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Who is doing what to whom? Young infants' developing sense of social causality in animated displays

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Abstract. In two different experiments a visual habituation/dishabituation procedure was used to test groups of 3 – 10-month-old infants for their ability to discriminate the role reversal of two abstract figures (discs of different colors) chasing each other on a computer screen. Results of the first experiment point to a reliable age effect. Only 8 – 10-month-old infants tended to dishabituate to a role reversal between chaser and chasee. A second experiment shows that in dishabituating to the role reversal, 8 – 10-month-olds do base this discrimination on relational information between the two discs and not merely on the contrast between their respective vitality or discrete dynamic. By the age of 8 – 10 months, infants demonstrate sensitivity to information specifying what one disc does to the other, at a distance. These findings point to important changes in perceptual-cognitive development and are discussed in the context of a well described key transition in social-cognitive development occurring at around 9 months of age.

1 Introduction

Action at a distance is a trademark of social exchanges. In contrast to the direct contact characterizing most transactions in the object world (with the exception of physical gravity and magnetic phenomena), people and animals communicate and can affect each others behavior indirectly, via gesturing, vocalizing, postural expression, or goal-oriented actions. A predator will affect a prey's behavior before they actually get in direct physical contact. On the contrary, physical objects affect each others behavior by exerting direct force such as pushing, pulling, or colliding—notwithstanding magnets that form an exception to the rule of direct physical contact. Actions and their effects at a distance contrast social from physical causality.

The detection and understanding of physical causality is an early fact of life. On the basis of habituation techniques, research shows that by at least 10 months of age, infants detect changes in the invariant features specifying physical causality among animated visible objects (Oakes and Cohen 1990). Other studies indicate that the detection of physical causality might even be manifested at younger ages (Leslie 1984; Leslie and Keeble 1987; Spelke et al 1992).

In the context of self-produced action, numerous studies show that infants as young as 2 months express a sense of their own body as agents, capable of causing predictable and direct changes in the physical environment. They learn to kick, suck, or perform particular limb movements to produce interesting sounds and sights, as well as to make objects move (Kalnins and Bruner 1973; Lewis et al 1985; Rochat and Striano 1999a; Rovee-Collier 1987). Early on, infants behave as active entities inclined to explore systematically, exerting physical force and controlling direct transformations on objects in the environment (Gibson 1988; Rochat 1989).

If the grasp of physical causality is an early fact of life, it is not clear what are the developmental origins of social-causality detection (ie the effect of action at a distance). As adults, we have a compulsive inclination to perceive meaningful functional links in the motion of objects, people, and even abstract entities moving and interacting on a two-dimensional surface. The seminal work of Michotte (1963) demonstrates that physical causality is systematically perceived in the context of specific sequential movements of objects. Particular timing and velocity of two abstract entities, moving in a display (eg two squares), determine adult perceivers' impression of physical causality: that one square pushed, entrained, or launched the other's motion. Michotte elegantly demonstrated that the intuition of causal physical events by adults depends on specific motion information specifying dynamic links among objects. Furthermore, his research shows that phenomenal physical causality is typically associated with impressions of activity by one object onto another, one object perceived as doing something to the other: getting at it, hitting it, pushing it, withdrawing from it. At least in adults, phenomenal causality is somehow inseparable from the attribution of agent or patient roles to the protagonists of dynamic events.

Years ago, Heider and Simmel (1944) demonstrated that adults detect social causality in dynamic visual events involving abstract entities interacting at a distance. In their study, college students were asked to describe and interpret the motion of three geometrical figures moving in and out of a rectangle, a section of which opened and closed like a door. Heider and Simmel reported that the figures were perceived and systematically interpreted by the participants as *persons* with particular personality traits and expressing particular needs and dispositions (eg aggression, escape to safety, or rescue). The authors showed that such interpretation depended on the relative proximity of the geometric figures, their movement characteristics, and the relative temporal contingency between their respective motions. Basili (1976) confirmed that particular movements of two discs chasing each other on a computer screen are perceived by adult observers as standing for particular patterns of social interaction. The work of Basili shows that such interference depends on specific variations in the spatiotemporal contingencies between the two abstract objects moving on the screen.

More recently, Dittrich and Lea (1994) further documented the propensity of adults to perceive intentional motion in the animation of nondescript objects. Participants were presented with letters moving on a computer screen. Their task was to detect the one letter that did not move randomly, its motion being oriented toward one of the distractor (ie randomly moving) letters. Results showed, once again, that such detection 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. In all, studies with adults provide strong evidence that social causality, phenomenal reciprocity of action, and intentional movements are compulsorily inferred on the basis of specific movement information. Nondescript abstract objects interacting at a distance on a two-dimensional screen tend to be reliably perceived as meaningful social events.

Although it is not clear when in development infants propensity to perceive social causality in animated displays might start to show, research indicates that from at least 6 months of age, and possibly earlier, infants express a categorical distinction between animate and inanimate motions (Legerstee 1992). Research with point-light displays indicates that 3–5-month-old infants detect the canonical biological movement of a person from a perturbed spatial and temporal patterning of the same person's point lights (Bertenthal et al 1987). Interestingly, such findings were not replicated when the point-light displays depicted a spider; 5-month-old infants appear to have a stored knowledge of the human form and how it is supposed to move (Bertenthal and Pinto 1993).

Further evidence of an early distinction between a person and an animated physical object is provided in studies on imitation showing that infants are more inclined to imitate actions performed by a person rather than by an animated object (Legerstee et al 1987) or a machine (Meltzoff 1995). In addition to the distinction between a person and animated objects, some recent studies indicate that infants from an early age discriminate between social and physical causality. Infants are reported to perceive and understand by the age of 6 months that physical causality among inanimate objects entails physical contact (ie no action at a distance), and that interaction among people does not. Based on a violation-of-expectation paradigm, infants aged 6 months are reported to look significantly longer at the outcome of a partially occluded event violating the no-action-at-a-distance rule typically governing animated physical objects, notwithstanding magnets and other celestial bodies. Results suggested that infants suspended this rule when the event involved people rather than objects (Spelke et al 1995).

Beyond an early person versus object discrimination, based on core physical principles or particular dynamic information, infants begin some time around their first birthday to discriminate between intentional and non-intentional actions, namely actions that are perceived as planned and deliberate rather than random and lacking detectable aboutness. By the age of 9 months, infants discriminate between intended and unintended manual reaches toward an object (Woodward 1999). At a more abstract level, 9-month-old and 12-month-old infants, but not 6-month-old infants are shown to discriminate between objects moving on a computer screen in more or less 'rational' ways relative to each other (Csibra et al 1999; Gergely et al 1994, 1995). In these studies, infants were habituated to a display of a ball gaining momentum, jumping over an obstacle, and approaching another ball. In post-habituation test trials, the obstacle was removed and the first ball either went straight toward the second ball or behaved as if the obstacle were still there. By the age of 9 months, infants dishabituated (ie regained visual attention) to the latter vignette although it was identical to the one they habituated to. In contrast, they did not dishabituate to the other vignette which was novel but irrational in relation to the goal of getting to the other ball.

More recently, Schlottmann and Surian (1999) found that 9-month-old infants do demonstrate a sensitivity to causation at a distance in a computer-animated display. Infants were habituated to a red square moving toward a green square. In one condition, the green square moved after the red square stopped (pause event). In another condition, the green square started moving while the red square was still approaching (reaction event). Once habituated to either event, infants were tested with the habituation vignette played in reverse. This test inverted the causal role of the squares while equating spatiotemporal changes across conditions. Schlottmann and Surian reported that infants did dishabituate to a causal role reversal in the reaction event but not in the pause-event condition. They concluded that infants by this age demonstrate sensitivity to causation at a distance, typical of social exchanges.

Altogether, these data obtained in the context of computerized displays fit nicely with the abundant literature documenting what is sometime coined as the '9 month revolution' or the '9 month miracle' in social cognitive development. It is at around this age that infants start actively to engage in triadic exchanges with other people and objects, developing secondary intersubjectivity (Trevarthen 1979) and an understanding of people as intentional agents with particular attentional foci (Tomasello 1995). It is by their first birthday that infants start engaging in joint attention episodes, manifest first production and understanding of gestural communication such as pointing and gaze following (Bates et al 1979; Carpenter et al 1998), and begin to demonstrate social referencing that cannot be accountable by mere emotional contagion (Striano and Rochat 1999, 2000).

The production and comprehension of intentional action in social context emerging by the end of the first year is a landmark progress. It leads infants toward symbolic functioning and language acquisition typically taking place by the second year. First-word acquisition is sometimes linked to the children's capacity to detect intentional action toward named objects by an adult partner (Baldwin 1993; Tomasello and Akhtar 1995; Tomasello and Barton 1994).

If the discrimination between intentional and random or accidental action appears to emerge at around 9 months of age, the nature of such discrimination and what might precede and announce its emergence in early ontogeny is yet unclear. For example, questions remain whether such discrimination is merely perceptual or, on the contrary, based on more elaborated categorical and conceptual inferences.

Recently, Rochat et al (1997) tested 3–6-month-old infants for their visual preference for two different dynamic displays presented on two side-by-side computer monitors. Each display consisted of a pair of colored discs moving either independently or in systematic interaction, one chasing the other but never actually contacting one another (action at a distance). Except for the relative spatiotemporal dependence of the movements of the discs, all dynamic parameters on the two displays were controlled and maintained equal. We found that adults as well as infants looked differentially at the displays. However, patterns of preference varied with age. Adults, as well as most of the older infants, demonstrated enhanced visual attention to the display of independent rather than chase movements of the discs (Rochat et al 1997). We concluded that from at least 3 months of age, infants develop a sensitivity to movement information specifying social causality. However, it is not yet clear when infants might start to use this information as a basis for higher-order inferences about plans and intentions attached to such abstract dynamic displays, a proclivity clearly demonstrated by adults (Dittrich and Lea 1994; Heider and Simmel 1944; Michotte 1963).

Our present research is a follow up to Rochat et al's (1997) findings. It was specifically designed to address the question of when infants start to infer social causality in abstract dynamic displays, beyond the mere perceptual (surface) discrimination they demonstrate from at least 3 months of age. In other words, the question guiding the research is when do infants start to show reliable signs of inference regarding social causality and intentional roles (ie who is doing what to whom) among abstract protagonists interacting at a distance on a computer display.

We used an habituation paradigm, presenting infants repeatedly with a vignette involving a blue disc and a red disc constantly moving on a screen, never actually in contact with each other. In the first experiment, 3–9-month-old infants were habituated with the display of either the red disc or the blue disc chasing the other. Once habituated, infants were presented with a test trial in which there was a role reversal: the chaser became the chasee, and vice versa. The rationale was that, if infants dishabituated to the role reversal (ie looked longer than in the last habituation trials), they inferred in the computer vignette who was doing what to whom and hence understood the display as depicting abstract entities animated by particular motives or intentions (ie either to get at the other, or escape from the other). The second experiment was designed to test a possible leaner interpretation, controlling for surface information (ie specific movement dynamics or vitality of each individual disc) as a possible basis for dishabituation in the first experiment.

There were three basic working hypotheses guiding the research, each corresponding to a particular experiment. The first was that by the age of 8–10 months infants do start to infer intentional roles in abstract computer displays, inferring who is doing what to whom. By this age, infants start understanding in addition to perceiving social causality (experiment 1). The second hypothesis was that by the age of 8–10 months, what is detected in the computer animation is not only the respective vitality of each protagonist, but actually their respective relational roles as social agent and patient (experiment 2).

2 Experiment 1

On the basis of an habituation paradigm, this first experiment investigated when in early development infants begin to manifest a sense of social causality in animated displays. Infants were habituated with the computer display of one disc chasing another without any actual contact; the chased disc accelerated away from the other as it got close (panic distance: see technique below). The discs were identical except for their color (red versus blue). One habituated, infants were presented with a test trial in which there was a role reversal: the chaser becoming the chasee, and vice versa. Again, the rationale was that, if infants dishabituated to the role-reversal test trial (ie looked longer than in the last habituation trials), this would suggest that they might infer who is doing what to whom, hence presumably attributed specific intentions or motives to each of the animated protagonists in the vignette. Support for this rich interpretation was tested in the first experiment. An alternative 'leaner' interpretation was tested in the second experiment.

2.1 *Method*

2.1.1 *Participants.* Fifty-one healthy, full-term infants were tested and included in the final sample. Their age ranged between 3 and 10 months; they were divided into three age groups spanning approximately 2 months of chronological age: fifteen 3–5-month-olds (range = 90–161 days, mean = 120.13 days; eight males and seven females), sixteen 5–7-month-olds (range = 173–229 days, mean = 184.81 days; eleven males and five females), twenty 8–10-month-olds (range = 240–300 days, mean = 274.60 days; ten males and ten females). Nineteen additional infants were tested but not included in the final sample, nine for technical errors, two for fussiness, and eight for no evidence of habituation. Infants who failed to habituate before the 14th trial habituation phase was complete were not included in the final sample (see procedure for habituation-criterion calculation). The infants were recruited from a participant pool consisting of over five-hundred infants born at the Northside Maternity hospital of Atlanta, GA. Races were representative of the Northeastern Greater Atlanta population, predominantly of Caucasian middle class.

2.1.2 *Apparatus and setup.* Each participant was seated on his/her parent's lap on a chair facing a computerized, dynamic event on a 25-inch computer monitor of an Apple II Macintosh, located on a wooden stage surrounded by a background of black felt, approximately 1.5 m in front of the infant. The parents wore opaque sunglasses and were requested to remain still to ensure that they did not bias their infants' visual attention in any way. The ambient lights were dimmed to capture the infant's attention toward the computer monitor and to avoid other visual distractions. Above the computer monitor, through a small hole in the black background material, a small CCTV camera (Panasonic black-and-white CCTV HWV-BL294) provided a view of the infant's face watching the computer monitor. Two experimenters were required for each testing session. One experimenter stood behind the computer display, out of the infant's view, behind the black background, and viewed the infant's face on-line on a small TV monitor, as picked up by the CCTV camera. This experimenter recorded on-line the infant looking at the computer monitor by pressing on a key from a keyboard connected to another Apple II computer, releasing the key when the infant looked away. This experimenter also operated the rising and lowering of a screen made of a light opaque (white) foam-core board covering the computer screen that faced the infant. The recording of the infant's gazing behavior was fed into an habituation program [HABIT 6.70, University of Texas at Austin (UTA), copyright 1996, compliment of Professor Leslie Cohen]. The second experimenter sat quietly, approximately 2 m behind the infant and his/her parent, on the floor of the experimental room. Her task was to control the display presented to the infant.

2.1.3 *Stimuli.* Each infant was presented with a computerized dynamic event on the computer monitor placed in front of him/her. Figure 1 presents a split video image of an infant attending to the computerized animation. This event consisted of a pair of discs, one chasing the other, never actually making contact with each other. The presentation of this dynamic event was continuous throughout each trial which lasted as

Figure 1. Split video image illustrating an infant seated on her mother's lap and attending to the computerized animation of the two discs, one chasing the other.

long as the infant looked at the display, for at least 2 s and up to a maximum of 30 s (see details of the infant-controlled-habituation procedure below). The chase scenario consisted of continuous sequences of one disc (the chaser) approaching the other, and the other disc (chasee) accelerating away when a pre-established 'panic' distance was reached. The discs were of equal size and shape (circles 45 pixels in diameter), but had different colors: one was solid red, and the other solid blue. The discs moved on nonlinear paths all around a white background screen. Once again, they never came into contact with each other.

The events were generated on-line by a computer program, therefore not prerecorded and replayed. The program determined the starting position of each disc on the computer screen (not displayed to infants) and the exact parameters of their respective movements based on a random-number generator running on the computer's clock.

In more specific terms, in the repeated continuous chase sequences that the infants viewed throughout the habituation and test phase of the experimental session, the discs were spatiotemporally related to one another. The chaser (blue or red) was programmed to move constantly closer (reduce its absolute distance) to the chasee without following its path ('heat-seeking' rather than 'path-following'). During the distance-closing portion of the 7 s sequence, the chaser moved at a constant velocity of 80 pixels s^{-1}, and the chasee had a velocity of 60 pixels s^{-1}. 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 s^{-1} until it reached the predetermined 'relax' distance of 225 pixels from the chaser. When this relax distance was reached, the chasee resumed its 60 pixels s^{-1} velocity until the preset 'panic' distance was once again reached by the chaser. The sequence was repeated seamlessly 8 (+1 or −1) times per minute.

2.1.4 *Procedure and design.* An infant-controlled-habituation/dishabituation paradigm was used. A complete design for an individual infant participant consisted of an habituation phase of no more than 14 trial presentations followed by a test presentation of a new dynamic event (ie role reversal). During the habituation phase, half of the infants of each age group saw the red disc chasing the blue disc, and vice versa for the other half. Infants saw two types of displays during the entire session. The computer running the habituation (Habit) program computed and signaled to the experimenters when the sum of looking in a habituation trial was less than 50% of the mean looking duration of the first 3 trial presentations. This calculation determined the habituation criterion for each infant, based on the recording of infant looking in the course of each trial presentation. There was a minimum of 4 and a maximum of 14 habituation trials in the Habit program. Infants had to reach the habituation criterion within 14 trial presentations in order to be included in the study. Each trial presentation started with the lowering of the screen covering the computer monitor and ended with the screen raised to occlude the monitor. The Habit program signaled the end of a trial with a sound. A trial was preset to start with a minimum of 2 s continuous looking at the monitor by the infant, from the time the screen was lowered. It ended with the infant looking away from the monitor for 2 s or more. Once the computer signaled the end of a trial, the screen was raised to occlude the monitor. Intertrial interval with the screen raised was approximately 10 s. Reliability of the experimenter's on-line coding of infant looking was assessed by comparing this coding with that of another independent observer coding from video records. On the basis of the complete session of five randomly selected infants, Pearson r correlation between the two observers was 0.92.

In order to control for spontaneous recovery of attention during habituation (Bertenthal et al 1983), for half of the infants of each age group (lag group), 2 additional habituation trials were added before test-trial presentation. The test-trial presentation consisted of an identical dynamic chase event but with chaser – chasee role reversal. If, for example, during habituation the red disc was the chaser and the blue disc the chasee, the colors were inverted for the test trial: blue disc was the chaser and red disc was the chasee.

Time between the last habituation trial and the test was identical to the intertrial time during habituation (10 s). During all intertrial pauses, noise of computer typing and other required operations of the apparatus were maintained constant. Fake keying of the computer keyboard was produced in between habituation trials, mimicking the keying required by the test-trial change once habituation criterion was reached.

2.2 *Results*

On average, infants reached the habituation criterion in 8.68 trials (SD = 3.25). The means were, respectively, 10.6 (SD = 2.28) for the group of 3 – 5-month-olds, 8.9 (SD = 2.28) for the group of 5 – 7-month-olds, and 7.05 (SD = 2.28) for the 8 – 10-month-olds. A one-way ANOVA on the mean number of habituation trials with age as the between-subjects factor revealed a significant main effect of age ($F_{1,50} = 6.23$, $p < 0.004$). A posteriori Tukey tests indicated that the 3 – 5-month-olds took reliably more trials to habituate compared with the 8 – 10-month-olds ($p < 0.05$). An analogous age effect was found, regarding the average cumulative looking duration at the monitor, during habituation. The overall average cumulative looking was 73.57 s (SD = 53.04 s). The means per age were, respectively 101.74 s (SD = 72.5 s) for the group of 3 – 5-month-olds, 71.58 s (SD = 41.90 s) for the group of 5 – 7-month-olds, and 54.05 s (SD = 33.42 s) for the 8 – 10-month-olds. ANOVA yielded a significant age effect ($F_{1,50} = 3.88$, $p < 0.027$) with a posteriori Tukey tests indicating that the cumulative looking of 3 – 5-month-olds was significantly greater than that of the 8 – 10-month-olds ($p < 0.05$). In all, as a function of the three age groups, there was a marked decrease in the number of required trials and the overall looking duration for infants to reach the habituation criterion.

Results were computed as the ratio of looking duration toward the computer display during the test-trial presentation divided by the average looking duration toward the computer display during the last 3 habituation trials (T-ratio). A ratio of 1 or less indicated no dishabituation with either equal or more looking during the last habituation trials, than during the new (role-reversal) test trial. A ratio greater than 1 indicated dishabituation, with the infant looking longer at the display during test than during the last habituation trials.

With T-ratios of dishabituation as the dependent measure, one-way analysis of variance yielded no significant difference between lag and no-lag groups of infants. In further age comparison, we therefore collapsed the lag versus no-lag presentation variable. A one-way analysis of variance (ANOVA), with age as a variable, yielded a close-to-significant main effect ($F_{2,48} = 3.115$, $p < 0.053$). A posteriori Tukey tests revealed that T-ratios of the oldest group of infants tended to be significantly greater than those of the youngest group ($p < 0.05$). Although marginal, this age main effect is reinforced by both correlational and nonparametric statistics.

As shown in figure 2, when ordering all fifty-one tested infants according to age in days, the T-ratio tended to increase linearly above values of 1. Pearson r correlation coefficient was 0.41 ($p < 0.05$). As a function of age, infants tended to demonstrate increased dishabituation during test-trial presentations.

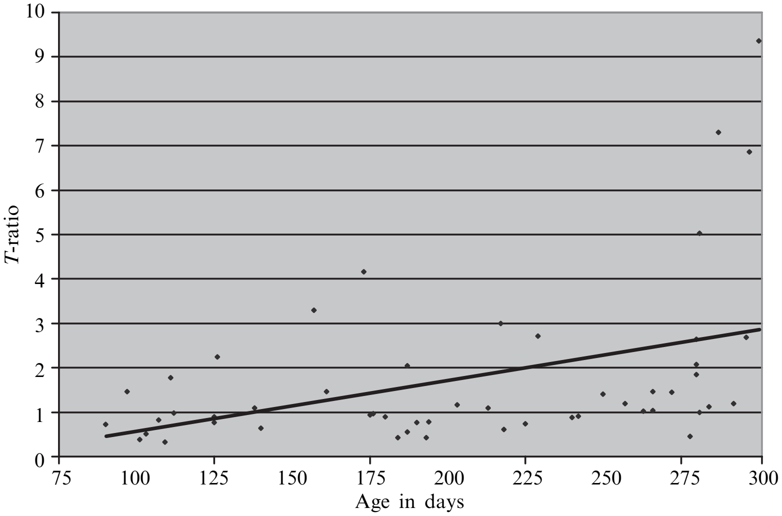

Figure 2. Scatter plot of the T-ratio scores as a function of age in days. T-ratios above 1 indicated that the infant looked proportionally more at the role-reversal test trial compared with the average of the last 3 habituation trials.

Nonparametric statistics (χ^2) computing the number of infants that showed greater looking at the display during test trial, namely T-ratios greater than 1, yielded an overall test effect, $\chi^2_{2,51} = 8.39$, $p < 0.015$. Overall, the proportion of infants with T-ratios greater than 1 from the two younger age groups were, respectively 6 out of 15, and 6 out of 16. In contrast, 17 out of the 20 older infants (85%) had a T-ratio greater than 1. The same analysis comparing the results between the three age groups yielded no significant difference between the two youngest groups (3–5-month-olds against 5–7-month-olds, $p < 0.80$). However, significant differences were found between 3–5-month-olds and 8–10-month-olds ($\chi^2_{1,35} = 5.87$, $p < 0.015$) as well as between 5–7-month-olds and 8–10-month-olds ($\chi^2_{1,36} = 6.75$, $p < 0.009$). These results support further the developmental trend toward marked signs of dishabituation to role reversal in the chase event by the age of 8–10 months. One-tailed binomial tests on the proportion of infants with a *T*-ratio greater than 1 confirm this trend, yielding a significant result only for the group of older infants (17 out of 20, $p < 0.001$), and not for the two younger groups (respectively, 7 out of 15, and 10 out of 16, ns).

As a further assessment of this trend, we compared the *T*-ratios of the older and younger 8 – 10-month-olds, forming two equal subgroups according to age with approximately equal gender distribution: ten aged 8 months 0 days to 9 months 8 days and ten aged 9 months 10 days to 10 months 0 days. A one-way ANOVA comparing the *T*-ratios between these two subgroups yielded a significant age effect, the *T*-ratio increasing significantly as a function of age ($F_{1,18} = 7.901$, $p < 0.011$). This result provides additional support for the developmental progression described in figure 2, pointing in particular toward an important transition between the ages of 8 and 10 months when infants might begin to show a reliable sense of social causality in animated displays. Note that this developmental trend would not be observed without the four outlier infants that have *T*-ratios greater than 5, all belonging to the oldest age group compared in this study (see figure 2).

2.3 *Discussion*

In general, the developmental pattern of visual attention observed in the present visual habituation/dishabituation test, in terms of the required number of trials to reach criterion and average duration of looking at the display, nicely corroborates what is typically reported in the literature (Colombo 1995). This result confirms that what we observed is not idiosyncratic, but tapping into the normal range of infants' visual-attention responses.

As hypothesized, results indicate that between the ages of 3 and 9 months infants do appear to become increasingly sensitive to subtle changes potentially specifying intentional roles in abstract computer displays. By at least 8 – 10- months of age, infants manifest significant dishabituation to role reversal in the chase event based on an inversion of color identity. This supports the contention that by 8 – 10 months of age infants might indeed start to infer intentional roles in abstract computer displays, inferring who is doing what to whom. By this age, infants appear to pick up and construe social causality, namely reciprocal action at a distance between two abstract entities moving on a screen. However, such strong claims do not yet eliminate leaner interpretation, in particular the interpretation that dishabituation might be accountable by mere perceptual or surface discrimination. In our first experiment, infants who dishabituated might have looked longer (ie dishabituated) during test trials on the basis of previous association between levels of animation or vitality, and each individual color disc. In general, the chasee always demonstrated more vitality moving faster while accelerating away from the chaser; the latter always moved at a slow but steady pace toward the chasee. Chaser and chasee had intrinsic vitality attached to them: calm but steady for the chaser, sporadically agitated and frantic for the chasee. Hence, one possibility is that during habituation trials infants picked up on the color associated with a particular vitality of a disc, and dishabituated to the change of color association during the test. In this case, infants' dishabituation would not index any inference of role reversal per se, but rather discrimination of vitality to color association of each individual disc. Such perceptual or surface learning would not be sufficient to account for social-causality understanding. The second experiment was designed to control for such an alternative interpretation, testing 8 – 10-month-old infants in a condition where a red disc and a blue disc moved *independently* of each other (no chase) on the computer screen, each, however, with specific vitality (calm and steady movements for one, sporadic agitation and acceleration for the other). Infants were tested for a reversal in the association between color and vitality of each individual disc, without any apparent chase linking the movement of one relative to the movement of the other.

The rationale was that, if 8 – 10-month-olds in the first experiment did indeed construe social causality (who is doing what to whom) in the animated computer display, not merely a response to surface changes, then infants of the same age in the second experiment should not show any signs of dishabituation.

3 Experiment 2

Another group of 8 – 10-month-old infants was tested with the same habituation paradigm and procedure as in experiment 1, except that the dynamic event consisted of an independent, rather than a chase, event. In the independent event, the blue discs and red discs on the screen did not interact with each other (ie one approaching and the other accelerating away when getting too close and reaching the 'panic' distance). Rather, they moved independently of each other while maintaining the vitality or specific movement dynamics specifying chaser and chasee in the case of a chase event. In other words, in the independent event, both discs behaved as either chaser or chasee but without chasing each other. They somehow shadow-chased and shadow-escaped simultaneously on the screen.

3.1 *Method*

3.1.1 *Participants.* Fourteen healthy full-term infants, eleven male and three females, were tested and included in the final sample of this study and compared with age-matched infants of the previous study. Only one 8 – 10-month-old group of infants was tested (range = 233 – 336 days, mean = 289.57 days, on average 15 days older than the 8 – 10-month-olds of the first experiment, hence closer in age to the older infants of this age group). The infants were recruited from a participant pool consisting of over five-hundred infants born in the various maternity hospitals of the Greater Atlanta, GA area. Four additional infants were tested but not included in the final sample, one due to a technical error, two for fussiness, and one for failure to reach the habituation criterion.

3.1.2 *Apparatus and setup.* The apparatus, setup, and recording technique were the same as for experiment 1.

3.1.3 *Stimuli.* As in experiment 1, the blue disc and red disc were of equal size (45 pixels in diameter), moved on nonlinear paths around a white background screen, and never came into contact with one another. The events were generated on-line by the same computer program, with the same parameters as those in experiment 1 determining chaser and chasee's behavior, except that the movements of the discs were unrelated (randomly generated or nondeterministic). One of the discs moved at a constant velocity of 110 pixels s^{-1} while the other moved at a velocity of 45 pixels s^{-1} with sudden, spontaneous (probabilistic) acceleration to 400 pixels s^{-1}. The acceleration event occurred 8 (+1 or −1) times per minute and lasted between 2 and 3 s, as in experiment 1, before it resumed its 45 pixels s^{-1} velocity. In other words, all the behavioral parameters of the discs were identical to those of experiment 1, except that they occurred independently and were not codetermined as in the chase event. There were no preset panic or relax distances governing one of the discs' behavior, nor was there any systematic tracking of one disc by the other. The only preset relational constraint between the discs was the maintenance of a minimum distance of 60 pixels between them while evolving on the screen.

Systematic measurements of average distance between the discs, the number of accelerations per minute, and the surface covered by each disc on the screen over a 1 min period in either the chase event of experiment 1 or the independent event of this experiment revealed no significant differences. The number of accelerations was assessed by having independent observers counting their occurrences over a 3 min period.

Distance and spatial measurements were performed on photographic printouts (Sony UP-860) of frozen video frames taken at 5 s intervals over a 3 min period when chase or independent events were running with the preset parameters (for similar analyses, see also Rochat et al 1997).

3.1.4 *Procedure and design.* As in the previous study, an infant-controlled-habituation procedure was used. Once they reached the habituation criterion (see section 2.1), half of the infants (lag group) had 2 additional habituation trials to control for eventual spontaneous recovery of visual attention. For the test, infants were presented with a color inversion of the discs, the color corresponding to the particular behavior of each disc being suddenly switched. Once again, a screen was lowered and raised to cover the monitor in between trials (approximately 10 s intertrial intervals). As in experiment 1, reliability of the experimenter's on-line coding of infant looking was assessed by comparing this coding with that of another independent observer coding from video records. On the basis of the complete session of five randomly selected infants, Pearson r correlation between the two observers was 0.96.

3.2 *Results*

On average, infants reached the habituation criterion in 9.07 trials (SD = 3.65). The average cumulative looking duration at the monitor during habituation was 64.56 s (SD = 42.32 s).

We first compared the average looking time at the monitor during the last 3 habituation trials with the looking time during the subsequent test trial where the color of each disc was reversed. A 2 (group: lag versus no-lag group) × 2 (trial: habituation versus test) mixed-design ANOVA yielded no significant main effect of group ($F_{1,12} = 3.05$, $p < 0.11$) or trial ($F_{1,12} = 0.85$, $p < 0.37$), nor any significant interaction of group by trial ($F_{1,12} = 0.611$, $p < 0.45$).

To further assess these results and to compare them with the results obtained with same-age infants of experiment 1, we computed the T-ratio of dishabituation for each individual infant (ie looking duration toward the computer display during the test-trial presentation divided by the average looking duration toward the computer display during the last 3 habituation trials). A ratio of 1 or less indicated no dishabituation, the infant looking either equally or more during the last habituation trials than during the new (role reversal) test trial. A ratio greater than 1 indicated a dishabituation, the infant looking longer at the display during test than during the last habituation trials. Figure 3 shows that the average T-ratio for the 8 – 10-month-olds of experiment 1 tested with a chase event is markedly greater than the average T-ratio of the 8 – 10-month-olds tested in this experiment with an independent event sharing the same vitality or movement-dynamic parameters.

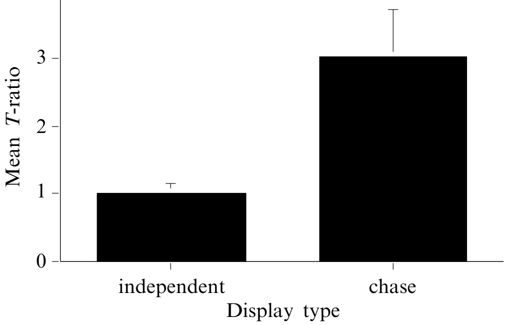

Figure 3. Mean T-ratio of dishabituation and standard errors for the same age groups (8 – 10 month-olds) tested with an independent display (experiment 2) and a chase display (experiment 1).

T-ratios were used as a dependent measure and confirmed the trend depicted by figure 3; a 2 (event: chase versus independent) × 2 (lag or no-lag habituation trials) between-subjects design analysis of variance (ANOVA) yielded a significant event effect only ($F_{1,26} = 7.75$, $p < 0.009$).

3.3 *Discussion*

The negative results found in this second experiment and their significant contrast with the results obtained with same-age infants in experiment 1 indicate that by the age of 10 months infants do not seem to be sensitive to the mere association between a particular color and a particular vitality or movement dynamics (ie calm by moving at constant velocity, versus agitated by moving with sporadic, sudden acceleration and nervous turns).

Pitted against the positive dishabituation results of experiment 1, it appears that it is not the particular vitality of each disc treated separately that is picked up by the infant, but rather information regarding how the vitality of one disc relates to the other. The movement of one disc *in relation* to the other is the foundation of the sensitivity of 8 – 10-month-olds to color reversal and potentially the index of their sense of social causality.

As hypothesized, our results support the idea that what 8 – 10-month-olds detect in the computer animation is not the respective vitality of each individual protagonist tagged by particular colors that are switched during test trials. Their dishabituation appears to be based on the detection of a change in the relational dynamics of the discs, this dynamics specifying social causality and who is doing what to whom on the display (ie chase interaction between two protagonists). The negative results of experiment 2, which eliminated any relational dynamics between the discs, support the idea that 8 – 10-month-olds' significant dishabituation in experiment 1 is based on the attribution of roles to the animated discs, each perceived as agent and patient of a reciprocal exchange *at a distance* specifying social causality.

4 General discussion

The general aim of our research was to investigate the developmental origins of the powerful phenomenon by which adult perceivers are compelled to infer social causality in abstract dynamic displays (Basili 1976; Dittrich and Lea 1994; Heider and Simmel 1944; Michotte 1963).

This study is an important follow-up to previous investigations. Rochat et al (1997) used a preferential-looking paradigm to report that by the age of 3 months infants already demonstrate an ability to discriminate between the movements of two discs on a screen, either in independence of each other, like fish in a bowl, or in dependence of each other, one disc chasing the other. Because all the dynamic parameters of the discs on either monitor were carefully controlled, making the independent and the chase displays comparable at a basic perceptual level, preference for either display corresponded to a discrimination of the relational dynamics (ie movements of one disc in relation to the other) specifying either a chase or its absence. Rochat et al demonstrated that from the age of 3 months infants express reliable discrimination, not looking randomly at either display. This previous research showed that very early on infants appear to pick up dynamic, relational information that adults use to infer social meaning and intentions in abstract displays, inferring for example who is doing what to whom (eg Heider and Simmel 1944).

Although these previous findings point to an early perceptual discrimination of relational action-at-a-distance between abstract entities, they did not provide any evidence of infants' putative construal of social causality and *aboutness* of the discs on the screen.

Based on the habituation and role-reversal dishabituation test, experiment 1 provides strong evidence that it is by the age of 8–10 months that infants begin to manifest a sense of social causality and show signs of construing who is doing what to whom in animated displays. Our results suggest that it is at around the age of 8–10 months that infants start to show a propensity analogous to what Heider and Simmel (1944), and Michotte (1963) described in the verbal report of adults who saw similar abstract, two-dimensional animated displays.

Once again, experiment 2 was designed to control for a leaner interpretation by which infants who dishabituated to the role reversal between chaser and chasee did so without having to take any putative intentional stance, not necessarily having to infer who is doing what to whom to discriminate the novel display. Accordingly, instances of dishabituation could be accounted for by the detection of surface changes in the association between movement and color of either disc treated as discrete (ie noninteracting) entities. It is indeed feasible that dishabituating infants of experiment 1 could have associated the particular vitality of either disc to their particular color, dishabituating to a mere change of color–vitality association during test. The interpretation would not entail any detection of relational movement between the discs, but rather the detection of a change in the discrete characteristics of the discs (color + particular movement characteristics) perceived in *independence* of each other. No relational information would underlie infants' dishabituation, hence would not correspond to any kind of role-reversal detection.

The second experiment controlled for this alternative account of the significant dishabituation to role reversal manifested by the 8–10-month-olds of experiment 1. Same-age infants did not show any signs of a discrimination in the color change of the discs moving in independence on the screen. Although they had the same opportunity to associate a particular vitality with a particular colored disc, they did not demonstrate any evidence of such association when the discs moved in independence of each other.

These observations support the interpretation that 8–10-month-olds dishabituating to a color change in the chase display are sensitive to relational rather than discrete perceptual information. They appear to detect the dynamics of the interaction *at a distance* between the discs, hence probably identify their respective role as patient and agent in interactive exchanges characterizing social causality. These results confirm and reinforce the recent findings reported by Schlottmann and Surian (1999) on the perception of causation at a distance by 9-month-olds, who used an analogous habituation/dishabituation paradigm but a different set of controls (ie sequence of the causal event played in reverse during test, see section 1). These results also corroborate the findings of Gergely et al (1994, 1995) and Csibra et al (1999) demonstrating that 9-month-olds are capable of making teleological inferences on the basis of abstract entities interacting at a distance on a screen.

In all, the reported findings suggest that the developmental key transition occurring at around the age of 9 months in the realm of social cognition generalizes also in the way infants perceive, construe, and eventually infer social scripts in the relative motion of abstract entities on a computer screen.

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