Original Communication

Cohesion as a Principle for Perceiving Objecthood

Does It Apply to Animate Agents?

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Abstract. Previous research found that cohesion manipulations (e.g., splitting an object into two parts) may have deleterious effects on infants' object representation. The present study investigated whether the cohesion principle is relevant only when assessing the continuity of inanimate objects, or whether it is equally fundamental for the perception and representation of animate agents. In two experiments, we assessed 8-month-old infants' tracking behavior in events in which an agent (an animated snail) was either split in half, fused together, or simply changed its shape. Infants managed to individuate fused snails and snails that had changed their shape, but failed to track split snails, even in a perception-based paradigm. This suggests that the effects of cohesion manipulation apply to animate agents as well as inanimate objects. Moreover, these results suggest that infants' inability to track split snails is not a consequence of a violation of core principles, but rather a consequence of the increased processing demands that arise when they are tracking multiple entities moving in different directions.

Keywords: infants, animate agents, continuity, cohesion

What enables infants to represent objects as distinct material entities with an independent continuous existence in space and time? According to the *core knowledge approach*, infants infer objecthood on the basis of three core principles: cohesion, continuity, and contact. More specifically, infants rely on the principles of *cohesion* (objects move as connected, bounded units), *continuity* (when objects move, they trace exactly one connected path over space and time), and *contact* (objects do not interact at a distance) to define which perceptual features count as objects with stable identities (Spelke, 1994, 2000; Spelke & Kinzler, 2007). The principle of cohesion thereby constitutes but also limits infants' appreciation of object continuity: First, infants consider only cohesive, bounded wholes as having an independent continuous existence (Cheries, Mitroff, Wynn, & Scholl, 2008; Chiang & Wynn, 2000; Huntley-Fenner, Carey, & Solimando, 2002; Rosenberg & Carey, 2009). Second, infants expect continuous objects to remain cohesive, stable units (e.g., Needham, Cantlon, & Ormsbee Holley, 2006; Needham, Dueker, Lockhead, 2005; Spelke, 1990). However, it is not yet clear whether violations of cohesion really impair infants' ability to represent objects as being continuous and whether the same core knowledge principles of physical objects also apply to animate agents. We address these topics below and especially focus on cohesion and continuity.

The Impact of Cohesion Manipulation on Representations of Object Continuity

Recently, the role of cohesion in the ability to represent objects as being continuous was tested in human adults, human infants, and nonhuman primates. In these studies, the participants were presented with events in which the apparent cohesion of a solid object was manipulated by, for example, breaking the object into multiple parts of different sizes and shapes (Cacchione, 2013; Cacchione & Call, 2010; Cacchione, Hrubesch, & Call, 2013; Cheries et al., 2008; Chiang & Wynn, 2000; Huntley-Fenner et al., 2002; Mahajan, Barnes, Blanco, & Santos, 2009; Mitroff, Scholl & Wynn, 2004; Rosenberg & Carey, 2009; vanMarle & Scholl, 2003). If cohesion is necessary to identify objects as being permanent, manipulations that downgrade object cohesion should affect infants' continuity assessment, thus impairing their ability to represent the manipulated object as existing at a given location. Several studies have demonstrated the deleterious effects of the splitting manipulation on the object representations of human infants (Cacchione, 2013; Cheries et al., 2008) and nonhuman primates (Cacchione & Call, 2010; Cacchione et al., 2013). Al-

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though cohesion manipulations affected object representations, leaving them downgraded and in a less functional condition, representations usually survived the split (i.e., infants were able to localize the objects, but not to quantify them). Therefore, these studies found no evidence that cohesion violations disrupted the appreciation of object continuity, at least when using action-based paradigms in which the participants actively searched for the manipulated object (Cacchione, 2013; Cacchione et al., 2013).

In contrast, when infants were tested with a perception-based rather than an action-based paradigm, cohesion manipulations strongly impaired infants' appreciation of object continuity. Chiang and Wynn (2000), for example, compared 8-month-olds' reasoning about nonfood solid objects and collections of objects (such as noncohesive pyramids of blocks) in occlusion events by measuring infants' looking behavior. In their study, infants were successful at tracking and individuating solid pyramids when the pyramids maintained their boundaries throughout the occlusion event. However, if infants first saw the decomposition of the pyramid into five blocks and then their recomposition into a pyramid, they failed to reliably assess whether the pyramid was present behind the occluder (i.e., failed to look longer when the decomposed and recomposed pyramid was moved behind the occluder, and the occluder was then removed to reveal an empty stage). Chiang and Wynn (2000) concluded that infants did not apply the core principle of continuity to noncohesive collections. Therefore, manipulating the cohesion of objects seems to have a much stronger impact in perception-based paradigms than in action-based paradigms. This is striking, as sensitive perception-based methods have often proved to better detect even weak intuitions (e.g., Hood, Carey, & Prasada, 2000).

One reason why cohesion manipulations have a stronger impact in perception-based paradigms might be that cohesion manipulations affect the visual processing and tracking of objects. Paradigms in which participants' visual behavior is observed would therefore be better able to detect the deleterious effects of these manipulations. However, the study by Chiang and Wynn (2000) is also the only one that has ever investigated the effects of cohesion manipulations on the ability to visually track objects. The first aim of this study is therefore to confirm the strong effects of cohesion manipulations with perception-based paradigms.

The Impact of Core Principles Across Domains: The Core System of Agents

In the core domain of physical objects, infants rely on a set of core principles to represent all patterns that move as bound cohesive units as distinct physical objects. Similarly, the core system of animate agents also includes a set of abstract principles that allow infants to individuate and represent animate agents and infer their behavioral properties (e.g., Spelke & Kinzler, 2007). Also, in this domain, infants rely on specific kinematic cues to individuate animate agents in the perceptual array (Leslie, 1994, 1995; Mandler, 1992, 1998, 2000; Premack, 1990). At a very basic level, the impression of agency, goal directedness, or even intentionality may therefore be captured by the visual system in an analogous fashion as the physical structure of the world (Blythe, Todd, & Miller, 1999; Cisbra, Gergely, Biró, Koós, & Brockbank, 1999; Dittrich & Lea, 1994; Gelman, Durgin, & Kaufman, 1995; Gergely, Nádasdy, Csibra, & Biró, 1995; Scholl & Tremoulet, 2000), rather than the infant needing to rely on a conceptual understanding of the animate/inanimate distinction (e.g., Scholl & Tremoulet, 2000). Basically, the aspects of motion that are proposed to possibly convey animacy are: (1) onset of motion (self-propelled vs. caused); (2) line of trajectory (smooth vs. irregular); (3) form of causal action (action at a distance vs. action from contact); (4) pattern of interaction (contingent vs. noncontingent); and (5) type of causal role (agent vs. recipient; see Rakison & Poulin-Dubois, 2001, for a review).

An important signature limit of core knowledge systems is their domain specificity: Core principles crucial in perceiving and reasoning about physical objects may not be used, or may not be as important in the core domain of agents (e.g., Spelke & Kinzler, 2007). Objects are stable in form and space as they cannot move or change their form in the absence of an external force. Animates, instead, can move alone and in a nonrigid fashion without necessarily preserving stable pattern boundaries. For example, animate bodies may display an expanding/contracting shape while moving (which is indeed challenging when tracking inanimate bodies, see vanMarle & Scholl, 2003), or their extremities may oscillate or move in a discontinuous fashion. Furthermore, animates can partially change their form by engaging in events of fission or fusion (e.g., incorporating or ejecting other objects, as during metabolic processes, in deliveries, or during defensive behavioral patterns, like lizards losing their tails). It is therefore possible that the cognitive mechanisms designed to individuate/represent animates might allow more degrees of freedom regarding connectivity and shape preservation. Indirect evidence that this may be the case comes from Landau and Leyton (1999), who found that children accept a greater range of shape transformations for animates when generalizing object names. However, agents are also fundamentally material objects and, thus, they not only have physical dimensions (e.g., shape and size), but also engage in physical interactions and displacements, being subject to physical laws (e.g., cohesion, continuity, and solidity), like physical objects do, and are for example tracked in a similar way as objects are (e.g., Scholl & Tremoulet, 2000). It is therefore important to investigate the extent to which the core principles of physical objects are really domain-specific, as predicted by the core knowledge approach, or whether they also extend to processing of animate agents, which despite being partly similar to objects, also have a higher degree of freedom in their movements. Only a few studies have ever addressed the impact of core principles across core domains. For example, Kuhlmeier, Bloom, and Wynn (2004) suggested that 5-month-olds apply the continuity principle to physical objects, but fail to do so to people. On the basis of these findings, Kuhlmeier et al. (2004) argued that the two core domains are fully separated and infants do not use the same principles across domains. These findings have been questioned by Saxe, Tzelnic, and Carey (2006), who found that infants expect humans to be solid like all material objects. Further evidence that infants appreciate the solidity of humans comes from a study using point-light displays (Moore, Goodwin, George, Axelsson, & Braddick, 2007). In contrast, Woodward, Philips, and Spelke (1993) found that 7-month-old infants did not apply the contact principle to people and appreciated that, in contrast to physical objects, people can move without prior contact to other people/objects. This is in line with Kosugi and Fujita (2002), who reported that 8- to 10-month-olds appreciate different causal principles between objects and humans, even considering the possibility of communication between persons. In sum, the few existing studies suggest that infants differ in the way they use core principles across domains, but generally understand the ambiguity of animates, who are at the same time agents and material bodies. The second aim of this study is therefore to better analyze whether cohesion manipulations have a similar effect on the two different core domains of physical objects and animate agents.

The Present Study

In this study, we investigate whether the cohesion principle is equally necessary to represent physical objects and animate agents and, secondarily, whether cohesion manipulations have stronger effects when perception-based paradigms are used. To do so, we implemented a perception-based paradigm designed in accordance with the study of Chiang and Wynn (2000). Instead of inanimate objects (e.g., Lego blocks), we presented 8-month-old infants with animate agents, that is, with animated film clips in which two snails crawled behind screens or out of the display. In contrast to the inert Lego blocks used by Chiang and Wynn (2000), which were moved by hands, the snails in our study were conferred animacy status by being self-propelled and not moved by hands. Various studies have found that even highly abstract characters conveying agent-like movement patterns are typically perceived as animate agents by human adults and children (e.g., Gergely et al., 1995; Scholl & Tremoulet, 2000), an effect that has also been confirmed by neuroimaging studies (see Blakemore et al., 2003). Would infants fail to continue to represent a split snail behind a screen as was the case for inanimate Lego towers in the Chiang and Wynn (2000) study? Or do the deleterious effects of cohesion manipulations result from a domain-specific processing mechanism that exclusively concerns the perceptual tracking of inanimate objects?

Experiment 1

In this experiment, we investigated whether infants are able to track and individuate the number of snails in a scene after the snails have been split in two and then hidden behind a screen. Infants were presented with two test conditions: a baseline and a fission condition. As in the Chiang and Wynn (2000) study, we used a split-screen procedure (see also Spelke & Kestenbaum, 1986; Xu & Carey, 1996). Infants saw two snails crawling into the scene and then either moving behind one of two spatially separate screens or out of the display. In the baseline condition, the snails performed these movements as untouched wholes. In the fission condition, one snail was split in two before it moved behind the screen or out of the display. The screens were then dropped to reveal the outcome of only one snail being behind one screen. This outcome was expected in the "move-out-of-display" action sequence ("expected disappearance"), but unexpected in the "move-behind-screen" action sequence ("magical disappearance"). We reasoned that if infants manage to track the items in both conditions and expect them to maintain spatio-temporal continuity, they should look longer at magical over expected disappearance events in both conditions (see Chiang & Wynn, 2000).

Method

Participants

Forty full-term 8-month-olds (19 females, 21 males; mean age = 247.1 days; SD = 8.3 days) participated in this experiment. Infants were randomly assigned to one of two test conditions (baseline, fission). All infants were recruited from a database consisting of infants whose caregivers had volunteered to participate in child development studies. They received a small gift for their participation. Eighteen other infants were excluded from the sample due to equipment failure (n = 2), parental interference (n = 2), or fussiness and failure to complete two consecutive trials twice (n = 14).

Apparatus and Stimuli

In both conditions, infants saw three familiarization and two test events (film clips). All film clips were created by graphic artists from a local art school using Adobe Flash CS3 Professional. They involved two snails that were created to comply with infants' most basic notion of animate objects as "self-moving interactors" (see Mandler, 2008; Opfer & Gelman, 2011; Rakison & Poulin-Dubois, 2001): The snails (1) started motion by themselves, (2) interacted with others at a distance (i.e., were shooed by a gloved human hand), (3) moved in an animate fashion, and (4) showed typical featural qualities (i.e., a face). Thus, rather than using a naturalistic depiction, we employed symbolic drawings, which allowed us to pre-

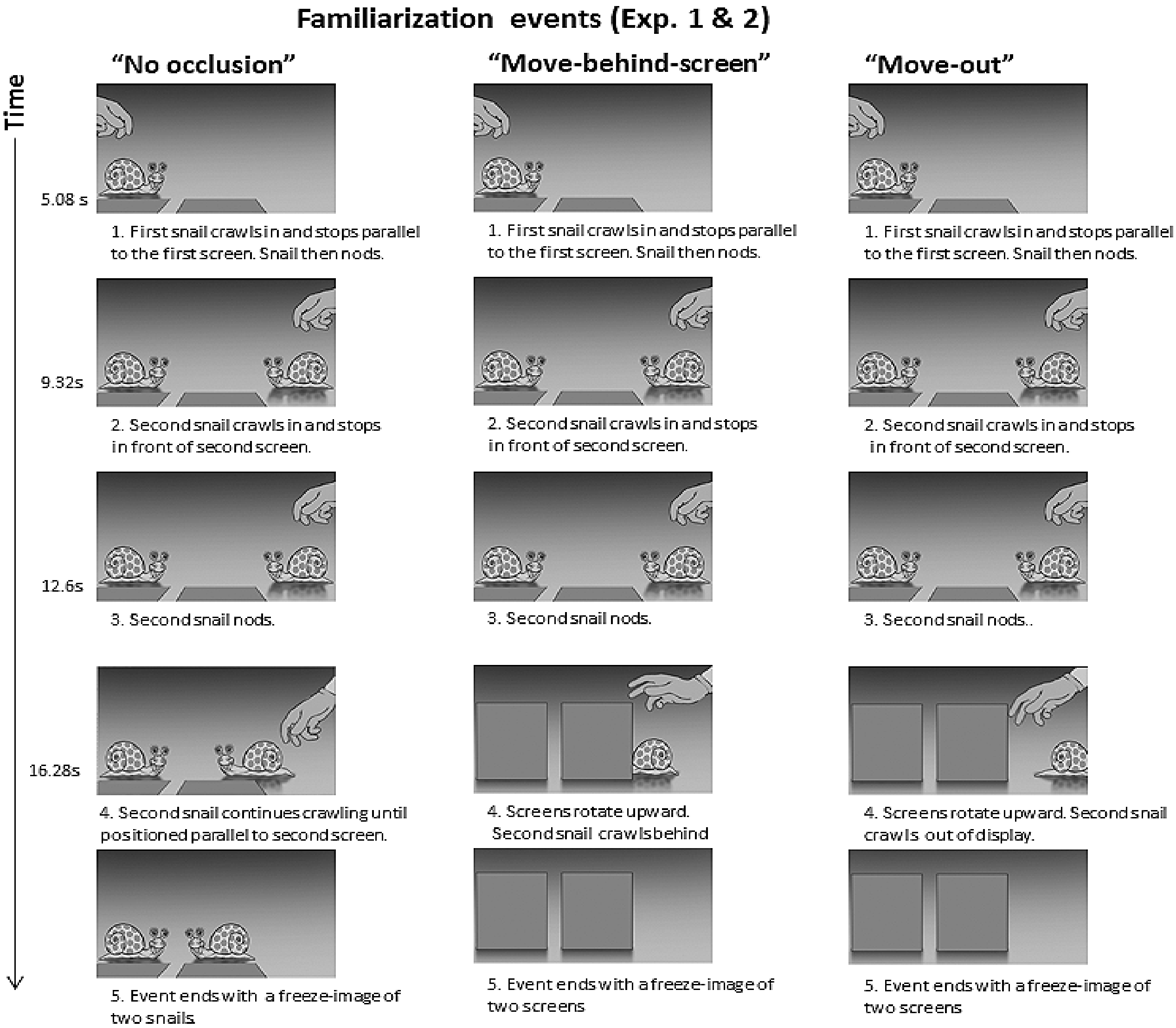

Figure 1. Sequence and timing of the three familiarization events used in Experiments 1 and 2. The time bar denotes the duration (in seconds) after which a given sequence is completed.

sent the animacy cues in a very accentuated fashion. The only exception was the near-to-authentic dynamic movement of both snails and hands.

The events were presented on a 30-inch computer monitor. Infants sat on the caregiver's lap in a dimmed room approximately 70 cm in front of the computer screen. Dark brown curtains hanging from the ceiling to the floor prevented visual distraction of the infants. A camera located above the computer screen monitored and recorded infants' looking direction and duration.

Familiarization Events

The familiarization phase was exactly the same in both conditions and included the following events: (1) a no-occlusion familiarization event introducing the two snails without occlusion, (2) a move-behind-screen familiarization event in which both snails moved behind screens, and (3) a move-out familiarization event in which one snail moved behind a screen and the other moved out of the display. The structure and timing of the familiarization events are depicted in Figure 1.

The no-occlusion familiarization event was used to familiarize the infants with the snails and the hand. It included the following sequences: (1) Shooed by a gloved hand, the first snail crawled in and stopped when it was parallel to the first screen; (2) the first snail nodded; (3) shooed by the gloved hand, the second snail crawled in and stopped in front of the second screen; (4) the second snail nodded; (5) shooed by the gloved hand, the second snail continued to crawl until it was parallel to the second screen. The event

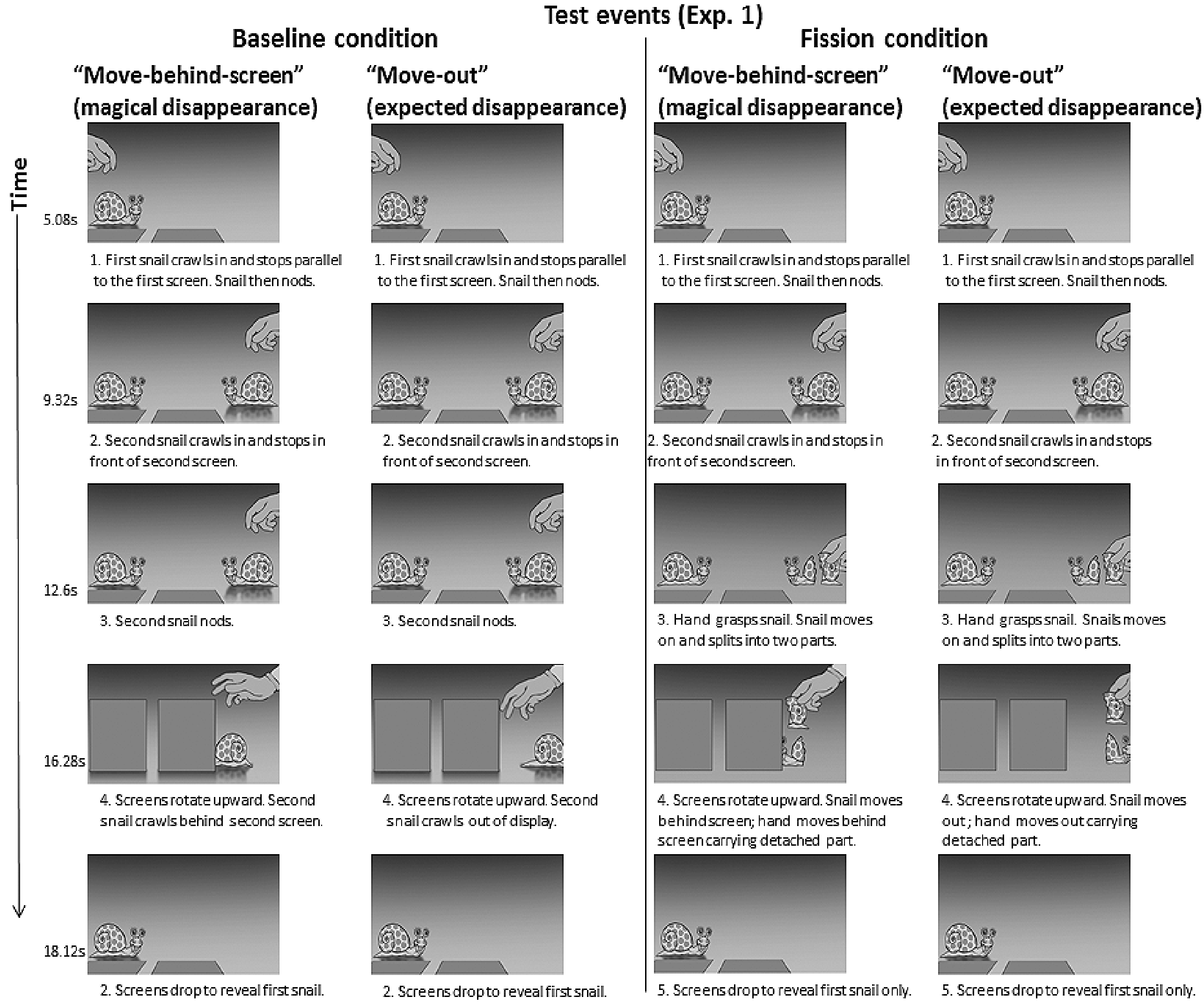

Figure 2. Sequence and timing of the two test events in the baseline and fission conditions of Experiment 1. The time bar denotes the duration (in seconds) after which a given sequence is completed.

ended with a freeze shot of the snails in full view (total duration = 16.28 s).

The move-behind-screen and move-out familiarization events were used to familiarize infants with the snails moving behind the screens and moving out of the display, respectively. The move-behind-screen familiarization event included the following sequences: (1) Shooed by a gloved hand, the first snail crawled in, stopped when it was parallel to the first screen and nodded; (2) shooed by the gloved hand, the second snail crawled in and stopped in front of the second screen; (3) the second snail nodded; (4) the screens rotated upward, thereby covering the first snail; shooed by the gloved hand, the second snail crawled behind the second screen; (5) the event ended with a freeze shot of the two screens (total duration = 16.28 s). The move-out familiarization event was exactly the same, except that the second snail crawled out of the display instead of behind the screen.

Test Events

In addition, in both conditions, infants observed two test events: (1) a move-behind-screen test event in which both snails moved behind the screens and (2) a move-out test event in which one snail moved behind a screen and the other moved out of the display.

The structure and timing of the test events in Experiment 1 is depicted in Figure 2.

Baseline Condition

The move-behind-screen and move-out test events were identical to the move-behind screen and move-out familiarization events, except that the test events ended with both screens dropping down to reveal only one (the first) snail. For the move-out test event, this outcome was expected, but it was unexpected for the move-behind-screen test event (one snail had magically disappeared). The test events were slightly longer than the familiarization events (total duration = 18.12 s).

Fission Condition

The fission-condition test events were identical to the baseline-condition test events, except that the second snail's nodding was replaced by a fission manipulation. The gloved hand grasped the snails' shell while the snail was moving forward; as a result, the snail split into two parts. After the split, the snail continued moving forward, keeping its modified contour. The gloved hand then carried the detached part behind the screen (move-behind-screen event) or outside the display (move-out event; total duration = 18.12 s in both cases). Again, the fission movement replaced the nodding movement so that the overall duration of movements across all test events was identical.

Design and Procedure

Familiarization Phase

The three familiarization events were presented to the infants before the two test events. First, the infants saw the no-occlusion familiarization event, after which the move-behind-screen and move-out familiarization events were presented in a counterbalanced fashion (i.e., half of the infants saw the move-behind-screen events first and half saw the move-out familiarization events first). We used an infant-controlled procedure, that is, the intervals were adapted to each individual infant. The experimenter coded familiarization performance online on a computer. Stimulus presentation and calculation of the criteria for trial ending were controlled by the computer program. Each familiarization trial ended when the infant looked away for 2 s or when a maximum of 60 s had elapsed.

Each trial began with an attention getter directing the infant's attention to the computer screen. Once the infant's attention was secured, the experimenter started the familiarization event by pressing a computer key. The experimenter observed the infant's gaze via a monitor outside the viewing chamber and coded the infant's performance by pressing computer keys. Infants' looking behavior was recorded from the beginning of each familiarization event. The final scene remained on the screen until the program signaled the end of the trial (computed according to the criteria mentioned above), after which the attention getter reappeared. The familiarization phase ended after the infant had seen all three familiarization events.

Test Phase

Immediately after the familiarization phase, the infants were exposed to the move-behind-screen and move-out test events of their condition. The order of the test events was counterbalanced across infants (i.e., half of the infants saw the move-behind-screen events first and half saw the move-out events first). Infants' looking behavior was recorded after the screens had dropped down to reveal the outcome (after 18.12 s). The final scene remained on the screen until the program signaled the end of the trial. Each test trial ended when the infant looked away for 2 s or when 60 s had elapsed.

Coding

Data coding of the test trial performance was conducted online (as outlined above) and all infants were videotaped. The test trial performance of 10 randomly chosen participants was reassessed by a second observer (blind to the experimental condition) to calculate interobserver reliability. The average Pearson correlation between the two observers was .98.

In addition, for each infant and test event, we checked whether the infants had seen the critical movements of the second snail (move behind screen or out of the display). In all cases, the infants had seen the critical movements.

Results

Preliminary analyses revealed no effects of sex. Thus, the data were collapsed over this variable in subsequent analyses. Figure 3 shows the mean looking times in Experiment 1. A 2 × 2 ANOVA on infant looking times with test event (magical vs. expected disappearance) as a within-subject factor and condition (baseline vs. fission condition) as a between-subjects factor revealed a significant effect of test event, $F(1, 38) = 6.65$, $p = .014$, $\eta_p^2 = .15$, with infants looking longer at the magical disappearance event (M = 15.17 s, SE = 1.58) than at the expected disappearance event (M = 11.70 s, SE = 1.31). Furthermore, there was a significant interaction between test event and condition, $F(1, 38) = 4.79$, $p = .035$, $\eta_p^2 = .11$. Posthoc *t*-tests on the looking times in each of the two conditions revealed that the infants in the baseline condition looked significantly longer at the magical disappearance (M = 18.06 s, SE = 2.20) than at the expected disappearance event (M = 11.63 s, SE = 1.67), $t(19) = 3.71$, $p = .001$ (Cohen's d = .74). In contrast, the infants in the fission condition looked equally long at the magical disappearance (M = 12.29 s, SE = 2.21) and the expected disappearance event (M = 11.76 s, SE = 2.06 (Cohen's d = .06)), $t(19) = .25$, $p = .803$.

Discussion

The infants failed to continue to represent the split snail when it was behind the screen. They readily tracked the movement of the whole snails and expected them to maintain spatio-temporal continuity. Thus, in Experiment 1,

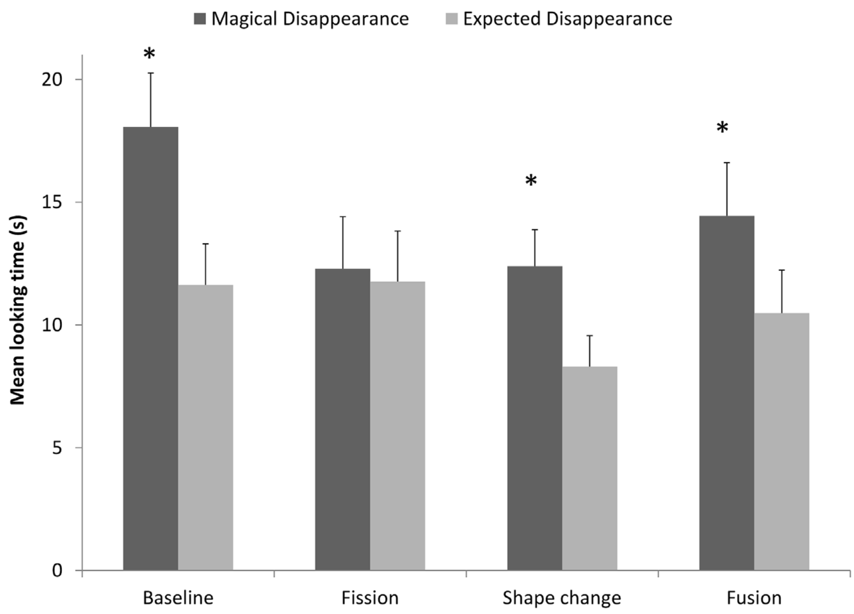

Figure 3. Infants' looking times (and standard errors) during the magical and expected disappearance events in the baseline and fission conditions (Experiment 1), and in the shape-change and fusion conditions (Experiment 2).

they performed the same way the infants in the Chiang and Wynn (2000) study did with inanimate objects, which suggests that the deleterious effects of cohesion manipulations are not restricted to the perceptual tracking of inanimate objects, but are equally encountered during the tracking of animate agents.

There are three possible reasons why the infants failed to detect the magical disappearance of the split snail. First, as suggested by the core knowledge account (e.g., Spelke, 1994; Spelke & Kinzler, 2007), infants may have failed to appreciate a split, noncohesive entity as an object, thus also failing to perceive it as continuous. This explanation may also be conceptualized from the theoretical perspective of the object-file account (Kahneman & Treisman, 1984; Kahneman, Treisman, & Gibbs, 1992; Pylyshyn & Storm, 1988). In this view as well, cohesion manipulations would affect the tracking of entities by interfering with infants' intuition that each physical body follows exactly one continuous trajectory through space and time. Accordingly, infants would fail to appreciate the continuous existence of split objects/agents because they failed to reassign the open object file to multiple resulting parts, as a single object file cannot address multiple locations. Both the core knowledge and the object-file account therefore predict that all cohesion manipulations resulting in spatio-temporal path anomalies should impair infants' object representations. The core knowledge account specifies two types of events violating infants' expectations on object cohesion: (1) fission events, in which objects suddenly follow more than one spatio-temporal path, and (2) fusion events, in which two objects suddenly follow one and the same spatio-temporal path (van de Walle & Spelke, 1996). From the spatio-temporal view, both fission and fusion events violate infants' intuition that objects/agents follow one spatio-temporal trajectory and have been proposed to exert an equal impact on the ability to represent objects/agents (van de Walle & Spelke, 1996). Therefore, if spatio-temporal path anomaly was the reason for infants' failure to track the split snail in Experiment 1 (spatio-temporal path anomaly hypothesis), the same effects would be expected in events in which infants track a fusion of snails.

A second possible explanation for infants' failure to detect the magical disappearance of the split snail is that infants have more general difficulties tracking objects that change their configural properties (e.g., shape) while moving. In this case, infants' problems would arise from perceiving general pattern changes, not from cohesion violations per se. If this is true (configural change hypothesis), infants should not only fail when being presented with a fission or fusion event, but also when tracking objects undergoing a change in shape.

A third explanation views infants' problems as reflecting oversized processing demands (Cacchione, 2013). It is possible that infants' processing capacity is simply overwhelmed when they attempt to track multiple trajectories of detached parts drifting apart. The spatial ambivalence created by the split might place too much cognitive load on infants, impairing their ability to process and individuate entities, as they would have to process a complex transformation and simultaneously track multiple entities moving in different directions. If this is true (spatial ambivalence hypothesis), infants should fail at tracking objects that are split, but should be successful when objects fuse or change their shape because in both events spatial ambiguity does not increase (in contrast to fissions, which always imply an increase in spatial ambiguity).

In the next experiment, we tested these hypotheses. We presented infants with a test condition in which the spatio-temporal path of objects was manipulated without producing spatial ambivalence (fusion condition) and a test condition in which the surface properties of the object were changed, with the snail extending its neck, but the spatio-

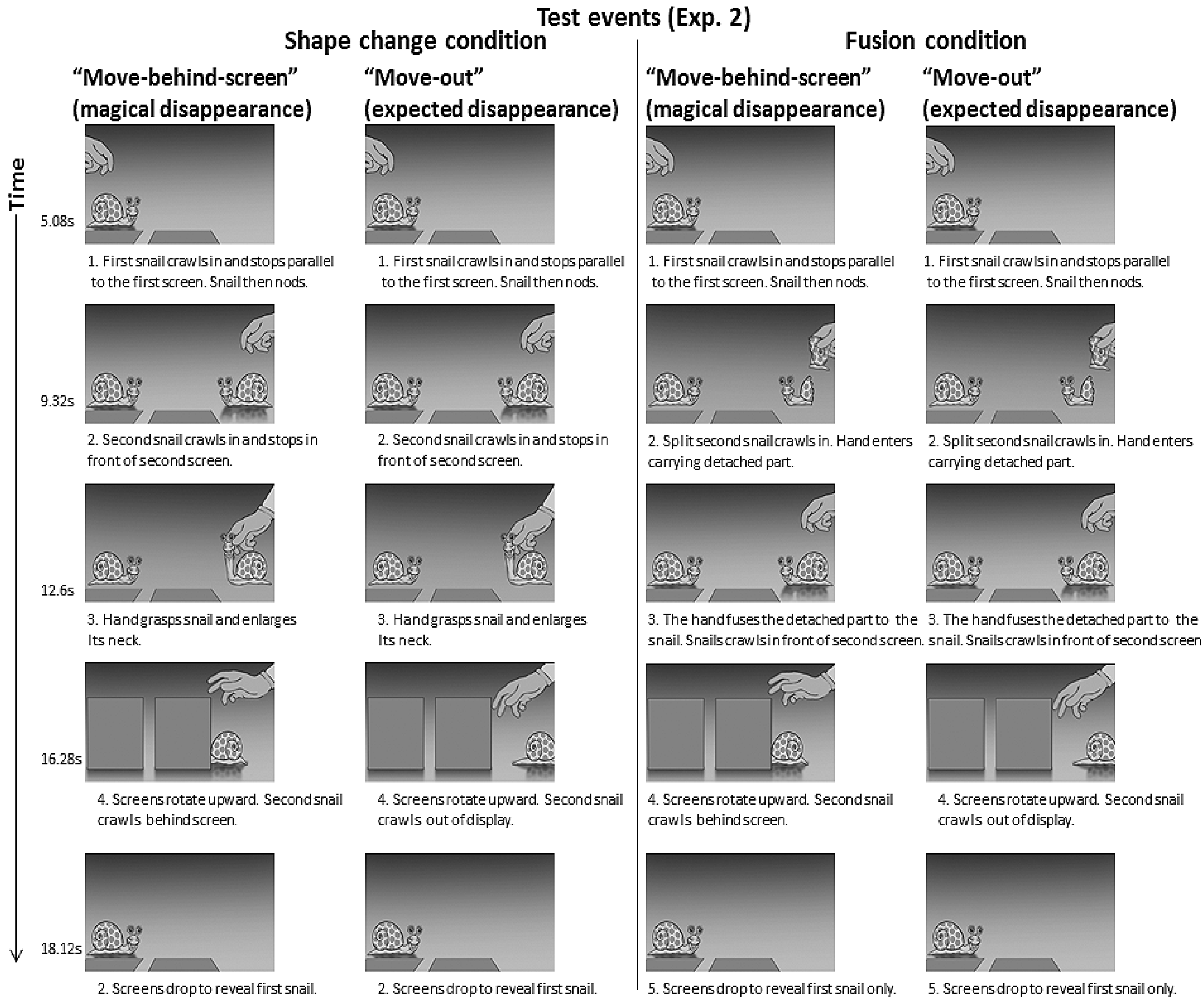

Figure 4. Sequence and timing of the two test events in the shape-change and fusion conditions of Experiment 2. The time bar denotes the duration (in seconds) after which a given sequence is completed.

temporal trajectory (shape-change condition) remained unchanged. In the fusion condition, the snails that were crawling were already missing a detached part, which was carried in from behind by a hand and then attached to the snail, making it whole again. In this case, the spatio-temporal path was as anomalous as in the fission condition because the object failed to follow one continuous trajectory through space and time. If infants react to a spatio-temporal path anomaly alone, they should fail to detect the magical disappearance in the fusion condition (but not in the shape-change condition). If infants react to configural changes alone, they should fail to detect the magical disappearance in the fusion as well as in the shape-change condition. Finally, if infants are simply cognitively overwhelmed by having to follow multiple trajectories, they should successfully detect the magical disappearance in both the fusion and the shape-change condition.

Experiment 2

Method

Participants

Participants were forty full-term 8-month-olds (20 females, 20 males; mean age = 244.5 days; *SD* = 8.3 days). They were randomly assigned to one of two test conditions (fusion and shape-change conditions). All infants were recruited from a database consisting of infants whose caregivers had volunteered to participate in studies of child development. They received a small gift for their participation. An additional 11 infants were excluded from the sample due to equipment failure ($n = 1$), or fussiness and failure to complete two consecutive trials twice ($n = 10$).

Apparatus and Stimuli

The apparatus was the same as in Experiment 1. Again, in both conditions, infants saw three familiarization and two test events (film clips). All clips were created by graphic artists from a local art school using Adobe Flash CS3 Professional and involved the same two snails that were now performing different movements.

Familiarization Events

The familiarization events were exactly the same as in Experiment 1 (see Figure 1).

Test Events

Again, in both conditions, the infants saw two test events: (1) a move-behind-screen test event in which both snails moved behind screens and (2) a move-out event in which only one snail moved behind a screen and the other moved out of the display. The structure and timing of the test events in Experiment 2 are depicted in Figure 4.

Shape-Change Condition

The test events were identical to those of the baseline condition of Experiment 1, except that instead of the second snail's nodding, a shape-change manipulation was carried out. The gloved hand grasped the snails' neck pulling at it, whereupon the snail stretched its neck upward. After the shape change, the snail continued its movements, keeping its modified contour (total duration = 18.12 s). The shape-change movement replaced the nodding movement so that the overall duration of movements across all test events was identical.

Fusion Condition

The test events in the fusion condition were a reversal of the sequences shown in the fission condition of Experiment 1. The second snail entered with its posterior already detached, the detached part being carried by the hand. The hand fitted the detached part to the snail, whereupon the snail moved forward as a whole. After the fusion, the snail continued its movements as in the baseline condition (total duration = 18.12 s). Again, the fusion movement replaced the nodding of the second snail so that the overall duration of movements across all test events was identical.

Design and Procedure

The design and procedure were identical to that in Experiment 1.

Coding

Coding was identical to that in Experiment 1. Again, the test trial performance of 10 randomly chosen participants was reassessed by a second observer. The average Pearson correlation between the two observers was .99. Furthermore, in Experiment 2 as well, all infants had seen the critical movements.

Results

Preliminary analyses revealed no effect of sex. Thus, the data were collapsed over this variable in subsequent analyses. Figure 3 shows the mean looking times in Experiment 2.

A 2 × 2 ANOVA on infant looking times with test event (magical vs. expected disappearance) as a within-subject factor and condition (baseline vs. fusion condition) as a between-subjects factor revealed a significant effect of test event, $F(1, 38) = 13.63$, $p = .001$, $\eta_p^2 = .26$, with infants looking longer at the magical disappearance event (M = 13.41 s, SE = 1.31) than at the expected disappearance event (M = 9.39 s, SE = 1.08). The interaction between test event and condition was not significant, $F(1, 38) = 0.01$, $p = .952$, $\eta_p^2 = .00$. Posthoc *t*-tests on the looking times in each of the two conditions revealed that the infants in both conditions looked significantly longer at the magical disappearance (fusion: M = 14.44 s, SE = 2.17; shape change: M = 12.39 s, SE = 1.49 Cohen's d = .25) than at the expected disappearance event (fusion: M = 10.48 s, SE = 1.75; shape change: M = 8.30 s, SE = 1.26 Cohen's d = .32), fusion: $t(19) = 2.78$, $p = .012$; shape change: $t(19) = 2.48$, $p = .023$.

Discussion

The infants tracked and individuated the snail after the fusion and after the shape change, detecting their magical disappearance in both cases. These results suggest that infants appreciated that fused and shape-transformed snails also maintain spatio-temporal continuity. Therefore, neither a noncohesive spatio-temporal path per se nor a mere configurational transformation can account for the infants' failure to track the split snail. Instead, the inability to track multiple parts drifting apart appears to be the most likely explanation for the infants' failure to track the split snail in Experiment 1.

General Discussion

In this study, infants detected the magical disappearance of snails in various conditions. They detected that a snail was missing in the baseline condition, in which they saw it crawling behind the screen, but the screen dropped down to reveal nothing. Likewise, they detected the missing snail in the shape-change and fusion conditions, in which the snail changed its shape or was fused before crawling behind the screen. However, they failed to detect the magical disappearance of the snail when it had been split in two before moving behind the screen (fission condition), suggesting that infants' reaction to the fission event was qualitatively different from their reaction to all other events presented in the study. Moreover, a purely low-level explanation cannot account for our results since the fusion event was the exact reversal of the spatio-temporal motion sequences shown in the fission event and thus consisted of exactly the same visual patterns (and number of parts) presented in a different order.

The first conclusion is therefore that fission events have the same effect on participants' representations of inanimate objects (Chiang & Wynn, 2000) and animate agents. Accordingly, the effects of cohesion manipulations are not restricted to the perceptual tracking of inanimate objects as predicted by the core knowledge approach (e.g., Spelke & Kinzler, 2007), but they also extend to the processing of animate agents. It is remarkable that the processing of animate agents is as vulnerable to noncohesive patterns as the processing of inanimate objects, even though animate movement is much more variable than rigid inanimate motion is.

The second conclusion is that infants' failure in perception-based tasks seems to be the result of increased processing demands of simultaneously tracking multiple entities moving in different directions, rather than a result of the violation of core principles. In this study, the infants failed to detect the magical disappearance of the snail in the fission condition, but not in the fusion condition. From a spatio-temporal point of view, fusion events affected object cohesion the same way fission events consisting of exactly the same visual patterns presented in a different order did (see Spelke, 1994). In both cases, the snail failed to follow exactly one spatiotemporal path. Fusion events should therefore have violated infants' appreciation of continuity like fission events did, opening two different files pointing to the same spatio-temporal location. Nevertheless, infants failed to detect the magical disappearance in the fission but not in the fusion condition. Therefore, failure in the fission condition does not depend on the violation of object cohesion per se because otherwise the infants would have had the same reaction in both the fission and fusion conditions. Although the fission and fusion events consisted of exactly the same patterns presented in a different order, changing this order apparently had important effects on infants' looking behavior. This suggests that infants perceived these sequences as two qualitatively different events, each conveying a specific causal structure, and not simply as mere sequences of stimuli (see Leslie & Keeble, 1987). The results of this study therefore confirm that fissions and fusions are processed differently by children and that violation of object cohesion per se cannot account for the results obtained, which contrasts with the core view that noncohesive movement patterns generally impair infants' continuity inferences (e.g., van de Walle & Spelke, 1996). Of course, this is not to say that altering the spatio-temporal path of an entity has no effect at all: Cohesion violations might have a minor, gradual effect on infants' ability to represent entities (see Figure 2, with looking time after the magical disappearance in the baseline condition being the longest across conditions). However, the fact that infants perceive fusioned entities as continuous clearly implies that cohesion violations do not necessarily disrupt infants' ability to represent entities.

If manipulating object cohesion cannot explain our results alone, it is plausible to consider fissions as cognitively more demanding than fusions, as only fissions increase the spatial ambivalence and require participants to simultaneously track multiple entities moving in different directions (in contrast to fusions and shape-change events, which do not increase the spatial ambivalence). Alternatively, fissions might be more cognitively demanding because only fissions introduce ambiguity with respect to which item is the original one to be tracked. Moreover, it is also possible that fusions are not really perceived as violations of the spatio-temporal path, but rather as a collection of items moving together, which infants can easily track (e.g., Chiang & Wynn, 2000). Future studies will need to better explore which of these different explanations is true. However, our results clearly show that infants do not process fissions and fusions in the same way and that altering the spatio-temporal path of one entity is not necessarily enough to impair infants' ability to track this entity, in contrast to what the core knowledge account predicted (van de Walle & Spelke, 1996).

Infants also failed to detect the magical disappearance in the fission condition, but not in the shape-change condition. Therefore, failure in the fission condition cannot result from infants' inability to track objects changing their configural properties while moving, as otherwise the infants' reaction would have been similar in the fission, fusion, and shape-change conditions. Infants instead successfully detected the magical disappearance both in the fusion and in the shape-change conditions, but not in the fission condition, suggesting that they were simply cognitively overwhelmed by having to follow multiple trajectories of the split snail in the fission condition.

Finally, this study might explain the counterintuitive finding that cohesion manipulations more deeply affect infants' performance in perception-based than action-based paradigms. In this study, 8-month-old infants appear to have failed in the fission condition because they were cognitively overwhelmed by having to follow multiple trajectories. However, in an action-based task, 8-month-old infants were able to track a split cracker through occlusion (Cacchione, 2013). This action task, however, posed very low processing demands, as infants were presented with only one entity and had to follow the path of its fragments to their final (hidden) location (Cacchione, 2013). Similarly, infants' performance when tracking objects is also improved by reducing the cognitive load in perceptual tasks in other contexts (e.g., event-mapping vs. event-monitoring tasks to measure infants' object individuation; e.g., Baillargeon & Wang, 2002; see Krøjgaard, 2004, for a review).

Therefore, the putative differential impact of cohesion manipulations in action-based vs. perception-based paradigms might simply be a consequence of differences in processing demands.

However, at present, we can only speculate. Several questions are still open and more research is needed to get a clearer picture of why cohesion manipulations appear much more deleterious to infants' visual tracking than to their search behavior. For example, differences between performance in perception- and action-based paradigms might also be linked to the different stimuli generally used in these tasks (i.e., nonfood vs. food items, which might be particularly motivating for infants). Future research should focus on the conditions that facilitate or hinder infants' ability to track noncohesive patterns through occlusion and compare situations that differ in terms of conceptual significance as well as in terms of processing demands. Moreover, futures studies should address why fissions are cognitively more demanding than other manipulations, including fusions, and which principles besides cohesion operate for both animate agents and inanimate objects.

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