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REPORT

'Core Knowledges': a dissociation between spatiotemporal knowledge and contact-mechanics in a non-human primate?

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Abstract

Human toddlers demonstrate striking failures when searching for hidden objects that interact with other objects, yet successfully locate hidden objects that do not undergo mechanical interactions. This pattern hints at a developmental dissociation between contact-mechanical and spatiotemporal knowledge. Recent studies suggest that adult non-human primates may exhibit a similar dissociation. Here, I provide the first direct test of this dissociation using a search paradigm with adult rhesus monkeys. Subjects watched as a plum rolled behind one of two opaque barriers. In Experiment 1, subjects had to locate the plum based on the position of a wall that blocked the plum's trajectory. Subjects searched incorrectly, apparently neglecting information about the location of the wall. However, subjects searched correctly in Experiments 2–4 when they were given spatiotemporal information about the plum's movement. Results indicate that adult monkeys use spatiotemporal information, but not contact-mechanical information, to locate hidden objects. This dissociation between contact-mechanical and spatiotemporal knowledge is discussed in light of developmental theories of core knowledge and the literature on object-based attention in human adults.

Introduction

One of the most renowned theories in the field of cognitive development is Spelke's Core Knowledge hypothesis (Spelke, Breinlinger, Macomber & Jacobson, 1992). Core Knowledge (CK) posits that human infants are innately endowed with an understanding of physical objects, how they move in space and time and how they interact. To date, developmentalists have amassed a great deal of evidence in support of this theory (Baillargeon, 1995; Leslie, 1994; Spelke, 1994). Much of this evidence utilizes an empirical technique known as the expectancy violation paradigm. In one example, Spelke and colleagues (1992) showed 4-month-old infants a display in which a ball was dropped behind a screen and onto a shelf. Infants then saw one of two test events: either the ball landed on the upper surface of the table, an expected physical outcome, or the ball landed under the table, an unexpected outcome given the constraints of the table. Infants looked longer at the unexpected outcome, suggesting that they understood that the ball could not pass through another solid object. These results along with many others suggest that infants possess a rich understanding of physical objects and the way they interact.

The CK theory has also received support from work with non-human primates (hereafter, primates). If human infants come to this world equipped with an evolved capacity to reason about physical objects, as the CK theory contends, then one would predict that this knowledge should be shared with closely related primate species. This prediction has held up in many studies with primates using similar looking paradigms: primates can track objects that move behind an occluder (Hauser, MacNeilage & Ware, 1996; Uller, Hauser & Carey, 2001), understand that a solid object cannot move through another object (Santos & Hauser, 2002) and recognize that objects cannot move without first being contacted by another object (Hauser, 1998). Adult primates seem to reason about physical objects in much the same way as human infants; in particular, they reason about objects using the principles of CK.

Despite the wealth of evidence for Spelke's CK theory, the theory has not gone unchallenged. To date, CK has been attacked on a number of theoretical (Smith, 1999; Haith, 1998) and methodological grounds (Bogartz,

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Shinskey & Speaker, 1997). However, the most recent challenge to an innate understanding of objects is an empirical one. Recent work suggests that human toddlers fail to appreciate how hidden objects interact with other objects. Hood, Carey and Prasada (2000), for example, presented 2-year-olds with a display like the one used by Spelke *et al.* (1992) and found that they failed to locate a falling toy. Two-year-olds reliably searched under the table for a dropped toy, apparently neglecting that the table should impede the toy's trajectory. Similarly, Berthier, Deblois, Poirier, Novak and Clifton (2000) found that 2-year-olds failed to locate a ball that was rolled along a stage behind a screen and into a barrier (see also Butler, Berthier & Clifton, 2002). These results suggest that 2-year-olds are unable to use the principles of CK to solve search tasks. Recent work suggests that adult primates also fail search tasks. Hauser (2001) presented rhesus monkeys with a task similar to that of Hood and colleagues (2000). Like human toddlers, adult rhesus failed to locate a piece of apple dropped behind an occluder and onto a solid table; they too searched under the table for the apple.

Human toddlers and adult primates nonetheless succeed on some search tasks involving hidden objects (Feigenson, Carey & Hauser, 2002; Hauser, Carey & Hauser, 2000). Feigenson and her colleagues (2002) found that 12-month-old human infants performed well on a task in which different numbers of crackers were added to two boxes. At quantities up to about three, infants not only successfully retrieved hidden crackers, but also reliably chose the box with more crackers. Hauser and colleagues (2000) showed similar successes in an identical task with adult primates.

Why do human toddlers and adult primates perform well on some object search tasks but not others? One possibility is that the types of tasks in which subjects fail tap into different kinds of representations than tasks in which subjects succeed. A closer look at the pattern of successes and failures across different tasks shows that this might be the case. Many of the failures on search paradigms occur in situations where subjects are required to reason about *mechanical interactions* between objects. Hauser's (2001) dropping task, for example, requires rhesus subjects to reason about solidity and support – mechanical interactions between the falling apple and the shelf. Similarly, Berthier *et al.*'s (2000) rolling task requires human toddlers to understand that the wall blocks the trajectory of the ball. Again, this type of understanding requires knowledge of contact-mechanics, the way two physical objects interact. In contrast, the studies where subjects succeed do not involve reasoning about mechanics. Instead, these search experiments require subjects to reason about how objects move in time and space. Feigenson and colleagues' (2002) number task, for example, requires subjects to watch the trajectory of objects as they move behind occluders and understand that these objects continue to exist as bounded entities even while occluded. At no point in these number studies, however, do subjects have to reason about a physical interaction *between* objects. In short, the pattern of results across a number of experiments hints at a dissociation between performance on spatiotemporal tasks, like number experiments, and contact-mechanical tasks, like solidity experiments. Such a pattern of successes and failures suggests that there may be a dissociation between *spatiotemporal* knowledge, the understanding that subserves number tasks, and *contact-mechanical* knowledge, the understanding that subserves tasks involving collision, support and solidity. Scholl and Leslie (1999) propose just such a dissociation. In contrast to the idea of a single core knowledge, they argue that infants' initial knowledge of objects consists of two distinct representational systems. The first of these, a spatiotemporal system, results from the mechanisms of object indexing and serves to track objects across time and space. The second, a contact-mechanics system, represents the interactions between physical objects (Leslie, 1994).

Although existing data already suggest a potential dissociation between performance on spatiotemporal and contact-mechanical tasks, no study to date has directly compared either human or non-human subjects' performance on these two types of tasks. Here, I directly compared performance on spatiotemporal and contact-mechanical search tasks using the same subjects, apparatus and procedure. If contact-mechanical knowledge differs from spatiotemporal knowledge then performance on these two tasks should differ. Specifically, subjects should succeed on a spatiotemporal task but fail on an identical task that incorporates contact-mechanics. To test this prediction, I used adult rhesus macaques from the Cayo Santiago population. These subjects are ideal for this type of comparative analysis because this population has already been tested on a number of experiments exploring physical reasoning (Hauser, 2001; Santos & Hauser, 2002). As such, we already have a rich background on what this population understands about object motion.

Methods

Subjects

I tested free-ranging rhesus macaques (*Macaca mulatta*) from the Cayo Santiago field site (see Rawlins & Kessler, 1987). This site is home to approximately 800 individuals. Because of over 70 years of research at this field site, subjects are well habituated to human experimenters. Studies using similar paradigms have been conducted on this island for the past five years (see Hauser, 2001; Hauser, Carey & Hauser, 2000; Sulkowski & Hauser, 2001; Santos, Hauser & Spelke, 2001; Santos, Sulkowski, Spaepen & Hauser, 2002). We tested 30 subjects. Nine additional subjects were dropped from the experiment due to experimental error or interference from other individuals.

Apparatus

The experimenters presented subjects with a display in which a plum (4 cm) was rolled into a solid wall behind one of two barriers. The display was constructed of plywood, foamcore and masking tape (see Figure 1). The display consisted of a flat base (125 cm) with two short runners on each side (1 cm high). The runners allowed the plum to roll smoothly and continuously along the display. The front of the display contained two black foamcore barriers (20 × 18 cm) which were used to occlude the plum. A solid white foamcore wall could be placed behind either of the two barriers (52 cm). The wall, which was visible from behind the top of the barrier, was used to stop the rolling plum. Three nails at the base of the wall pierced the rolling plum and prevented it from bouncing off the wall. The display was also equipped with a small ramp (11 cm high) which allowed the plum to roll the entire length of the display. A black screen (76 × 34 cm) was used to block subjects' view of the plum's trajectory.

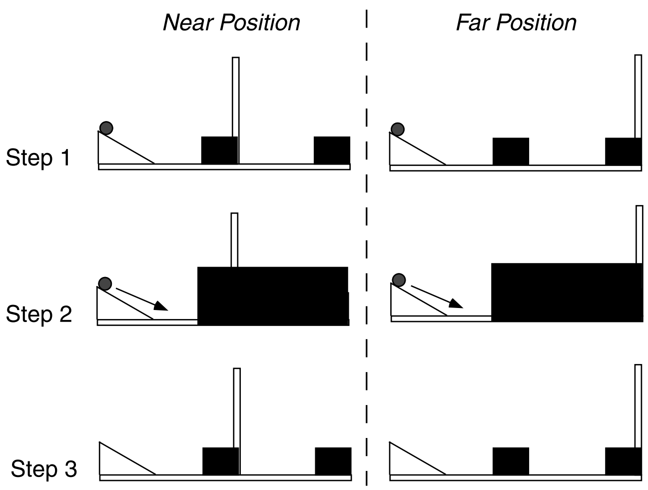

Figure 1 *Procedure used in Experiment 1 for near and far position groups.*

Procedure

Experimenters chose subjects opportunistically by locating lone individuals who were seated in a flat, clear area. Two experimenters ran each session. One, the presenter, introduced the display and performed the actions; the other, the cameraperson, videotaped the session from approximately 3 m away.

Subjects were divided into two groups: the *near position* group and the *far position* group. Subjects in both groups were presented with a single rolling event. For subjects in the near position group, we placed the solid wall behind the barrier nearer to the ramp. During testing, the experimenters approached the subject and placed the display on the ground. The presenter drew the subject's attention to the solid wall by tapping on it, removed a plum from her waistpouch, and placed the screen in front of the apparatus. She then rolled the plum down the ramp, behind the nearer barrier, and into the nails on the base of the wall. Once the plum was resting behind the nearer barrier, the experimenter removed the screen and walked away. The experimenter walked away with her back to the apparatus and departed on a path that was equidistant from the two barriers. The subject was then allowed to approach the display and search for the plum.

The procedure for subjects in the far position group was similar to that of the near position group except for the position of the wall and the final location of the plum. Subjects in the far position group were presented with a display in which the wall was positioned behind the barrier that was further from the ramp. As such, the plum rolled and stopped behind the barrier in the far location. The cameraperson scored subjects' choices as the first barrier they looked behind. Subjects were dropped from the experiment if they failed to approach or searched in an ambiguous way.

Results

Only 19 out of 30 subjects searched for the plum in the correct location (Binomial: $p = .10$). However, subjects did show a consistent search pattern: both groups searched behind the barrier that was nearer to the ramp (24/30, $p = .0007$). Subjects had a tendency to search in the near location no matter where the plum was actually located.

Discussion

Like 2-year-old human children, adult rhesus failed to locate a plum rolled behind a barrier and into a visible solid wall. When searching for the plum, monkeys apparently failed to take into account an obstacle that would have blocked the trajectory of the plum. In fact, rather than reason about this event using the mechanics of the wall, rhesus seemed to use a simple strategy: look for the plum in the location where it was last visible. In fact, 80% of subjects searched for the plum behind the barrier nearer to the ramp, the spot closest to where they saw the plum disappear behind the screen. These results are consistent with those of Hauser (2001). In these experiments, adult rhesus watched as an apple rolled behind an occluder and into one of two linearly aligned boxes. Hauser found that rhesus searched in the nearer box, in this case the correct location. However, as these results suggest, this success was not due to an understanding of the mechanics of the apple and the box, but instead to a strategy of searching in the location nearest to where the apple moved out of sight.

Experiment 1 demonstrated that rhesus do not take into account contact-mechanics when searching for an invisibly displaced plum. In Experiment 2, I examined whether rhesus could use spatiotemporal knowledge to find the plum under similar circumstances. To do so, I transformed the contact-mechanics task of Experiment 1 into a spatiotemporal task. Specifically, I allowed subjects to see whether or not the plum moved behind each of the two barriers, thereby adding spatiotemporal information to indicate the plum's location. If subjects can use this type of knowledge to solve an invisible displacement task, then subjects should find the plum in Experiment 2 in spite of their failures on a contact-mechanical task.

Experiment 2

Subjects

Thirty subjects were tested in this experiment. Nineteen additional subjects were dropped from the experiment due to experimental error or interference.

Apparatus

I used the apparatus from Experiment 1 with some slight modifications. First, the presenter used a short wall (4 cm) that could be placed behind the barriers. This short wall was able to block the trajectory of the rolling plum but was not visible from the face of the display. As such, subjects could not see the short wall at any point during the experiment.

Procedure

The general procedure of Experiment 2 was similar to that of Experiment 1. Again, subjects were divided into *near position* and *far position* groups. For subjects in the near

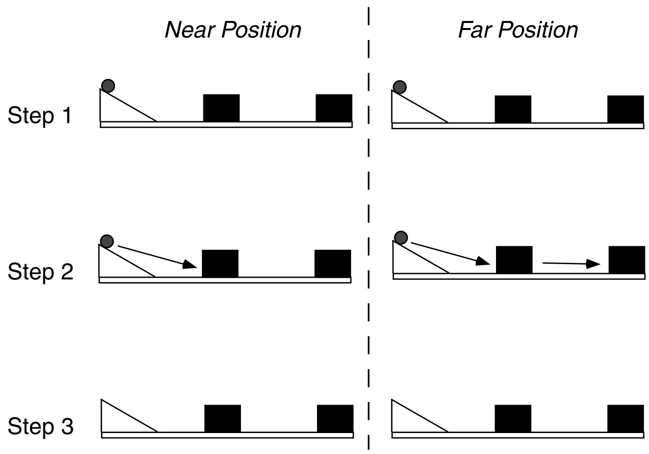

Figure 2 *Procedure used in Experiment 2 for near and far position groups.*

position group, we placed the short wall behind the barrier that was nearer to the ramp (see Figure 2). During testing, the presenter drew the subject's attention to the display and then rolled a plum down the ramp, behind the nearer barrier, and into the nails on the base of the short wall. Unlike in Experiment 1, no screen occluded the trajectory of the plum. Therefore, from the subject's perspective, it should have appeared as though the plum rolled behind the first barrier and stopped. Once the plum was resting behind the nearer barrier, the experimenter walked away. The subject was then allowed to approach the display and search for the plum behind one of the two barriers.

The procedure for subjects in the far position group was similar to that of the near position group except for the position of the short wall and the final location of the plum. Subjects in the far position group were presented with a display in which the short wall was positioned behind the barrier further from the ramp. As such, the subject saw the plum roll behind the nearer barrier, then in-between the two barriers, and then behind the barrier that was further from the ramp.

Results

All subjects in both conditions searched in the correct location (30/30: $p = .0001$). Performance in Experiment 2 was significantly different from that of Experiment 1 ($\chi^2 = 13.47$, $p = .0002$).

Discussion

Adult rhesus who are given spatiotemporal information quickly solve an invisible displacement task. All of our subjects were able to locate the plum when they were given spatiotemporal information about the plum's location. These results come in contrast to the results of Experiment 1, where subjects failed to locate the plum on the same apparatus. This difference between performance in Experiments 1 and 2 cannot be explained by an appeal to means–end problem-solving or problems with the apparatus, since these factors were held constant across the two experiments. Instead, the difference in performance demonstrated here suggests a dissociation between subjects' understanding of spatiotemporal and contact-mechanical relations. Specifically, it suggests that subjects can reason about the behavior of hidden objects using spatiotemporal information, but not contact-mechanical information.

An alternative explanation for this dissociation, however, is that Experiment 1 is somewhat more complicated than Experiment 2. After all, Experiment 1 involves one more object than Experiment 2: the wall. In addition, subjects must hold the position of the plum in memory while the occluding black screen is present. It is possible that these extra demands somehow impair subjects. If this is the case, subjects would have performed poorly on Experiment 1 not because of the mechanical interaction involved, but because of the presence of these extra objects in the display which makes the task too complex.

To deal with this alternative, I performed two additional experiments in which I equated the complexity of the spatiotemporal and contact-mechanical tasks. In Experiment 3, the experimenter simply added the wall after subjects watched the plum roll behind the barriers. In Experiment 4, the experimenter added the screen after subjects watched the plum roll behind the barriers. These additional constraints add extra complexity to the task, but preserve the spatiotemporal information present in Experiment 2. If subjects failed Experiment 1 because of problems with additional objects present in the display, then subjects should perform poorly in Experiments 3 and 4 as well. However, if subjects failed Experiment 1 because they were unable to represent the mechanical interactions involved, then subjects should succeed in Experiments 3 and 4 despite the addition of these extra demands.

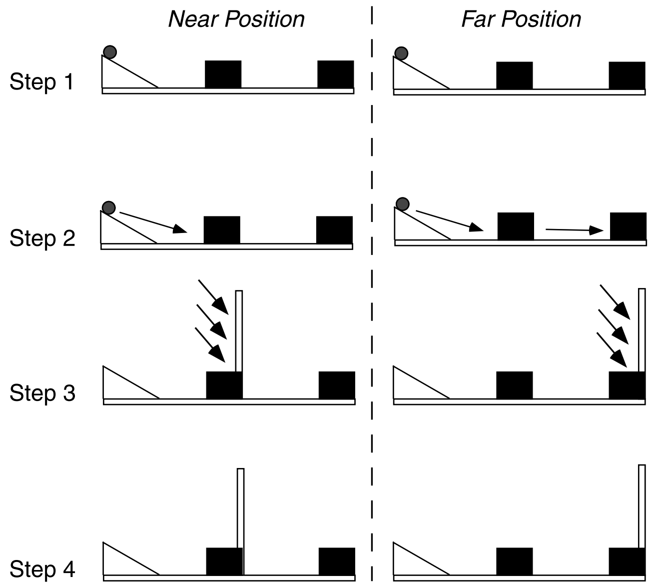

Figure 3 *Procedure used in Experiment 3 for near and far position groups.*

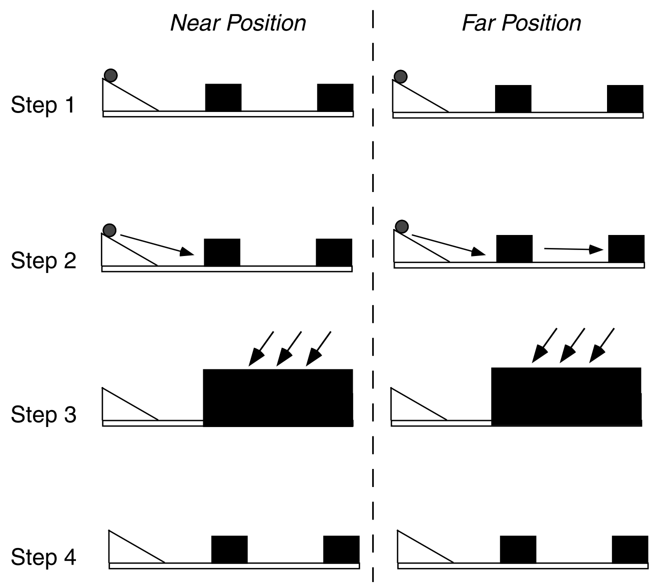

Figure 4 *Procedure used in Experiment 4 for near and far position groups.*

Experiments 3 and 4

Subjects

Thirty subjects were tested in each of these experiments. Forty additional subjects were dropped from both experiments due to experimental error or interference from other individuals.

Procedure

Again, subjects were divided into *near position* and *far position* groups. The procedure of Experiment 3 was exactly the same as that of Experiment 2 except that after the plum was resting behind the barrier, the experimenter then inserted the large wall from Experiment 1 behind the barrier (see Figure 3). She then walked away.

The subject was then allowed to approach the display and search for the plum behind one of the two barriers.

The procedure for Experiment 4 was exactly the same as that for Experiment 2 except that after the plum was resting behind the barrier, the experimenter then placed the screen in front of the display for three seconds, removed the screen and then walked away.

Results

In both Experiments 3 and 4, subjects searched in the correct location (Experiment 3: 30/30; $p = .0001$; Experiment 4: 30/30; $p = .0001$).

Discussion

In both Experiments 3 and 4 subjects successfully locate the plum. These results demonstrate that subjects can solve a search task involving the vertical wall and the addition of a black screen. As in Experiment 2, if subjects are given spatiotemporal information about the plum's location, they are able to successfully locate the plum. The results of Experiments 3 and 4 suggest that subjects' failures in Experiment 1 are purely the result of the mechanical nature of the task; without spatiotemporal information, subjects cannot locate where the plum has rolled.

General discussion

Although adult rhesus are able to solve an invisible displacement problem using spatiotemporal information, they fail the exact same task if they are required to use contact-mechanical information. This dissociation holds true even when all the task demands are carefully held constant as they were in Experiments 3 and 4. The dissociation demonstrated here is consistent with Hauser's (2001) search task testing the same population in the vertical domain. In this study, adult rhesus failed to locate an apple dropped behind a screen and into a cup sitting on top of a table; instead of searching in the correct top cup, subjects consistently searched in the cup under the surface of the table. However, if the experimenter dropped the apple in the absence of the screen, thereby providing spatiotemporal information about the object's trajectory, rhesus succeeded on this task. When spatiotemporal information was available, subjects correctly searched for the apple in the top cup.

Why do adult rhesus perform worse on tasks involving contact-mechanical information than on tasks involving spatiotemporal information? One possibility is that subjects find spatiotemporal tasks easier to solve than contact-mechanical tasks. Subjects could, for example, have used a simple strategy that worked better for the spatiotemporal task than the contact-mechanical task. This alternative is unlikely because of the findings of Experiments 3 and 4, in which I carefully controlled the task demands across the spatiotemporal and contact-mechanical tasks. Instead, I favor a different explanation. Namely, rhesus perform differently on spatiotemporal and contact-mechanical tasks because these tasks tap into two different knowledge systems. In other words, these findings suggest a distinction between rhesus' knowledge of spatiotemporal aspects of an object's motion and their knowledge of contact-mechanics. Such a dissociation between spatiotemporal knowledge and contact-mechanics is inconsistent with the CK theory, which argues that a single system of knowledge underlies the perception of object motion and physical reasoning. Instead, these results imply that our knowledge of physical objects might instead be subserved by two separate systems: one that represents objects as bounded entities moving on continuous spatial paths and one that represents objects as participants in mechanical interactions (see Scholl & Leslie, 1999).

The idea that object knowledge is made of two distinct systems leads to a number of other hypotheses about the nature of initial knowledge. First, if object knowledge is subserved by two systems, then it is likely that the cognitive (and presumably neural) architecture that makes up these two systems will be different in critical ways. Scholl and Leslie (1999) have argued that the spatiotemporal system relies heavily on the architecture of object-based visual attention, which tracks objects across time and space. If they are correct, then the 'knowledge' that makes up the spatiotemporal system cannot be seen as a system of theoretical principles, as the CK theory argued. Instead, spatiotemporal knowledge would emerge from the action of visual tracking mechanisms in the absence of theory-like principles about object motion. The contact-mechanics system, however, may be architecturally quite different from the spatiotemporal system. This system, which represents mechanical interactions between objects, is unlikely to be based simply on the mechanisms of object tracking. Instead, contact-mechanical knowledge is likely to be theory-like and principle-based (see also Leslie, 1994).

Another important distinction between the architectures of these two systems is their levels of informational encapsulation (Scholl & Leslie, 1999). As Fodor (1983) originally explained in his famous treatise on modularity, some representational systems, like visual illusions, are impervious to outside information. There is much evidence to suggest that the contact-mechanical system does not operate like a visual illusion. Our perception of a mechanical event is influenced by many properties of the objects involved: whether or not they are hard, squishy, alive, etc. For example, both human infants and adult primates expect living objects to violate contact principles (Hauser, 1998; Santos, Flombaum & Hauser, 2002; Spelke, Phillips & Woodward, 1995). Similarly, Baillargeon (1987) has shown that human infants expect squishy objects to interact differently than rigid objects. These observations suggest that the contact-mechanical system is not informationally encapsulated; top-down influences about an object's kind and material can affect our perception of a mechanical event. The spatiotemporal system, in contrast, seems to work more like a visual illusion. No matter what an object is made of, it cannot magically disappear when hidden or move in a disconnected spatiotemporal path. This distinction between the encapsulation of contact-mechanics and spatiotemporal knowledge provides further evidence that the two systems are architecturally distinct.

Perhaps most importantly, however, a two-systems theory of initial knowledge clarifies some aspects of the dissociation between performance on expectancy violation and search experiments. Specifically, it explains why researchers observe this dissociation in contact-mechanical but not spatiotemporal tasks. Spatiotemporal knowledge seems to result from the seemingly automatic and encapsulated operation of object-based attentional mechanisms. Such mechanisms are unlikely to be disrupted by outside influences even during search tasks. Contact-mechanical knowledge, on the other hand, seems somewhat less encapsulated, taking in more top-down information during processing. It is possible, then, that outside influences could disrupt the operation of the contact-mechanical system while sparing performance on spatiotemporal search tasks. Such disruptions could take the form of perseverative biases, naïve theories or problems with task demands. For example, Hauser (2001) proposed that adult primates use a naïve theory that objects fall straight down. It is possible that when subjects search for a falling object, this naïve theory overrides conflicting information from the contact-mechanical system, and subjects search for a falling object in a place that a mechanical analysis would never predict (e.g. under a solid table that would have blocked the object's trajectory). In other words, the outputs of the contact-mechanical system may be more susceptible to outside influences than the spatiotemporal system, and thus we would expect to see subjects making search errors in contact-mechanical tasks but not on spatiotemporal tasks. For these reasons, the present results have narrowed down the scope of the unexplained divergence between performance on looking and search tasks.

The challenge now facing psychologists is to discover more about the nature of the contact-mechanical system and why its operation is compromised during search but not looking tasks. While much is known about the mechanisms that human adults use to track objects in space and time (Leslie *et al.*, 1998; Scholl & Leslie, 1999), much less is known about how adult subjects reason about mechanical interactions. Current evidence suggests that even adults hold a number of incorrect notions about how objects move and fail to accurately predict the outcomes of physical events (see McCloskey, Washburn & Felch, 1983). Exploring the nature and development of these incorrect notions may provide important insight into the nature of these capacities and why they are so fragile even into adulthood.

The studies reported here present the first dissociation between contact-mechanical and spatiotemporal knowledge in an adult primate. If human infants demonstrate a similar dissociation, then the well-known notion of core knowledge may be in need of revision. The new notion – one of two core 'knowledges' – will link current work in cognitive development with the adult literature on human object-based attention.

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