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Short Research Note

Apes' Tracking of Objects and Collections

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Abstract. Recent research suggests that great apes are less vulnerable to cohesion violations than human infants are. In contrast to human infants, apes successfully track nonsolid substances or split solid objects through occlusion (Cacchione & Call, 2010a; Cacchione, Hrubesch, & Call, 2012, 2013). The present study aims to investigate whether the lower vulnerability of great apes to cohesion violations also manifests when they are tracking collections. While even very young human infants appreciate the continuous existence of solid bound objects, they fail to show similar intuitions when tracking collections of objects (Chiang & Wynn, 2000). In a manual search task inspired by recent infant research, we tested whether humans' closest relatives, the great apes, showed a similar contrast in their reasoning about single solid objects and objects *within* collections. The results suggest that, in contrast to human infants, great apes appreciate the continuous existence of objects within collections and successfully track them through occlusion. This confirms the view that great apes are generally less vulnerable to cohesion violations than human infants.

Keywords: objects, collections, continuity, comparative research

Numerous studies have documented a sharp contrast between infants' reasoning about cohesive solid objects and reasoning about noncohesive entities such as nonsolid substances, fragmented objects, or collections of objects. While even very young infants appreciate the continuous existence of solid bound objects (e.g., Wang, Baillargeon, & Paterson, 2005) and successfully track them through space and time (e.g., Feigenson, Carey, & Spelke, 2002; Koechlin, Dehaene, & Mehler, 1997), they fail to show similar competencies when presented with noncohesive entities, unbound mass, or collections of objects (Cheries, Mitroff, Wynn, & Scholl, 2008; Chiang & Wynn, 2000; Huntley-Fenner, Carey, & Solimando, 2002). For example, 12-month-olds failed to appreciate the spatiotemporal continuity of a graham cracker that was split into two halves (Cheries et al., 2008) or had problems tracking sand piles through occlusion (Huntley-Fenner et al., 2002; but see vanMarle & Wynn, 2011).

Similar processing problems are also reported for the tracking of collections of objects. For instance, Chiang and Wynn (2000) presented 8-month-old human infants with events in which either single solid objects or comparably sized collections of objects were hidden. In a solid object condition, infants saw two solid Lego pyramids placed next to two spatially separated occluding screens. Then either both moved behind the screens (magical disappearance event) or only one of them moved behind a screen while the other moved outside the display (expected disappearance event). In both cases, the screens were dropped to show only one object present in the scene. The rationale was that, if infants track both objects, they should be surprised to see only one object present in the magical disappearance event (where both pyramids moved behind the screens), but not in the expected disappearance event (where only one of them moved behind the screens). This was exactly what was observed in the solid object condition. However, in a similar collection condition, infants did not differentiate between expected and magical disappearance.

This is a remarkable finding because the collection condition was identical to the object condition with the exception that, before moving behind the screen/out of the display, the Lego pyramid was first decomposed into its constituting blocks and then recomposed into a pyramid. Thus, while 8-month-olds were able to track the solid pyramid and expected it to exist continuously when moving out of sight, they failed to do so when they were first shown that the pyramid was not cohesive but an aggregated collection of single blocks. Moreover, the infants also failed to reconstruct and track the collection as "multiple objects." This result was not due to higher task demands in the collection condition (e.g., greater length or complexity of the collection events or greater number of elements to be tracked). In a similar condition, in which infants first saw single blocks lined up in a row and then saw them piled up, they did not fail to track the pyramid. This suggests that the

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problem was actually connected to the infants' initial construal of the Lego pyramid as a "solid" object and not associated with a greater complexity of the collection event.

The idea that noncohesive entities violate the spatiotemporal conditions of objecthood and thus interfere with the tracking and individuating of objects is in accord with the core knowledge thesis. This nativist account suggests that a basic notion of what it is to be an object is innate to human infants and has a long phylogenetic history (e.g., Spelke, 1994, 2000; Spelke & Kinzler, 2007). The present study investigates whether a similar contrast between reasoning about single solid objects and reasoning about collections of objects as observed in human infants may also be found in great apes. According to the core knowledge account, we would expect the same cognitive core properties that are universal in humans to also be shared with other primate species, particularly those closely related to humans. In fact, recent research suggests that intuitions regarding continuity and cohesion of objects are also present in different great ape species (e.g., Cacchione & Burkart, 2012; Cacchione & Call, 2010a, 2010b; Cacchione et al., 2012, 2013; Cacchione & Krist, 2004; Cacchione, Call, & Zingg, 2009; Mendes, Rakoczy, & Call, 2008, 2011). However, several studies also showed that nonhuman primates including great apes are less vulnerable to cohesion violations than human infants because under specific conditions they were found to quite successfully track portions of nonsolid substances or split objects through occlusion (Cacchione & Call, 2010a; Cacchione et al., 2012, 2013; vanMarle, Aw, McCrink, & Santos, 2006). The present study investigates whether the lower vulnerability of great apes to cohesion violation is a general trait of their tracking performance pertaining to all types of entities (i.e., nonsolids, split objects, and collections of objects) and whether this therefore principally distinguishes them from human infants. Specifically, the present study investigates whether the tracking of great apes of collections follows the same lines as that of human infants or whether they also outperform human infants in this respect.

Experiment 1: Solid Objects Versus Collections

To investigate the ability of great apes to track collections of objects, we used a manual search task inspired by original infant research (e.g., Chiang & Wynn, 2000). A search task was used because it provides a more conservative test of cognitive processing than looking-time measures and offers better comparability to previous research on cohesion violation in great apes and monkeys (Cacchione & Call, 2010a; Cacchione et al., 2012, 2013; vanMarle et al., 2006). Apes were presented with single solid objects (banana pieces) or collections of objects (sets of banana slices) that were hidden under two spatially separated cups. They were tested with three conditions. In the *object condition*, different numbers of solid banana pieces were hidden under the cups. In the *solid-to-slices condition*, solid banana pieces were introduced, but decomposed into single slices and then recomposed into "solid" pieces before hiding them. In the slices-to-solid condition, single banana slices were introduced one by one, and then rearranged into "solid" pieces. If great apes, as human infants, expected the continuous existence of unitary solid pieces, but not of collections of objects, they should select the cup containing the greatest amount in the object condition, but not in the solid-to-slices condition. Moreover, if the tracking ability of apes depends on the way that they initially construe the tracked entity (as either solid object or collection), we would expect to observe performance differences between the slices-to-solid condition and the solid-to-slices condition.

Method

Participants

Twenty great apes, four gorillas (*Gorilla gorilla*), six orangutans (*Pongo abelii*), five bonobos (*Pan paniscus*), and five chimpanzees (*Pan troglodytes*) participated in the experiment. They were housed at Wolfgang Koehler Primate Research Center at Leipzig Zoo, Germany, and had had prior experience with various experiments on social and physical cognition. The apes were tested individually, except for mothers with offspring younger than 3 years, who remained in the company of their infants.

Materials

Banana pieces of approximately 1.5 cm in length served as stimuli. The "solid objects" corresponded to nonsegmented banana pieces. For the collections (solid-to-slices condition), the banana pieces were cut into three slices. The stimuli were placed on green plastic plates (22 cm × 22 cm) and then covered by opaque green plastic cups (15.5 cm diameter). Once the pieces were covered, the apes could not see them anymore.

Design and Procedure

Apes were presented with three conditions, each consisting of four trials: an object condition (OBJ), a solid-to-slices (SOLS) condition, and a slices-to-solid (SLIS) condition (see Figure 1). In the object condition (OBJ), solid banana pieces were hidden at both Locations A and B. In the solid-to-slices (SOLS) and slices-to-solid (SLIS) conditions, solid banana pieces were presented at only one location, while the pieces at the other location were manipulated before they were hidden. In the SLIS condition, three single banana slices were introduced and then rearranged into a perceptually "whole" piece (SLIS manipulation). In the SOLS condition, precut banana pieces were introduced as "whole" pieces. Then they were decomposed into three sin-

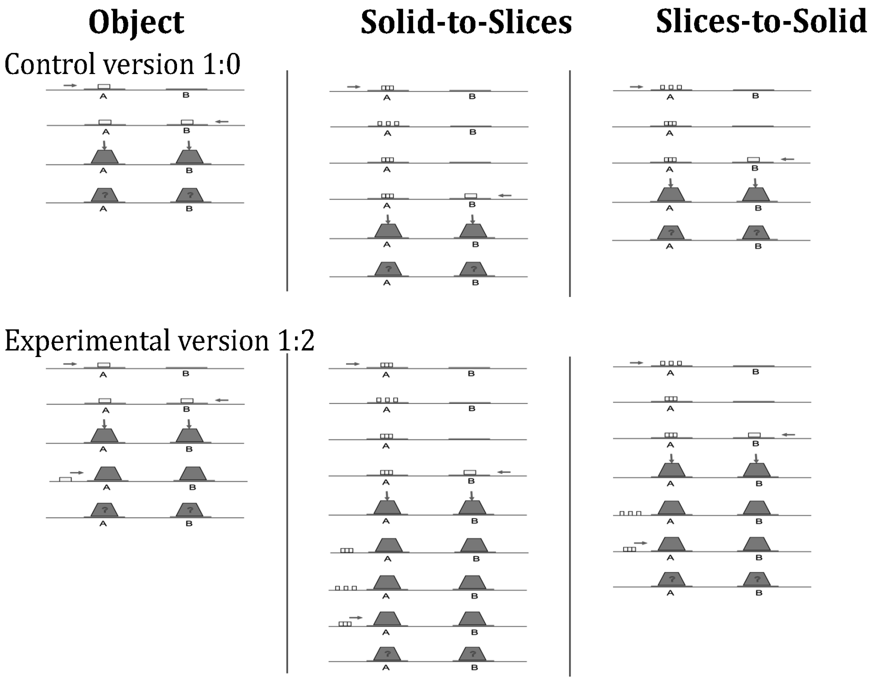

Figure 1. Testing procedure. Apes were to choose between two locations (A, B) with cups containing different (experimental version) or the same amounts (control version) of food. Food was either presented as a solid, whole piece (object condition) or manipulated before being hidden (solid-to-slices and slices-to-solid conditions).

gle slices and rearranged into "whole" pieces again (SOLS manipulation). All three conditions were presented with a 1:2 ratio (experimental version) as well as with a 1:1 ratio (control version to assess baseline preferences).

The subjects received three sessions with two conditions, but with only one session per day. The order of conditions, the ratio of cup amounts (1 vs. 1; 1 vs. 2), the side (larger amount of food in left or right location), and order of presentation (manipulated/larger amount placed first or second) were counterbalanced across individuals.

The ape sat behind a Plexiglas panel with two holes. Directly in front of the holes, approximately 50 cm apart, two plastic plates were presented on a sliding table. The experimenter (C. H.) sat opposite the ape and baited the plates. In the object condition (experimental ratio 1:2), E put a solid banana piece on Plate A and a second piece on Plate B (see Figure 1). After that, she simultaneously covered the pieces with the cups. Then she put a whole banana piece next to Plate/Cup A and subsequently moved it under the cup (without showing the piece that was already hidden there). Finally, she touched both cups and pushed the table toward the ape to let him/her choose.

For the SOLS and SLIS conditions, the procedure was the same, except that the pieces were manipulated before being hidden under the cup. In the SOLS condition, E introduced a presliced but whole banana piece, split it up into three aligned slices, and then rearranged them again into a "solid" piece (see Figure 1). In the SLIS condition, E lined up three single banana slices on the table and then arranged them into a "solid" piece. The control versions (ratio 1:1) of these three conditions were identical except that only one piece was hidden under each cup.

Analysis

We used Excel 2010 for Windows and SPSS 16.0 for our analyses. As our data did not meet the criteria of normal distribution, we calculated nonparametric statistics. Graphs show arithmetic means and standard deviation.

Results and Discussion

Experimental Ratio 1:2

Apes performed above chance in all three conditions (Wilcoxon test, OBJ: $z = -3.391$; SLIS: $z = -1.984$; SOLS: $z = -3.508$; $p < .05$ in all cases), see Figure 2. Overall, apes' performance only marginally differed between the three conditions (Friedman test, $\chi^2 = 5.922$, $df = 2$, $p = .052$). Posthoc tests indicated that subjects performed significantly worse in the SLIS compared to the other conditions (Wilcoxon test, OBJ-SLIS: $z = -2.077$; SOLS-SLIS: $z = -2.294$; $p < .05$ in both cases). Subjects' performance did not differ between the OBJ and SOLS conditions (Wilcoxon test, $z = -.557$; $p = .56$). The four species did not differ in their choice behavior in any of the conditions (Kruskal-Wallis test, OBJ: $\chi^2 = 2.390$; SLIS: $\chi^2 = .358$; SOLS: $\chi^2 = 2.420$; $df = 3$, $p > .05$ in all cases).

Control Ratio 1:1

The apes performed at chance level in all conditions (Wilcoxon test, OBJ: $z = -.728$; SLIS: $z = -1.842$; SOLS: $z = -.491$; $p > .05$ in all cases), see Figure 3. Their performance

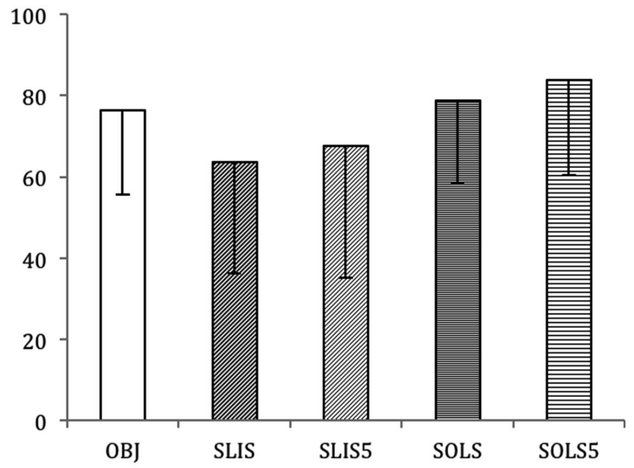

Figure 2. Mean percent of correct choices and standard deviation in the five conditions with ratio 1:2.

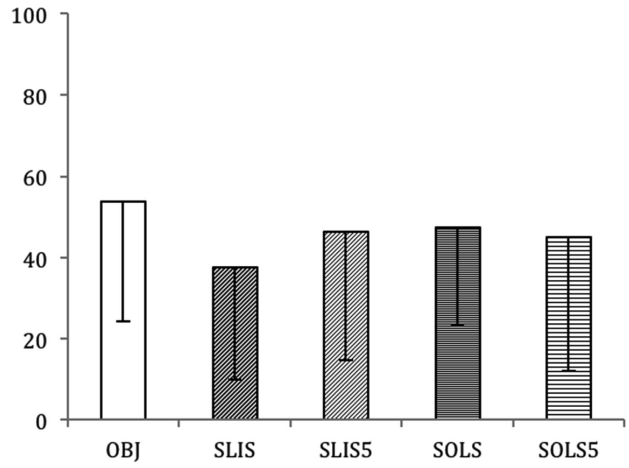

Figure 3. Mean percent of correct choices and standard deviation in the five conditions with ratio 1:1.

did not differ significantly across the three conditions (Friedman test, $\chi^2 = 3.129$, $df = 2$, $p = .21$). Also, there were no differences between species (Kruskal-Wallis test, OBJ: $\chi^2 = 4.788$; SLIS: $\chi^2 = 5.399$; SOLS: $\chi^2 = 4.451$; $df = 3$, $p > .05$ in all cases).

Thus, the apes successfully tracked objects and collections in all three test conditions. This suggests that, in contrast to human infants, great apes expected the continuous existence of both solid objects and collections of objects. Moreover, unlike human infants, apes performed worse if the entity was initially construed as a collection (e.g., slices-to-solid condition) than if construed as a solid piece (e.g., solid-to-slices condition). Apparently, apes also construed the single solid objects as qualitatively different from collections of objects. However, in contrast to infants, the differential performance of apes is not mediated by the presence or absence of cohesion violations since they perform worse in events in which *no cohesion violation takes place*. A more likely explanation for the poorer performance of apes in the slices-to-solid condition is a weak preference for whole banana pieces over collections of banana slices. Under specific circumstances, apes have been found to depart from the usual food maximizing rule and show a preference for smaller whole amounts over larger fractionated amounts of food (e.g., see Beran, Evans, & Ratliff, 2009). Indeed, apes showed a weak preference for the solid piece in the SLIS control condition. However, this preference was not substantial enough to reach statistical significance.

In contrast to the infants in Chiang and Wynn's (2000) study, in which the pyramids were decomposed into five parts, the apes in the present experiment were presented with three-part decompositions. Even if Chiang and Wynn (2000) were able to show that infants' failure was not connected to the number of objects to be tracked, we cannot exclude that the size of the collections affected the great apes. Experiment 2 addresses this possibility.

Experiment 2: Large Versus Small Collections

Apes might also fail to track collections of objects if they are composed of five items in contrast to three. There is substantial evidence that simultaneous object tracking is limited to about three to four items (Barner, Thalwitz, Wood, Yang, & Carey, 2007; Feigenson & Carey, 2005). Even if this signature limit was not evidenced in Chiang and Wynn (2000), we cannot fully rule out that apes would react differently to collections containing an item number below or above set size limit. Thus, we presented the apes with exactly the same conditions as in Experiment 1 but decomposed the banana piece into five parts in the solid-to-slices condition and introduced five single slices in the slices-to-solid condition.

Method

Participants

The same 20 great apes as in Experiment 1 participated in Experiment 2.

Materials, Design, and Procedure

The same materials as in Experiment 1 were used. However, banana pieces were slightly longer (2 cm length) and precut into five slices. Apes were presented with a solid-to-slices (SOLS5) and a slices-to-solid (SLIS5) condition. The design and procedure were identical to that of Experiment 1, except that the banana pieces were not de-/recomposed into three (below set size limit) but into five slices (above set size limit).

Results and Discussion

Experimental Ratio 1:2

The apes performed above chance in both conditions (Wilcoxon test, SLIS5: $z = -2.258$; SOLS5: $z = -3.639$; $p < .05$ in all cases), see Figure 2. Their performance in the two conditions differed reliably (Wilcoxon test, $z = -2.124$; $p < .05$). However, neither their performance in the SLIS5 nor that in the SOLS5 condition differed from that in the object condition of Experiment 1 (Wilcoxon test, SLIS5-OBJ: $z = -1.178$; SOLS5-OBJ: $z = -1.732$; $p > .05$ for both). The four species did not differ in their choice behavior (Kruskal-Wallis test, SLIS5: $\chi^2 = 1.699$; SOLS5: $\chi^2 = 1.675$; $df = 3$, $p > .05$ in all cases).

Control Ratio 1:1

Apes performed at chance level also for the ratio 1:1 versions with five slices (Wilcoxon test, SLIS5: $z = -.539$; SOLS5: $z = -.827$; $p > .05$ in all cases), see Figure 3. Their performance did not differ between conditions (Wilcoxon test, $z = -.129$; $p = .898$) or from the object condition in Experiment 1 (Wilcoxon test, SLIS5-OBJ: $z = -.789$; SOLS5-OBJ: $z = -.840$; $p > .05$). Also, there were no species differences in performance (Kruskal-Wallis test, SLIS5: $\chi^2 = 2.262$; SOLS5: $\chi^2 = 2.325$; $df = 3$, $p > .05$ in both cases).

Comparison of De-/recomposition into Three and Five Slices in Experiments 1 and 2

Overall, the apes performed equally well in conditions with decomposition into three parts and in conditions with decomposition into five parts in the experimental versions (Wilcoxon test, SLIS-SLIS5: $z = -.423$; SOLS-SOLS5: $z = -1.265$; $p > .05$ in both cases) as well as in the control versions (Wilcoxon test, SLIS-SLIS5: $z = -1.077$; SOLS-SOLS5: $z = -3.83$; $p > .05$ in both cases).

Thus, irrespective of whether objects were decomposed into three or five items, the apes successfully tracked objects and collections in all test conditions. Thus, in contrast to human infants, great apes expected the continuous existence of both solid objects and collections of objects. Again, apes performed reliably more poorly in the slices-to-solid than in the solid-to-slices condition, suggesting that they also construed solid objects and collections of objects differentially.

General Discussion

Great apes were equally successful in tracking solid unitary objects and collections of objects. Their above-chance-level performance in this task supports findings from previous research suggesting that, in many respects, great apes appear to be less vulnerable to cohesion violations than human infants (Cacchione & Call, 2010a; Cacchione et al., 2012, 2013). The present findings show that this observation holds true not only for their tracking of nonsolid substances and split solid objects, but also for collections of objects. Furthermore, apes were equally able to track collections composed of three (below set size limit) as well as five (above set size limit) elements. Thus, the number of distinct elements in the collection did not influence the performance of apes. This finding further adds to a large body of studies that found no set-size signature in great apes (e.g., Beran et al., 2009; Hanus & Call, 2007).

Chiang and Wynn (2000) proposed two possible sources of infants' difficulty tracking collections through occlusion. First, it is possible that infants conceived of the collections as nonobject entities blocking the application of object principles (such as spatiotemporal continuity) to them. Second, the decomposition of an entity initially construed as a solid body of matter may have disrupted the tracking process because of infants' inability to discard and replace the open object file. In light of these explanations, apes' better performance may be interpreted as follows. First, in contrast to infants, the great apes appreciated that collections are also composed of continuously existing material parts. Second, in contrast to infants, the great apes were able to re-encode fragmented entities and successfully track them through occlusion. Earlier studies supported a developmental explanation for the lower vulnerability of apes to cohesion manipulations (Cacchione & Call, 2010a; Cacchione et al., 2012, 2013). As in human infants, we also observed a developmental shift in great apes, with infants performing reliably worse than juvenile and adult apes (Cacchione et al., 2013). This explanation may also account for the present findings. It appears likely that the juvenile/adolescent and adult apes tested coped better than human infants with the cognitive load that cohesion violations impose on the tracking process. A second possible explanation is that the great apes had more experience with decomposed objects (bananas) than the infants did (Lego bricks). Indeed, Chiang and Wynn (2000) found that infants' performance improved if they had had prior experience with Lego towers. Even though apes were also found to track fragmented objects when tested with unfamiliar materials (e.g., Cacchione & Call, 2010a), their extensive experience with bananas may certainly have further enhanced their performance. It is even possible that extensive experience with fragmenting and reassembling objects is a major factor fostering the developmental progression in both humans and apes.

However, like infants, great apes also apparently construed single solid objects as being different from assemblies of objects – even though they appreciated the continuous nature of both types of entities and were able to track them. In contrast to infants, apes performed worse in the slices-to-solid condition, in which single slices were first lined up in a row. The poorer performance in this condition probably originated from a sometimes observed and, in terms of food maximizing, nonrational preference for whole amounts over fractionated amounts (e.g., Beran et al., 2009).

In sum, the present study confirmed that great apes are less vulnerable to cohesion violations than human infants. The most likely explanation for this finding is advanced developmental maturity of great apes. Future research should thus focus on the ontogenetic development of object tracking in the face of cohesion violations and compare the ontogenetic developmental trajectories of diverse nonhuman primate species with those of humans.

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