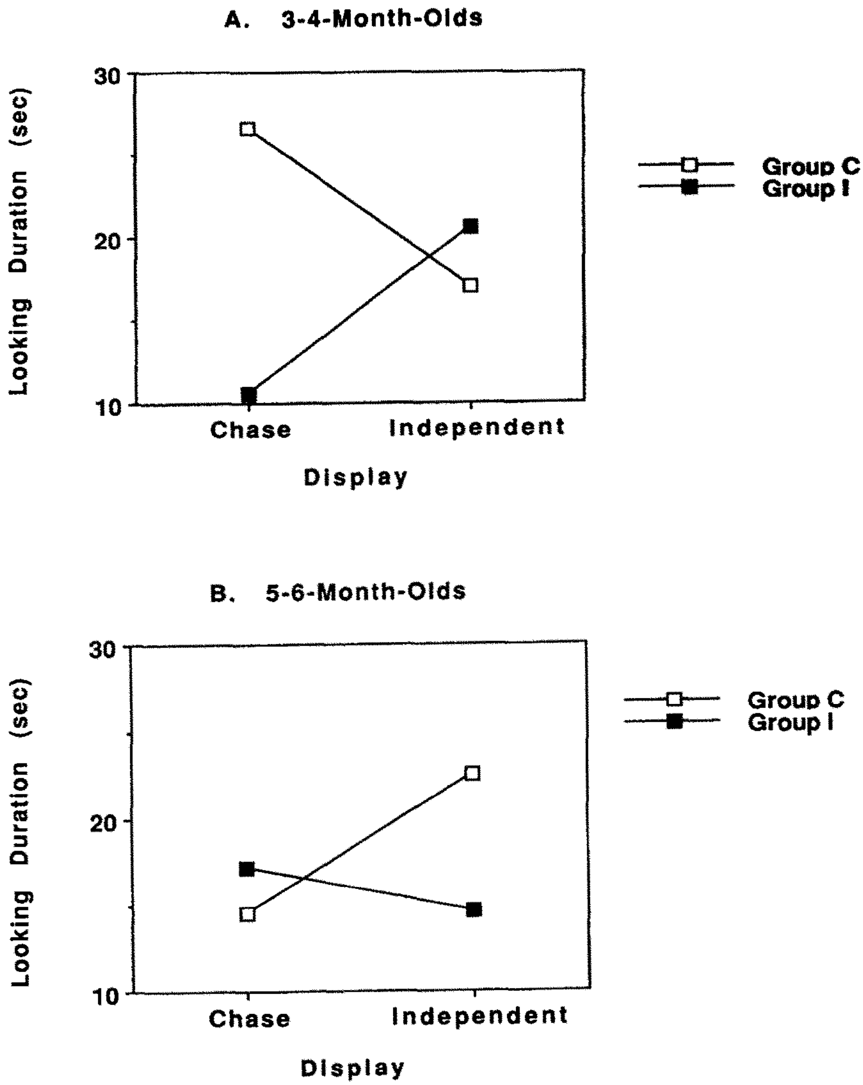

Figure 1. Mean looking time in seconds at either the Chase or Independent display, for the 3-4- month olds (A) and the 5-6-month-olds (B) of Group C and I infants.

125.5 (*SD* = 14.0) for Group C. The mean age of the older group was 171.0 (*SD* = 16.14) for Group I, and 167.0 (*SD* = 22.26) for group C. Finally, overall gender distribution was relatively close across both groups. Group C infants comprised 14 girls and 11 boys; Group I comprised 8 girls and 13 boys.

Table 3. Group (C) infants ($N = 25$): Means and standard deviations for Looking Duration in seconds (LD), First Gaze Duration in seconds (FGD), Frequency of Looks (FL), and Average Look Duration (ALD) for each condition: chase (CH) and Independent (IND) in both trial presentations, for both age groups of infants.

	LD		FGD		FL		ALD	
	CH	IND	CH	IND	CH	IND	CH	IND
A. Trial 1								
3-4 mos.								
M	79.7	51.0	27.4	11.9	13.0	10.9	14.1	8.4
sd	41.4	37.6	47.2	13.4	10.6	9.6	23.2	8.5
5-6 mos.								
M	43.7	67.7	3.3	8.2	15.3	17.4	3.5	5.1
sd	21.0	36.3	2.1	9.7	8.6	9.0	1.8	4.0
B. Trial 2								
3-4 mos.								
M	64.3	38.3	8.9	3.8	12.3	10.4	9.5	3.4
sd	43.0	29.8	8.8	4.2	8.9	6.0	16.1	2.0
5-6 mos.								
M	40.9	46.4	2.4	6.4	15.5	15.6	2.9	3.3
sd	14.1	13.9	1.3	7.7	6.4	6.2	.9	1.7

In addition, for both groups, the distribution of the preference score for either event, computed as difference scores of looking time (see below), was not significantly different from a normal distribution. This result is based on a Kolmogorov-Smirnov goodness of fit test performed on the distribution of these scores for both groups that yielded 2-tailed p values of .87 for Group C and .96 for Group I respectively.

Group C Infants

Table 3 presents the means and standard deviations regarding the various dependent measures for the Group C infants ($N = 25$).

Recall that the left or right side of the events was changed between the 2 trial presentations for half of the infants of each age group. Preliminary analyses comparing these subgroups of infants did not reveal any significant effect of side change from trial 1 to trial 2, and therefore side change was not introduced as a factor in subsequent analyses. A 2 (age) X 2 (trial) X 3 (minute) X 2 (event) mixed design ANOVA on the number of seconds spent looking at each display yielded a significant main effect of trial ($F(1, 23) = 14.55$, $p < .001$), and a significant trial-by-minute interaction ($F(2, 46) = 3.21$, $p < .05$). These results indicated that, overall, infants spent more time looking at either display during the first trial presentation (see Table 3), and less in minutes 2 and 3 during the second presentation only (respectively means of 19.6, 20.8 and 20.1 sec for the first presentation; 18.4, 14.7, and 14.4 sec for the second presentation). More importantly, the ANOVA also yielded a significant age-by-event interaction ($F(1, 23) = 4.68$, $p < .04$). This interaction rests on the fact that 3-month-olds spent more time looking at the Chase compared to the Independent event (oveall means were 72.0 sec and 44.6 sec, respectively). Inversely, 5-month-olds spent more time looking at the independent compared to the dependent "chase" event (overall means were 57.2 sec and 42.2 sec, respectively, see also Table 3). Confirming this, non-parametric comparisons revealed that over the two trials, eight of the twelve 3-4-month-olds looked longer at the Chase event (any difference considered), and ten out of the thirteen 5-month-olds looked longer at the Independent event ($p < .05$ for binomial test of the 5-6-month-olds' distribution only).

Regarding first gaze duration, a 2 (age) X 2 (trial) X 3 (minute) X 2 (event) mixed design ANOVA yielded a marginally significant age effect ($F(1, 23) = 3.72$, $p < .06$), the younger group of infants having on average an overall longer first gaze duration. The ANOVA also yielded a significant trial main effect ($F(1, 23) = 4.70$, $p < .04$), first gaze duration being overall significantly longer for either event in the first compared to the second trial presentation (means were 12.7 sec and 5.4 sec respectively, see also Table 3). Although the ANOVA yielded a marginally significant age-by-event interaction ($F(1, 23) = 3.66$, $p < .06$), non-parametric statistics indicated that on average over the two trials, nine out of the twelve 3-4-month-olds showed a longer first look duration towards the dependent ("chase") event than the Independent event, whereas eleven of the thirteen 5-6-month-olds showed a longer first gaze duration toward the independent event ($p < .05$ for binomial test of this latter proportion for the 5-6-month-olds, see also Table 3).

A 2 (age) X 2 (trial) X 3 (minute) X 2 (event) mixed design ANOVA regarding the number of looks at each event yielded only a significant minute-by-event interaction ($F(2, 46) = 4.22$, $p < .02$). Post-hoc Duncan tests yielded a significant event effect in the third minute only ($p < .05$), indicating that by the end of the trial, infants tended to show significantly fewer looks at the independent event compared to the chase event.

Regarding gaze alternation (i.e., "switches" from one display to the other as an index of the amount of comparison of the two events), a 2 (age) X 2 (trial) X 3 (minute) mixed design ANOVA yielded only a significant age effect ($F(1, 23) = 4.27$, $p < .05$). The 5-month-olds showed significantly more frequent gaze alternation between the two events compared to the 3-month-olds with means of 5.0 and 2.8 switches per minute, respectively. These results indicate that the older group of infants was more engaged in comparing the two events on display. Although marginally significant, the ANOVA also revealed that for both age groups, the frequency of gaze alternation tended to decrease both as a function of minute (from a frequency of 4.6 in the first minute to 3.4 in the third minute, $p < .07$) and as a function of trial (from a frequency of 4.5 in the first trial to 3.3 in the second trial, $p < .08$).

Finally, regarding the measure of infants' average look duration, a 2 (age) X 2 (trial) X 3 (minute) X 2 (event) mixed design ANOVA yielded a significant trial main effect only ($F(1, 23) = 8.98$, $p < .007$). The average look duration was significantly reduced during the second trial, pointing to an attenuation in infants' engagement with the display (means were 7.7 sec for trial 1 and 4.8 sec for trial 2, see also Table 3).

In summary, the main findings regarding the infants who completed the experiment by being attentive to both trial presentations were that in comparison to 3-month-olds, 5-month-old infants tended 1) to look longer towards the independent event compared to the chase event, 2) to have longer first gaze duration towards the independent event, and 3) to engage in more comparison of the two events. Overall, 3-4-month-olds tended to look longer and had a longer first gaze duration at the Chase event than did the 5-6-month-olds.

However, the distinction between the two age groups was arbitrary, in that the group of 3-month-olds included infants from age 3;0 to age 4;30 and that a comparable age spread existed for the group of 5-month-olds (see Method section). In some cases, infants only a day or two apart in age were assigned to different

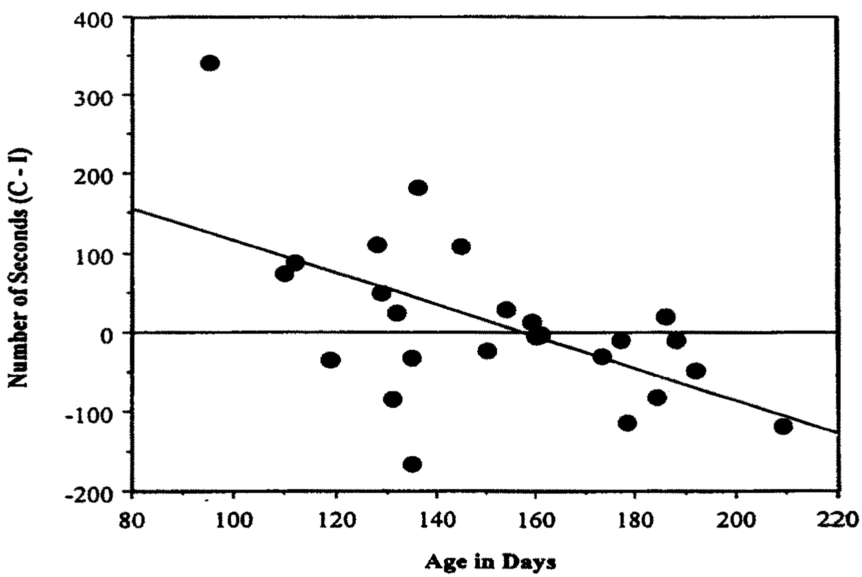

Figure 2. Scatter plot of the difference scores regarding the number of seconds each infant looked at the Chase (C) or Independent (I) event as a function of the particular infant's age in days (Group C infants only). The horizontal dotted line at zero on the Y axis corresponds to equal looking duration at either event (i.e., zero difference of (C) - (I) looking time).

Table 4. Group (I) infants ($N = 21$): Means and standard deviations for Looking Duration in seconds (LD), First Gaze Duration in seconds (FGD), Frequency of Looks (FL), and Average Look Duration (ALD) for each condition: chase (CH) and Independent (IND) in both trial presentations, for both age groups of infants.

	LD		FGD		FL		ALD	
Age	CH	IND	CH	IND	CH	IND	CH	IND
3-4 mos.								
M	32.6	61.7	3.7	6.9	11.4	16.7	2.8	4.3
sd	19.1	19.8	4.5	6.1	5.4	7.7	1.4	2.1
5-6 mos.								
M	51.6	43.9	4.0	3.3	22.4	20.0	2.5	2.5
sd	16.1	18.9	3.4	2.4	7.0	7.1	.9	1.0

groups. We thus decided to perform a more precise developmental analysis, considering age as a continuous variable. For each infant, we further calculated a difference score between the results obtained in relation to the chase and independent event (i.e., chase minus independent score) for each of the above measures and correlated these scores with the infant's age *in days*. Note that a negative difference score corresponded to a preference towards the independent event.

In particular, results obtained with the 25 infants that completed the two 3-min trial presentations of the original design were analyzed in relation to their precise age. Infants were compared on the basis of their age in days and the average difference score across the two trials for a particular measure of their visual attention. Figure 2 presents the scatter plot of the number of seconds the infants looked at the chase minus the number of seconds the infants looked at the independent event as a function of each infants' age in days.

Correlation coefficients between age in days and the different measures of visual attention were: –.571 for number of seconds; –.340 for number of looks; –439 for average look duration; and –.534 for first gaze duration. All coefficients were significant for $p < .05$. Note that the same correlation analysis was also performed using preference scores computed as percent looking time at the chase event. This analysis also yielded significant results (correlation of –.552, $p < .004$). These latter results confirmed that as a function of age, there is a progressive transition from a looking preference towards the dependent ("chase") event to a preference towards the independent event. As shown on Figure 2, the youngest infant appears as an outlier that might have biased the results. We re-calculated the correlation coefficients excluding this infant ($N = 24$). These coefficients were –.448 for number of seconds; –.353 for number of looks; –.260 for average look duration; and –.453 for first gaze duration. Except for the average look duration measure, all of these coefficients were significant for $p < .05$, confirming the general developmental transition.

The performance of both age groups of infants was then further compared to that of the group of adults. As adults and infants had different presentation times, the number of seconds looking at the chase event was calculated as a percentage of the total looking time at both events. This ratio allowed a direct comparison of all three age groups (3-, 5-month-olds, and adults). A 3 (age) X 2 (trial) mixed design ANOVA yielded a significant age main effect only ($F(2, 31) = 4.33, p < .022$). Post-hoc tests indicated that the ratios of looking at the chase event for adults and 5-month-olds were not significantly different from each other. However, both differed significantly from the ratio of the younger infants ($p < .05$ for Duncan tests). This latter result showed that 5-month-olds were comparable to adults in their tendency to look longer at the independent event.

Group I Infants

Separate analyses of the subset of infants who did not complete the second trial presentation ($N = 21$, ten 3-month-olds and eleven 5-month-olds) were performed (for the first trial presentation only). Means and standard deviations for all dependent measures obtained with this subset of infants are presented in Table 4.

A 2 (age) X 2 (event) ANOVA on the number of seconds looking yielded a significant age-by-event interaction ($F(1, 17) = 11.30$, $p < .004$). Post-hoc Duncan tests revealed that the group of 5-month-olds tended to look significantly longer at the chase event; whereas 3-month-olds tended to look longer at the independent event ($p < .05$). The direction of preference of these infants was reversed compared to that of the group (C) infants (see Table 3 and 4). Regarding the other dependent measures, similar analyses yielded an analogous pattern of results for the average look duration ($F(1, 17) = 5.47$, $p < .03$) and for number of looks ($F(1, 17) = 6.24$, $p < .024$, see also Table 4).

Infants were further compared on the basis of their age in days and their difference score for each measure of their visual attention (i.e., score relative to the dependent ("chase") event minus score for the independent event). Correlation coefficients between age in days and the measures of visual attention were: .431 for number of seconds; .387 for number of looks; .367 for average look duration; and .254 for first gaze duration. Coefficients for number of seconds and number of looks were both significant at $p < .05$. These results confirmed that this group of infants demonstrated an inverse developmental transition as compared with group C infants, from a looking preference towards the independent event to a preference towards the dependent ("chase") event.

Finally, as for Group C infants, we compared the performance of the Group I infants with the performance of the group of adults. Again, as adults and infants had different presentation times, the number of seconds looking at the chase event was calculated as a percentage of the total looking time at both events. This ratio allowed a direct comparison of all three age groups (3-4, 5-6 month-olds, and adults). For comparability, we included only the results obtained with adults during the first trial presentation (i.e., there was no trial variable as infants in this group completed only one presentation). A one-way ANOVA yielded a significant main effect of age ($F(2, 28) = 6.53$, $p < .005$). Post-hoc Duncan tests indicated that the ratio of looking at the chase event for adults was not significantly different from the ratios of both 3- and 5-month-olds. However, the ratios of 3-4- and 5-6-month-olds differed from one another ($p < .05$). In general, and in contrast to the same analysis performed with Group C infants, there was no significant developmental trend emerging from the comparison of adults with the Group I infants. Although both age groups differed from one another, neither of them differed significantly from the adults.

DISCUSSION

The results suggest that from an early age, infants are sensitive to movement information that specifies social events for adults. Long before their first birthday, infants appear to be capable of detecting the relative dependence between the movements of two abstract entities moving on a screen. Infants' preferential looking indicated that from 3 months of age they tend to discriminate between the independent or dependent movements of two identical pairs of discs, movements that specify random (nonsocial) or chase (social) events for adult observers.

However, the pattern of preferential looking reported here was not straightforward when infants who completed only the first trial presentation of the experiment were included in the analysis. The pattern changed not only in relation to age, but also in relation to the relative engagement of the infant with the computer displays. Infants who attended to the displays and sustained testing only for the first 3-minute trial presentation (Group I) showed a reversed pattern of preferential looking compared to the infants who completed both trial presentations (Group C). Analyses revealed differences in visual exploratory behavior between the two groups. In comparison to Group I infants, Group C infants spent significantly longer time attending to the display, with longer first gaze durations and average looks. These results might index different levels in the development of visual attention, memory, and the processing of visual information by same-age infants (Baillargeon, 1987; Colombo, Mitchell, Coldren & Freeseman, 1991).

If the reversed pattern of preferential looking between Group I and C infants is difficult to interpret, it does not preclude the basic finding of the present research: that 3-5-month-old infants display sensitivity to movement information specifying social causality for adults. We interpret the reversed pattern of preferential looking between the two groups of infants as linked to basic differences in visual exploration and attention. Depending on their level of visual attention and ability to sustain visual exploration, it appears that infants expressed differentially their basic sensitivity to movement information. That is, although both groups of infants discriminated between the two events, infants who were inclined to attend more, with longer looks at the display, tended to show a development from a preference for the Chase to the Independent display as a function of age. In contrast, less attentive infants expressed an opposite developmental trend.

It is interesting to note that, in the Chase display, events occurred over approximately 8 sec (one discrete chase event = approach of chaser + fleeing of chasee). Therefore, exploration of such events in full required a certain level of sustained visual attention. In contrast, the Independent display was randomly parsed with smaller events characterized by discrete movement changes of each circle on the screen. The Chase and Independent displays thus had different processing demands that need to be taken into consideration when trying to interpret the differential pattern of preferential looking. One possibility is that the younger infants of the less attentive group (Group I), looked longer at the Independent display, in which discrete, smaller events were easier to process. Over age, these less attentive infants would come to attend more to the longer events characterizing the Chase display. According to this interpretation, attentive and less attentive infants showed patterns of preference for different reasons. That is, analogous to adults, the older, more attentive group of infants searched for systematic patterns in the independent display. In contrast, the younger, less attentive infants attended preferentially to the independent display because of the shorter durations of discrete events. Future research is needed to test this interpretation that considers the level of visual exploration and attention as a determinant of the preferential looking patterns expressed by young infants. Still, even though this reversed pattern of preference is difficult to interpret, the basic finding of discrimination between the two events by both groups of infants, at both ages studied remains. The data reported here provide first evidence of young infants' sensitivity to movement information specifying social causality for adult observers.

More consistent data among infants might have been found if more highly contrasted spatio-temporal parameters specifying the chase and the independent events had been used. In order to control for the various movement parameters across conditions, we were constrained to use chase and independent events that were not maximally contrasted. In future studies, the spatio-temporal characteristics of events should be systematically varied in an attempt to tease apart exactly what perceptual information infants are using in their discrimination (e.g., relative velocity of the discs, temporal contingency, spatial proximity, etc.). Furthermore, future research should also attempt to replicate the present findings using a different experimental paradigm, and in particular an habituation/dishabituation paradigm. Such research would perhaps avoid inconsistencies that might be specifically attached to the preferential looking paradigm used in the present study.

In the present research, Chase and Independent displays differed exclusively in terms of the relational dynamics of the discs. Except for the difference in relational dynamics, all other spatio-temporal parameters of the displays were identical, with the discs moving in the same way and providing an identical level of animacy. Participants' preferential looking was tested against the null hypothesis of equal looking at each display. Had participants not detected any of the relational dynamics between the animated discs, hence merely perceiving the discs as unrelated entities moving independently on the screen, they should have attended equally to both events.

Because infants, as well as adults, attended differentially to the two displays, they appear to have been sensitive to differences in the relational dynamics of the discs. These results corroborate previous demonstrations that infants as young as 3 months detect and discriminate relational invariants in abstract dynamical displays, such as point light displays specifying biological motion (Bertenthal, 1993). They confirm that there is an early sensitivity to the relative movements or relational dynamic of animated entities.

Assuming that Group C infants were more comparable to adults in terms of their level of attention and probably the pace at which they detected invariant information specifying the dependent "chase" event, the comparison of these infants with the group of adults revealed an interesting developmental pattern. Adults spent more time looking at the independent event. A similar pattern was found with 5-month-olds, but not with 3-month-old infants (Group C infants). Results indicated that there was a significant shift of preference from the chase to the independent event between 3 and 5 months. This shift appeared remarkably progressive as a function of age. Interestingly, this developmental progression by these infants was oriented towards the pattern expressed by the group of adult participants. For adults, based on post-test interviews, it appears that the independent event was more interesting as it challenged participants' propensity to detect invariant relations in the dynamics of the two discs. It is feasible that the development of this propensity might underlie the attentional shift towards the independent event that occurred between 3 and 5 months for Group C infants. This shift would suggest that although movement information specifying the relative interaction between the two discs tended to be discriminated by the younger infants, what guides the actual attention to the event changes between 3 and 5 months. An analogous developmental shift has been reported by Bertenthal (1993) in the context of a discrimination of biological motions specified by point light displays. In this study, 3-month-old infants discriminated the point light display of a person walking either in a canonical or non-canonical orientation, whereas 5-month-olds discriminated the pattern of motion only when it was displayed in a canonical orientation. This developmental pattern of results was interpreted as the expression of a change towards an increasingly knowledge-based detection of biological motion (Bertenthal, 1993). Although our research does not provide any evidence of emerging categorization of motion and knowledge-based perception by young infants, it corroborates the observation of a developmental transition between 3 and 5 months regarding the detection and discrimination of relational invariants in abstract dynamical displays.

Interestingly, the present research and the series of studies performed by Bertenthal share a unique feature. Both pertain to the relative movements of abstract entities that are never in physical contact with one another, which do not specify any physical causality.

What is intriguing in the present findings is that infants younger than 6 months appear to detect relational invariants in the movement of a pair of objects that interact at a distance. The perception of physical causality by adults, as well as its discrimination by young infants depends on physical contact among moving objects. In the present experiments, what infants appear to discriminate are spatio-temporal invariants pertaining to the relative movements of the objects that are perceived as a pair, without any actual contact. These spatio-temporal invariants violate the *contact principle* or the principle of no action at a distance, an important aspect of the core physical knowledge documented in infants 6 months and younger (Baillargeon, 1993; Spelke, Breinlinger, Macomber, & Jacobson, 1992). These spatio-temporal invariants specify different *scripts* identified by adults as "chase" or "random" events. Note that it is feasible, although not yet clearly demonstrated, that these invariants might be already analyzed by young infants as *image-schemas* pertaining to specific types of reciprocal action at a distance (Mandler, in press).

The present findings indicate that from 3- to 5-months of age, infants tend to detect differences in the pattern of relational dynamics linking two objects that never contact one another. From 3 months, infants appear to be sensitive to the characteristics of a functional link between objects interacting at a distance. As mentioned in the introduction, Woodward, Phillips and Spelke (1993) have recently provided evidence that 6-month-old infants perceive physical causality involving objects on the basis of the contact principle, but appear to suspend this principle when the event involves people. Infants in that study were habituated to either two objects or two people moving back and forth behind an occluder. Woodward et al. reported that in the post-habituation tests when the occluder was removed, infants tended to look longer when there was no physical contact in the event involving objects. In contrast, they looked longer when there was a physical contact in an event involving people. These findings suggest that by 6 months infants apply different principles in their perceptual analysis of physical and social events. The results of the present experiment further indicate that young infants discriminate information, and in particular spatio-temporal invariants, that adults perceive as specifying social versus nonsocial events.

Based on the present findings, it appears that long before 9 months of age, when major social-cognitive skills, including joint attention (Tomasello, 1995), communicative gestures (Bates, Camaioni, & Volterra, 1975), and delayed imitation (Meltzoff, 1988) emerge, infants are already sensitive to perceptual information that potentially specifies social and nonsocial events. We propose that this sensitivity is the expression of an early perceptual ability that prepares infants to develop the social-cognitive competencies that emerge by the end of the first year. From 3 months of age, infants appear to be sensitive to dynamic information pertaining to the relative movement of individualized entities, information that specifies social (intentional) and nonsocial (unintentional) events for adults. This perceptual ability is probably at the origins of the intentional/rational stance that infants start to take within a few weeks of developmental time (Gergely et al., 1995). The developmental link between such early perceptual ability and later social cognitive development is an important question that deserves further investigation.

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