Research Article

Secret Agents

Inferences About Hidden Causes by 10- and 12-Month-Old Infants

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ABSTRACT—***Considerable evidence indicates that preverbal infants expect that only physical contact can cause an inanimate object to move. However, very few studies have investigated infants' expectations about the source of causal power. In three experiments, we found that (a) 10- and 12-month-old infants expect a human hand, and not an inanimate object, to be the primary cause of an inanimate object's motion; (b) infants' expectations can lead them to infer a hidden causal agent without any direct perceptual evidence; and (c) infants do not infer a hidden causal agent if the moving object was previously shown to be capable of self-generated motion.***

Causal attributions are central to human cognition, underlying representations of concepts and intuitive theories (Carey, 1985; Gopnik et al., 2004; Keil, 1989; Murphy, 2002), supporting prediction of future events, and allowing effective intervention in the service of goals. The capacity for causal attribution emerges early in infancy and is embedded in at least two distinct domains of reasoning, reasoning about inanimate objects for which the cause of motion must include contact (Ball, 1973; Cohen, Amsel, Redford, & Casasola, 1998; Cohen, Rundell, Spellman, & Cashon, 1999; Kosugi & Fujita, 2002; Kotovsky & Baillargeon, 2000; Leslie & Keeble, 1987) and reasoning about intentional agents in terms of their goals (Gergely, Nadasdy, Csibra, & Biro, 1995; Johnson, 2003; Kosugi, Ishida, & Fujita, 2003; Meltzoff & Brooks, 2001; Woodward, 1998; Woodward, Sommerville, & Guajardo, 2001).

Previous studies of infants' understanding of causal interactions have focused on the properties of the patient object (inert or animate) and on the spatiotemporal properties of the interaction. The studies show that infants expect an inert inanimate object to go into motion when and only when contacted by another moving object (Ball, 1973; Cohen et al., 1998; Kosugi et al., 2003; Kotovsky & Baillargeon, 2000; Oakes & Cohen, 1990, 1994; Spelke, Phillips, & Woodward, 1995; Wang, Kaufman, & Baillargeon, 2003), and that these expectations are suspended if the patient object is capable of self-generated motion (Kosugi & Fujita, 2002; Spelke et al., 1995).

Adults, however, have expectations not only about the patient of a causal interaction, and about the interaction itself, but also about the causal agent. By "causal agent," we mean the entity that is the purveyor of causal force, the source of motion or change, in an interaction (Leslie, 1994). Adults both distinguish between the roles of causal agent and patient in a visible interaction (e.g., one billiard ball hitting another) and expect a primary causal agent, usually an animate or intentional agent (e.g., the person holding the cue). The necessity of a primary cause can lead adults to infer the presence of a hidden causal agent, if none is visible. Imagine, for example, seeing a tennis ball or a shoe come flying over the backyard fence.

Some evidence suggests that infants distinguish between the roles of causal agent and patient in simple, fully visible interactions by 7 to 10 months of age (Leslie, 1984; Leslie & Keeble, 1987; Oakes & Cohen, 1994). However, no previous studies have examined whether infants infer the presence of an agent from motion of an object they have categorized as inert. The present studies fill that gap. In these studies, we explored the following questions: Seeing only the motion of an inert object, do infants infer that something must have caused that motion (the causal agent)? Do infants have expectations about the potential causal agent? In particular, do they consider a person more likely to be a causal agent than an inanimate object?

EXPERIMENT 1

In Experiment 1, infants were habituated to a live-action event in which a beanbag was thrown over a wall and onto a stage (see

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Fig. 1a), a real-life rendering of the animation in Experiment 2 of Csibra, Gergely, Koos, and Brockbank (1999). The beginning of the event was hidden; the beanbag emerged already in motion. Although only the beanbag is visible in this event, adults perceive the beanbag as "being thrown" by a person located beyond the wall. We asked whether infants, too, would infer that an agent had thrown the beanbag. If so, the infants might expect to see a human hand on the side of origin of the beanbag, and not on the opposite side (see Figs. 1b and 1c). Previous results suggest that infants attribute to hands both causal force and goal-directed action (Leslie, 1984; Woodward, 1998; Woodward et al., 2001).

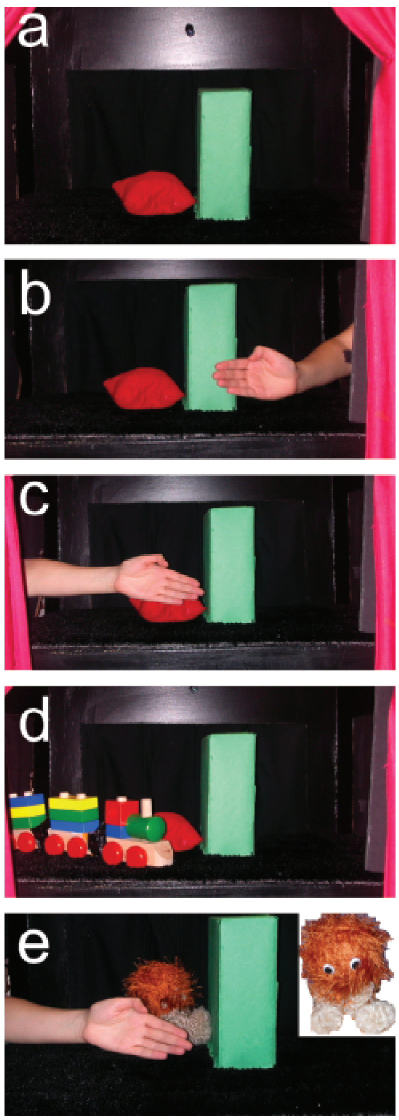

Fig. 1. Photographs of the experimental setup: the final configuration of (a) a habituation trial in which the beanbag emerged from off-stage right (Experiments 1 and 3), (b) a same-side test trial in the hand condition (Experiments 1 and 3; the hand emerged after the beanbag had landed), (c) a different-side test trial in the hand condition (Experiments 1 and 3), (d) a different-side test trial in the train condition (Experiment 1), and (e) a different-side test trial in the puppet condition (Experiment 2; the puppet is also shown in the inset).

To ensure that any differences in results between the same-side and different-side trials reflected an expectation that an agent was the cause of the beanbag's motion (and not, for instance, an expectation that all moving object came from the same side of the stage), we also included a control condition in which the hand in the test trials was replaced by a nonagent (a train; see Fig. 1d). We predicted that infants' looking time would not vary with the side of the stage on which the train appeared.

Method

Forty 12-month-old infants (23 male and 17 female; mean age = 12 months 1 day, range = 11 months 14 days through 12 months 22 days) participated in the study. An additional 2 infants were excluded because of fussiness ($n = 1$) and parental interference ($n = 1$). Half the infants were assigned to the experimental group (hand test trials), and the other half constituted the control group (train test trials).

In order to provide unambiguous evidence that the moving object was inanimate, we familiarized each infant with a bright red beanbag (5 in. × 5 in.) outside the experimental room before the experiment began. The experimenter played with the beanbag in front of the infant and then gave the beanbag to the infant.

All events were created live on a black stage (17 in. × 34 in.) 2 ft in front of the infant. The stage was covered by a red curtain that could be opened to reveal the stage. The infant was placed in a high chair in a darkened experimental room, facing the stage. The child's mother sat next to the high chair, facing him or her. The child's looking at the stage was recorded by a camera and fed to an on-line coding monitor in a different room; the coder was blind to the experimental condition. Trial endings, determined by a 2-s look-away criterion, were signaled by a computer beep. A second camera recorded the events on the stage so that the tape could be reviewed for experimental error and when recoding was necessary. The test trials for 55% of the subjects were recoded by a second coder off-line. Intercoder reliability was 96%.

The habituation events were identical for the experimental and control groups. Each trial began when the curtain opened, revealing a low wall, 4 in. wide, running the depth of the stage. On the first trial of habituation, the wall was green and 10 in. high. Subsequent trials used either that green wall, a yellow wall that was 7 in. tall, or a pink wall that was 4 in. tall (following the animation of Csibra et al., 1999). If necessary, an experimenter drew the infant's attention by knocking on the center of the back wall of the stage. Once the infant was looking at the display, the experimenter threw the red beanbag over the wall and onto the center of the stage, from off-stage left or right (Fig. 1a). The side of origin of the beanbag was kept constant for each infant, but was counterbalanced across infants. The infant's looking time was recorded from the moment the beanbag landed. Habituation trials continued until the infant habituated (i.e., the total looking time for 3 consecutive trials was less than half the total looking time for the first 3 trials), or for a maximum of 10 trials.

The edge of the curtain and a black screen occluded the hand, and the experimenter who controlled the beanbag wore a black glove, to ensure that the infant could not see the hand throwing the beanbag. Scrutiny of the videotapes confirmed that the hand was not visible. To minimize other evidence of an agent behind the stage, the experimenters reached the control area for the stage via an entrance behind the infant; the experimenters' bodies were entirely occluded, and the experimenters did not speak during the experiment.

Test trials began with the same event as the habituation trials, but always used the tallest (green) wall. In the experimental condition, after the beanbag landed, a human arm entered the stage from one side and stopped with the hand in the center of the stage, palm facing the infant and thumb up. Each infant saw four test trials. On alternating test trials, the arm came either from the side of origin of the beanbag (same-side trials) or from the opposite side of the stage (different-side trials; Figs. 1b and 1c). For half the infants, the first test trial was a same-side trial; for the other half, the first test trial was a different-side trial. Looking times were measured from the appearance of the hand.

The test trials in the control condition were identical to those in the experimental condition, except that instead of a live human hand, a brightly colored toy train rolled onto the stage after the beanbag landed (Fig. 1d). The side from which the train entered was counterbalanced as in the hand test trials. Looking times were measured from the appearance of the train. The motions of the hand (experimental condition) and the train (control condition) were similar, but were not identical. The train took longer to emerge after the beanbag landed (mean latency = 2.8 s) than did the hand (mean latency = 1.7 s). These differences in the test stimuli were eliminated in a follow-up study (described in Saxe, Tzelnic, & Carey, 2005).

Results and Discussion

Infants looked longer when a human hand emerged from the opposite side of the stage (8.1 s) than when it emerged from the same side as the beanbag (6.1 s; $p < .03$, paired-samples t test; 16/20 infants, $p < .05$, sign test), but there was no difference between same-side (7.6 s) and different-side (7.7 s) trials in the train control condition ($p > .9$, paired-samples t test; 9/20 infants, n.s.; see Fig. 2).

The experimental and control groups did not differ in the number of infants habituated in less than the maximum of 10 trials (9 of 20 in each group), the average number of habituation trials per infant (experimental group: 8.9, control group: 9.1), or the average looking time to the first three (experimental group: 4.7 s, control group: 5.2 s) or last three (experimental group: 3.3 s, control group: 3.9 s) habituation trials.

An analysis of variance (ANOVA) was conducted to test the effects of condition (hand vs. train), order (same-side test trial first vs. different-side test trial first), and trial type (same-side vs. different-side) on looking time during the test trials. The latency from the beanbag landing to the emergence of the test object (hand or train) was calculated for each trial and included in the analysis as a regressor. This analysis revealed the predicted interaction between trial type and condition, $F(1, 35) = 5.52$, $p < .03$. Infants in the hand condition looked longer to the different-side than the same-side test trials, whereas those in the train condition did not. In addition, the ANOVA revealed a main effect of the regressor, the latency of the test object, $F(1, 35) = 4.48$, $p < .05$, and an interaction between trial type and order, $F(1, 35) = 8.8$, $p < .01$: The effect of trial type was more pronounced for infants who saw a different-side test trial first than for infants who saw a same-side trial first. This interaction reflected the fact that all infants dishabituated to the first test trial, on which the novel test object (hand or train) was introduced for the first time (the difference between looking time on the first test trial and average looking time on the last three habituation trials was 7.6 s for the control group and 6.8 s for the experimental group, both ps $< .05$, two-tailed).

These results indicate that 12-month-old infants represent the invisible causal agent of an inanimate patient's motion and consider a person a more likely causal agent than a train. After

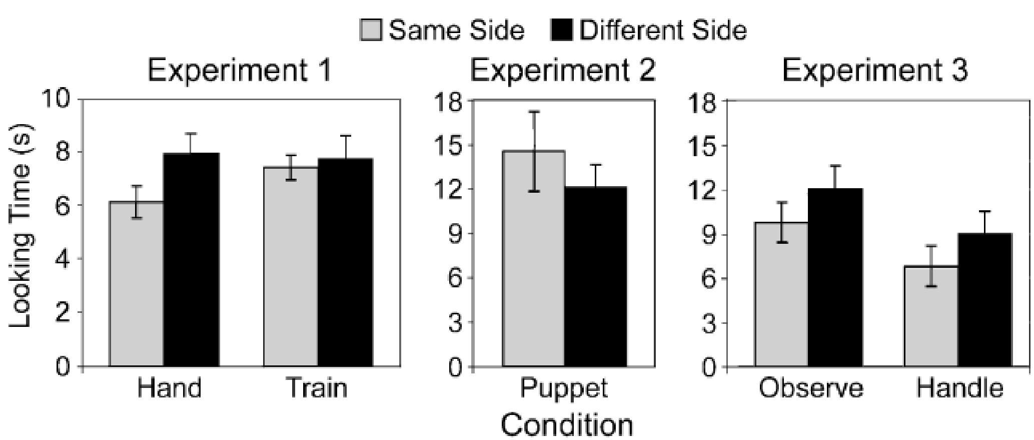

Fig. 2. Looking times on same-side and different-side test trials as a function of condition in Experiments 1, 2, and 3.

a beanbag "flew" onto the stage from one side, infants showed less surprise when a hand suddenly appeared on the stage on that side than when a hand emerged from the other side; looking times were equal for a train that emerged on the same side as the beanbag and a train that emerged from the other side. These results suggest that the infants distinguish between hands and trains as potential causal agents. Furthermore, the interaction between conditions rules out the possibility that infants' looking time in the hand condition was governed by a simple spatial association (e.g., "all moving things come from the left").

This is the first demonstration that infants can infer a causal agent that they have never seen. That is, infants not only inferred the occurrence of an occluded causal interaction, as in previous studies (e.g., Ball, 1973), but also inferred the existence of an unseen entity, the occluded causal agent. In a recent article, Kosugi et al. (2003) claimed to have demonstrated this as well. They habituated 10-month-old infants to a partially screened inanimate patient going into motion when no causal agent was visible, and then showed full events in which a hand (not before seen) either made contact with the patient or did not. The infants recovered interest when no contact was made, but not when there was contact between the hand and the patient. Kosugi et al. thus demonstrated that infants can represent the occurrence of an occluded causal interaction (i.e., contact) even when the causal agent is not visible during habituation. However, unlike the current study, their design did not test whether infants infer the existence and location of the hidden causal agent.

EXPERIMENT 2

Experiment 1 alone cannot establish that infants infer a causal agent to explain the motion of an object specifically because the object is inanimate. That is, if infants understand the hand in this paradigm to be the causal agent of the beanbag's motion over the wall, they should not infer a hand when some other explanation of the motion over the wall is available. We tested this prediction in Experiment 2 by replacing the beanbag with a small self-propelled furry puppet (Fig. 1e), so an external causal agent did not need to be inferred.

Method

Sixteen 12-month-old infants (8 male and 8 female; mean age = 12 months 4days, range = 11 months 8 days through 12 months 17 days) participated.

The experimental setup was identical to that of Experiment 1, except that the beanbag was replaced by a furry brown marionette (3.5 in. × 3.5 in. × 5 in.) with two legs and googly eyes (Fig. 1e). The puppet hung from black threads that were invisible against the black background and was controlled by the experimenter from above. Also, because of the constraints of the stage, the puppet always emerged from the infant's left. Infants were familiarized with the puppet when they were already in the experimental room: For 20 s, before the habituation trials, the puppet jumped slowly across the bare stage. All other parameters of the experiment remained the same as for the experimental group in Experiment 1.

Results and Discussion

Unlike infants in the hand condition of Experiment 1, infants in Experiment 2 did not look longer when the hand emerged from the side opposite the puppet (M = 12.1 s) than when the hand emerged from the same side (M = 14.5 s; $p > .3$, paired samples t test; 7 of 16 infants looked longer at different-side than at same-side trials, n.s.; see Fig. 2).

Fourteen of the 16 infants habituated in less than 10 trials; the average number of habituation trials per infant was 7.8. The average looking time was 9.8 s on the first three habituation trials and 5.15 s on the last three.

A three-way ANOVA examined the effects of trial type (same-side vs. different-side), experiment (Experiment 2 vs. hand condition of Experiment 1), and order (different-side trial first vs. same-side trial first) on looking times during the test trials. This ANOVA revealed the predicted interaction between trial type and experiment, $F(1, 32) = 3.547$, $p < .05$, one-tailed. There was also a main effect of experiment: Infants looked longer overall at a hand in the puppet condition (M = 13.3 s) than at a hand in the beanbag condition (M = 7.1 s), $F(1, 32) = 11.994$, $p < .005$. Post hoc analysis revealed that the recovery from habituation induced by the appearance of the hand on the very first test trial (regardless of the side) was significantly larger in the puppet condition (mean difference between the first test trial and the average of the last three habituation trials = 11.8 s) than in the beanbag condition (mean difference = 6.8 s; $p < .05$, one-tailed, independent-samples t test).

The results of Experiment 2 confirm that infants expect a hand as the source of motion of an inanimate object, but not an animate object. The infants did not infer an external causal agent to explain the motion of a self-propelled puppet. When they were habituated to the puppet flying over the wall, the infants' attention was not attracted selectively by a hand on the opposite side; rather, the infants looked longer at the hand in the context of the beanbag than in the context of the puppet, a finding that is consistent with our interpretation that the infants anticipated the presence of a causal agent when watching the motion of an inanimate patient—the beanbag—but not when watching the motion of a self-propelled puppet.

EXPERIMENT 3

Experiment 3 examined whether younger infants, 10-month-olds, would infer the presence of a person from the motion of the beanbag, and also explored a possible source of that inference. In Experiment 1, the infants were allowed to handle the beanbag before the experiment. We did this to ensure that they represented the beanbag as inanimate, but it may have established an association between the beanbag and hands. Therefore, in Experiment 3, we included a second group of infants who were familiarized with the beanbag only visually, just as the infants in Experiment 2 were familiarized with the puppet only visually.

Method

Forty 10-month-old infants (21 male and 19 female; mean age = 10 months 1 day, range = 9 months 14 days through 10 months 19 days) participated in the study. An additional 5 were excluded because of fussiness. Half of the 10-month-olds played with and handled the beanbag before the experiment (the *handle* familiarization condition), and half were allowed only to look at it (the *observe* condition).

The stimuli were identical to those of Experiment 1, and the handling procedure was identical to the familiarization procedure in the experimental condition of Experiment 1. In the observe condition, the infants were first brought into the testing room and placed in the high chair facing the stage. The curtains were opened, revealing the beanbag stationary on the stage floor. The beanbag remained visible and inert for 20 s, after which the curtains were lowered and the experimental session began.

Results and Discussion

Overall, the 10-month-olds looked longer at the hand on the opposite side of the stage ($M = 10.5$ s) than at the hand on the same side ($M = 8.4$ s; $p < .02$, paired-samples t test). This main effect of trial type was confirmed in an ANOVA, $F(1, 32) = 7.98$, $p < .01$, which also revealed an interaction between trial type and order, $F(1, 32) = 7.72$, $p < .01$, as in Experiment 1. Critically, there were no main effects or interactions involving familiarization condition (Fig. 2).

The only consequence of the familiarization manipulation was in habituation. Infants in the observe condition were more likely to habituate (14 of 20 infants) than were infants in the handle condition (7 of 20 infants) and saw fewer habituation trials on average (observe: 8.3 trials; handle: 9.3 trials), presumably because the beanbag was more familiar following the direct contact and so initial looking times were low in that condition. The infants in the handle condition looked less on the first three habituation trials (5.3 s) than did those in the observe condition (6.2 s; $p < .06$, independent-samples t test), but the two groups did not differ on the last three trials (handle: 3.8 s, observe: 4.0 s; n.s.).

Ten-month-olds, like 12-month-olds, expected a human hand on the side of origin of the beanbag and not on the other side of the stage. Also, the success in the observe condition shows that the longer looking times in the different-side test trials (relative to the same-side trials) in Experiment 1 were not due to an association between hands and the beanbag learned during the experimental session; rather, the longer times were due to the categorization of the beanbag as inanimate. The inference of a causal agent in this paradigm depended on the infants' knowledge about causation of the motion of inanimate objects.

GENERAL DISCUSSION

We found that 10- and 12-month-old infants expected a human hand on the side of the stage from which an inanimate object emerged in motion. Infants did not show the same side preference when a toy train rather than a hand appeared, or when the moving object was a puppet capable of self-motion. The same pattern of results was observed in follow-up studies in which the differences in the motion of the hand and train test stimuli were eliminated (Saxe et al., 2005). These results establish that infants' expectations in the experimental condition were not based on a simple spatial generalization (e.g., "all moving things emerge from the right").

Rather, infants seem to reason about the invisible causal agent of an inanimate patient's motion. This is the first empirical demonstration that preverbal infants' causal reasoning obeys two of Schultz's (1991, described in White, 1995) rules for perceiving agency and causality: "If an object moves and is an agent, then expect that there is no external cause of this movement" and "If an object moves and that object is a patient, then assume that there is an external cause of this movement" (p. 74). In addition, infants have expectations about what kind of entity qualifies as a plausible "external cause of [an inanimate patient's] movement": A human hand qualifies, but a toy train does not.

These results challenge leading models of how infants perceive and reason about agents in causal interactions. A long research tradition assumes the first stage of causal perception is the perceptual categorization of observed entities (e.g., as intentional agents or inanimate objects) on the basis of static and dynamic cues. Models in this paradigm may explain how infants (and adults) identify and reason about visually salient agents, but cannot explain how infants detect completely unobserved agents, as in our studies. Infants appear to detect intentional agents not only via bottom-up perceptual categorization processes, but also through top-down expectation-driven inferences of the best explanation.

A critical question (which cannot be resolved by the current study) is, what property of a human hand made the hand, but not a toy train, a plausible causal agent for the infants? There are at least three possibilities. First, human hands, but not toy trains, are the right shape and size for grasping and moving a beanbag. Infants may have recognized these mechanical affordances of the human hand. Second, human hands are also very common force generators in infants' experience. Therefore, the infants may have identified human hands as plausible causal agents or purveyors of causal force, in general. Third, by the age of 10 months, infants already expect the actions of human hands to be goal directed; that is, hands are categorized as intentional agents. At an early stage, infants may have a single concept that combines or conflates the notions of causal agent and intentional agent, and therefore may expect any such "agent" as the source of motion of an inanimate object. We are planning further experiments to distinguish among these three hypotheses.

These experiments bear on a recent influential proposal concerning infants' representations of goal-directed actions. According to this "teleological" model (Csibra et al., 1999; Gergely et al., 1995), infants classify events (e.g., as instances of rational action on the basis of properties like equifinality, a common endpoint), rather than categorizing entities. According to Gergely and his colleagues, infants do not make significant ontological distinction between agents (to whom goals can be attributed) and inanimate objects (to which goals cannot be attributed).

In the current study, infants made a distinction between causal agents and inanimate objects. We consider it likely that the infants also used the closely related conceptual distinction between goal-bearing and non-goal-bearing entities in interpreting these events as goal-directed actions. That is, infants may distinguish between animate or intentional entities, to whom goals are assigned, and inanimate objects, to whom goals are not assigned. When a moving object is inanimate, infants, like adults, may attribute to the inferred agent both a goal (e.g., of getting the object over a wall) and the causal power to accomplish that goal. However, further work would be required to establish this interpretation, and more generally to probe the relations between the ontological categories of causal agents and intentional agents.

On the basis of the current results, we speculate that infants possess the equivalent of (a) two distinct ontological categories, inanimate objects and intentional agents; (b) causal laws operative within each ontological category (e.g., agents move spontaneously to achieve their goals; objects move only if caused to move by contact with other moving entities); and (c) inferential principles that follow from these categories and laws and that relate entities across ontological categories—in particular, that in any system there is a primary cause, a causal agent. The idea that infants possess these two categories and laws regarding them is familiar from the previous literature (Kuhlmeier, Wynn, & Bloom, 2003; Spelke, Breilinger, Macomber, & Jacobsen, 1992). The proposal that infants possess inferential principles that relate entities across these categories is consistent not only with infants' performance in the current tasks, but also with widespread, deeply held expectations that persist into adulthood across cultures, informing intuitive theories of phenomena such as illness, the weather, and the origin of the universe (White, 1995).

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