Infants' Sensitivity to the Causal Features of Means–End Support Sequences in Action and Perception

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Current work has yielded differential findings regarding infants' ability to perceptually detect the causal structure of a means–end support sequence. Resolving this debate has important implications for perception–action dissociations in this domain of object knowledge. In Study 1, 12-month-old infants' ability to perceive the causal structure of a cloth-pulling sequence was assessed via a habituation paradigm. After seeing an event in which a supported toy was moved by pulling a cloth that it sat on, 12-month-old infants demonstrated longer looking to events that violated the causal structure of this sequence than to events that preserved the causal structure but varied other perceptual features of the event. Studies 2 and 3 investigated 10-month-olds' interpretations of means–end support sequences using both a habituation paradigm and a task that assessed infants' own means–end actions. Whereas 10-month-olds failed to demonstrate an understanding of the causal structure when tested using a flat cloth as the support (Study 2), sensitivity to this structure was apparent when a rectangular box was the support. These patterns were evident in both action and perception (Study 3). Moreover, individual variation in action task performance was related to visual habituation performance. The results are discussed with respect to the relation between action and perception in infancy.

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Infants evidence increasingly robust knowledge about the physics of everyday objects during the first year of life. This developing knowledge has been tapped in studies of infants' object recognition (e.g., Kaldy & Leslie, 2003), object segregation and individuation (e.g., Wilcox, Schweinle, & Chapa, 2003), knowledge of object principles (Baillargeon, 1995; Spelke, 1994), and understanding of causality governing object motion (e.g., Leslie & Keeble, 1987). Across these domains, object cognition has been assessed via infants' organized actions on objects, as well as by measures of infants' visual attention to objects and events. These two kinds of procedures sometimes appear to yield inconsistent evidence about infants' object knowledge.

A paradigmatic example of dissociations in infants' object cognition concerns the knowledge that an object continues to exist when hidden from view. Based on observations of his own children, Piaget (1953) concluded that an understanding of objects as independent entities with a continued existence does not develop until midway through the second year of life. Indeed, although infants search for fully hidden objects by about 8 months of age (or earlier; see Clifton, Perris, & McCall, 1999; Hood & Willatts, 1986), they are unable to solve more complex search tasks until 12 to 18 months of age (e.g., Kramer, Hill, & Cohen, 1975; Uzgiris & Hunt, 1975).

In contrast, studies using visual attention to tap infants' knowledge report evidence of object permanence as early as 3 to 4 months of age (see Baillargeon, 1995; Johnson, Bremner, Slater, Mason, & Poster, 2002; Spelke, Gutheil, & Van de Walle, 1995). Dissociations in early object knowledge as assessed via looking behavior versus via search tasks have recently been confirmed in direct examinations. Hofstadter and Reznick (1996) compared reaching responses and gaze responses in a task in which 5-, 7-, 9-, and 11-month-old infants could search for a hidden object after a delay. They found that successful performance was more likely with a gaze response, and that perseverative responding occurred more frequently in reach conditions than gaze conditions (but see also Bell & Adams, 1999). Similar dissociations have been documented with respect to the effect of object size on infants' reaching and looking preferences (Newman, Atkinson, & Braddick, 2001), the effect of visible separation and motion cues on infants' object segregation as assessed via looking behaviors versus reaching behaviors (Vishton, Ware, & Badger, 2005), and infants' ability to use object knowledge to guide visual tracking behavior alone versus tracking and reaching behavior together (Berthier et al., 2001). In addition, recent work with toddlers (Mash, Clifton, & Berthier, 2002) and preschoolers (Hood, Cole-Davies, & Dias, 2003) suggests that such dissociations extend into childhood.

Several different types of explanations have been put forth to account for these dissociations. Some investigators have suggested that habituation responses and search task performance yield different evaluations of infants' object knowledge

because action and perception may form functionally independent dissociable systems (e.g., Bertenthal, 1996). Other researchers speculate that irrespective of whether search tasks and looking time procedures rely on a separate or unified system, these two kinds of procedures differ in their dependence on executive functions. Investigators advocating this viewpoint assume that looking time tasks reveal infants' "true" object knowledge, whereas action task obscure this knowledge by making additional demands on the infant (e.g., Baillargeon, Graber, DeVos, & Black, 1990; Diamond, 1991). Finally, other investigators have suggested that action and looking time tasks differ in the type (e.g., Meltzoff & Moore, 1998) or quality (Hood, 2001; Keen, 2003; Munakata, 2001; Munakata, McClelland, Johnson, & Siegler, 1997) of knowledge that they assess. Models to account for dissociations across different response tasks can be further informed by investigating the presence or absence of dissociations across other domains of infant cognition.

Exploring Associations and Dissociations in the Context of Infant Problem Solving

To date, the majority of evidence for dissociations in object knowledge has been gleaned from studies of object permanence. Another central aspect of object cognition involves solving means–end problems, that is, problems in which one must act on an intermediary to attain a goal object (e.g., Willatts, 1999). Successful performance on means–end tasks requires not only the ability to segment and individuate objects from their intermediaries, but also an appreciation of the causal forces acting on objects that govern object motion (cf. Piaget, 1953).

Classic work on infants' action production indicates that means–ends abilities emerge at the same time as searching for hidden objects (Piaget, 1953; Uzgiris & Hunt, 1975). Starting at 6 or 7 months of age infants can be trained to act on one object to attain another (Menard & Aguiar, 2002; Munakata et al., 1997). Over the next several months, infants' behavior on means–end tasks becomes increasingly systematic (e.g., Willatts, 1999), culminating in spontaneous means–end behavior between 9 and 12 months of age (e.g., Bates, Carlson-Luden, & Bretherton, 1980; Diamond, 1985; Piaget, 1953; Uzgiris & Hunt, 1975; Willatts, 1990), an age that coincides with a host of other developments in motor competence, locomotion, social cognition, and referential understanding (Campos et al., 2000). Nevertheless, means–ends skills undergo continued refinement during the second year of life and beyond (e.g., Brown, 1990; Chen & Siegler, 2000; Frye, 1991; Piaget, 1953; Willatts, 1990), and across ages infants' success on means–ends tasks depends on many factors including the extent to which the intermediary and goal appear visually distinct, and the amount of spatial contact between the goal and intermediary (Bates et al., 1980; Piaget, 1953).

This prolonged course of development in action raises the question of whether infants understand the causal structure of means–end problems before they can produce well-organized solutions to these problems. To date, two studies have directly investigated infants' understanding of means–end support sequences using looking-time paradigms. In one study, Baillargeon, DeVos, and Black (1992) tested whether 5.5- and 6.5-month-old infants could understand that pulling the near end of a support is sufficient to move an object when the object sits on (and not adjacent to) the support. Infants were familiarized to an initial display featuring a rectangular box and a teddy bear. Infants then saw test events in which the near end of the box was pulled. In the impossible test events the teddy bear sat adjacent to the box. In the possible test events the teddy bear sat on the far end of the box. In both test events a screen covered the display (with a window in the upper right corner) and the actor reached behind the screen and pulled the near end of the box. The teddy bear then appeared in the window. Six-and-a-half-month-old infants looked longer at the impossible event, suggesting that they understood that pulling the box was sufficient to move the bear to the window when the bear stood on but not adjacent to the box.

However, findings by Schlesinger and Langer (1999) conflict with these results. As part of a larger study on infants' expectations about tool-use events, Schlesinger and Langer investigated infants' judgments of the conditions necessary to bring a toy within reach using a visual preference paradigm in which 8- and 12-month-old infants were shown videotaped test events. In the possible test events, infants saw a toy sitting on a cloth. The cloth was pulled, and the toy moved along with the cloth. In the impossible test events infants saw a toy sitting alongside a cloth. The cloth was pulled and the toy moved ("magically") with the cloth. Twelve-month-old infants, but not 8-month-old infants, looked significantly longer at the impossible test events, indicating that they were sensitive to the causal structure of the sequence.

In addition, Schlesinger and Langer (1999) examined infants' ability to recognize the conditions under which a supported object could be moved in their own actions. A second group of 8- and 12-month-old infants participated in an action task in which they were given the opportunity to pull a cloth to retrieve a toy. For half of the trials the toy was supported by the cloth (contact trials), and for half of the trials the toy sat adjacent to the cloth (noncontact trials). Infants' performance on the task was scored according to a three-stage coding system. The results indicated that the majority of both 8- and 12-month-old infants were at the objective stage, suggesting that infants differentiated between contact and noncontact trials and as such understood the causal structure of the sequence. The results from these studies led Schlesinger and Langer to conclude that infants first develop the ability to respond to violations to the causal structure of the sequence in action, and this ability subsequently informs their perceptual expectations about the event.

Goals of This Study

In light of these apparently contradictory findings, the goals of this study were threefold. First, we sought a method for assessing the causal structure of a means–end support sequence in infants' perception. As previously discussed, a wealth of evidence suggests that infants are sensitive to this structure in their own actions by 12 months of age (e.g., Willatts, 1990). With these findings in mind, in Study 1 we tested 12-month-old infants on a measure assessing perception of means–ends relations. We then extended this paradigm to younger infants in Studies 2 and 3. Second, we sought to reconcile the apparently discrepant findings of Baillargeon et al. (1992) with those of Schlesinger and Langer (1999) by investigating one factor that may have contributed to the discrepancy: the nature of the supporting object. As such, in Study 2 infants were tested using a flat cloth as the supporting object, and in Study 3 infants were tested using a box as the supporting object. Third, in an advance over prior experiments, we sought to directly assess the relation between action task and habituation performance by testing the same infants in matched versions of the two kinds of procedures in Studies 2 and 3.

STUDY 1

In Study 1 we sought to improve on Schlesinger and Langer's (1999) study in several ways. First, we implemented a visual habituation paradigm rather than a visual preference paradigm to provide a more sensitive estimate of infants' detection of violations to dynamic support events. Although some investigators advocate the use of test-trial-only looking paradigms, arguing that the inclusion of habituation trials may induce transient novelty or familiarity preferences (e.g., Bogartz, Shinskey, & Schilling, 2000; Bogartz, Shinskey, & Sneaker, 1997; Cashon & Cohen, 2000; Thelen & Smith, 1994), studies suggest that similar group-level results are obtained across studies whether or not habituation trials are included (e.g., Hespos & Baillargeon, 2001a; Wang, Baillargeon, & Brueckner, 2004).

Our own methodological decision to implement a visual habituation paradigm was based on the efficacy of using this paradigm to reliably assess individual differences in looking times. The inclusion of habituation trials provides observers with more opportunities to acclimate to the looking behavior of individual infants, thus improving observer accuracy and reliability. Furthermore, individual looking times can be influenced by a variety of extraneous variables such as infants' level of alertness or irritability and overall speed of information processing. The impact of these extraneous factors can be particularly prevalent on early trials, resulting in greater initial variability in looking times on early than on late

trials (Cohen & Gelber, 1975). Thus, the implementation of a visual habituation paradigm increases the likelihood that individual differences in infants' looking times reflect meaningful differences in their assessment of test events as opposed to the impact of extraneous variables that can impact both infant looking time and observer measurement of infant looking time.

Second, we aimed to show infants test events that were more closely matched than those used by Schlesinger and Langer (1999). In Schlesinger and Langer's experiments the inconsistent test events differed from the consistent test events both in terms of the position of the toy (it was off the cloth) and in terms of the object's motion (it moved independently).[1] We tested infants in a similar design to that of Schlesinger and Langer in one condition, but we also included a second condition in which the toy was off the cloth for both test events, and the two events differed only in terms of the motion of the object. We predicted that infants in both conditions would show longer looking on the inconsistent test events, indicating an ability to appreciate the causal structure of the means–end support sequence in perception.

Method

Participants

Sixteen infants between the ages of 11 months 4 days and 12 months 25 days participated in the experiment (M age = 11 months 23 days). Eleven of the infants were boys, and 5 were girls. Seven additional infants began the habituation task but were not included in the final sample because they became upset and were therefore unable to complete the procedure ($n = 2$), there was an experimental error ($n = 3$), or their eye gaze was not visible on the camera for part of the task ($n = 2$). Half of the infants participated in the fixed-toy condition, and half participated in the moving-toy condition.

Materials and Procedure

Figures 1 and 2 depict the habituation and test events for the fixed-toy condition and the moving-toy condition.

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[1]To assess baseline preferences for the outcome of the test events, independent of sensitivity to the causal structure, Schlesinger and Langer (1999) showed infants pretest trials that featured only the static outcome of the possible and impossible tool use events. Both 8- and 12-month-old infants looked equally to both types of test events. However, because pretest trials were only 10 sec in duration, and infants demonstrated near ceiling looking times to these events (e.g., 8-month-old infants looked 8.64 sec [$SD = 2.1$] to the impossible outcome and 8.57 sec [$SD = 2.3$] to the possible outcome) a baseline preference for the impossible outcome may have been obscured.

Habituation event

Inconsistent event   Consistent event

FIGURE 1   Fixed-toy condition.

The stage floor contained a blue cloth (30 cm × 25 cm),[2] that supported a pink plastic pig (5 cm × 5 cm). The cloth was mounted on a slightly elevated black display that allowed for the cloth to be attached to the display with hidden screws so that the cloth would move in a track when pulled and so the experimenter could surreptitiously move the toy from beneath the display. An actor sat behind the cloth facing the infant.

Habituation trials.   On habituation trials the white screen was lowered to reveal the display. On each trial, the actor said "Hi. Look," and reached toward the outer edge of the cloth and pulled it toward her until it could be pulled no further.
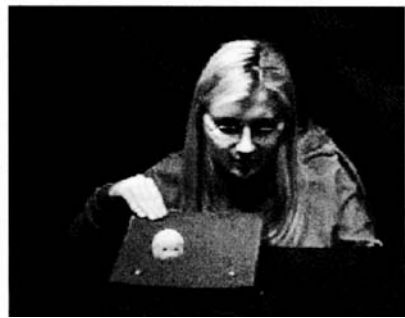
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[2]The cloths were actually rectangular, semirigid pieces of colored cardboard tabs.

Habituation event

Inconsistent event   Consistent event

FIGURE 2   Moving-toy condition.

As she did this, the actor looked at the bottom of the white screen (e.g., just beyond the location of the toy). The criterion for ending a trial was when the infant looked away from the event for 2 sec. The habituation phase was the same for both the fixed-toy condition and the moving-toy condition.

Test trials.   Infants viewed six trials during the test phase. On each test trial the screen was lowered and the actor said, "Hi. Look," and reached toward the outer edge of the cloth and pulled it toward her until it could be pulled no further. On inconsistent test trials the toy was not supported by the cloth, but nevertheless moved along with it, in apparent violation of physical principles. On consistent test trials infants viewed new but physically possible relations between the motion of

the cloth and the motion of the toy. Consistent and inconsistent test events were presented in alternating order, and the type of test event shown first was counter-balanced. The criterion for ending test trials was identical to the habituation phase.

In the fixed-toy condition (see Figure 1) prior to the test phase when the display was hidden from infants' view, the toy was removed from the cloth and placed on an invisible black platform that sat 8 cm to the (infants') right of the cloth. On inconsistent test trials infants saw the actor pull the cloth toward her while the pink pig moved toward her at the same rate as the cloth. The actor accomplished this by using a lever under the display to surreptitiously move the toy toward her. On consistent test trials the actor pulled the cloth toward her while the pig remained in place.

In the moving-toy condition (see Figure 2), the inconsistent test trials were identical to the inconsistent test trials for the fixed-toy condition. However, when the screen was raised after inconsistent test events, the pig was moved 8 cm to the (infants') left of the location at which it had been placed during habituation trials. Thus, in this condition, during consistent test events the toy was in a new location, but one in which it was possible for the cloth to entrain its motion.

Coding.   Infants' looking time was calculated online by an observer who watched the infant on a video monitor. The observer pushed a computer key when the infant was looking at the target area on a given trial (the area encompassing the cloths, toys, and actor). Looking time was calculated from the time the actor stopped moving (e.g., when the cloth was moved as far as it would go in the tracks) until the infant looked away for 2 sec. The observer was not informed of the trial type that infants were viewing and was only able to see the infant on the monitor. A computer program was used to calculate looking times and habituation criteria (Pinto, 1994).

Reliability.   A secondary observer, unaware of the condition in which the infant participated as well as the trial type, coded the infants' gaze from video-tape. The primary and secondary observer were coded as agreeing if they identified the same look away as ending the trial. They were in agreement for 92% of test trials. To ensure that disagreements did not occur systematically in favor of the hypothesis, disagreements were categorized into two groups: those that would have contributed to the hypothesized pattern of findings and those that would have worked against the hypothesized pattern of findings. Disagreements were randomly distributed, $\chi^2(1, N = 7) = 0.14, p > .71$.

Results and Discussion

Looking times to the last three habituation trials and test events for the fixed-toy condition and moving-toy condition are depicted in Figure 3. Infants averaged
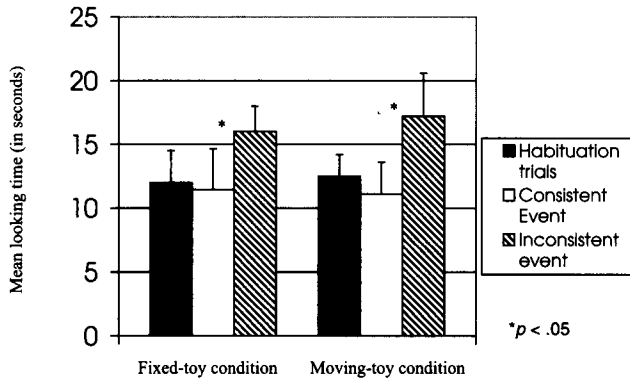
FIGURE 3   12-month-old infants' mean looking times (standard errors) to the habituation and test events (Study 1).

8.8 (SE = .8) habituation trials. The number of habituation trials did not differ across conditions ($t < 1.0$).

Because there was positive skew, the data were log transformed.[3] Preliminary analyses revealed no effect of trial pair or trial pair by trial type interaction. Therefore, subsequent analyses collapsed across trial pair. To explore infants' responses to the test events, an analysis of variance (ANOVA) on infants' looking times to the test events with test event shown first (inconsistent event vs. consistent event) and condition (fixed-toy condition vs. moving-toy condition) as the between-subjects variables, and trial type (consistent vs. inconsistent) as the within-subjects variable, revealed a main effect of trial type, $F(1, 12) = 18.70$, $p < .001$; a marginal effect of test event shown first, $F(1, 12) = 3.81$, $p < .08$; and no other reliable effects. Planned comparisons revealed that infants looked significantly longer at the inconsistent test event than at the consistent test event, $t(15) = 4.12$, $p < .001$, and that this was true whether infants received the inconsistent test event first, $t(7) = 3.0$, $p < .02$, or the consistent test event first, $t(7) = 2.65$, $p < .03$. This analysis indicates that infants in both the fixed-toy condition and the moving-toy condition looked longer on the inconsistent test events, suggesting that they were sensitive to the causal structure of the sequence. A paired-sign test confirmed this pattern of findings: 14 of 16 infants (7 of 8 in each condition) looked longer to the inconsistent event than the consistent event ($p < .004$).

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[3]Log transformations reduce positive skew in looking time data.

The findings from Study 1 confirm that 12-month-old infants are sensitive to the conditions under which a toy can be brought within reach in a cloth-pulling sequence.[4] That is, by this age infants can appreciate that a toy that is supported by but not sitting adjacent to a cloth, will move when the cloth is pulled. These findings are consistent with those of Schlesinger and Langer (1999) as well as Baillargeon et al. (1992).

STUDY 2

In Study 2, we tested 10-month-old infants in the paradigm developed in Study 1. Prior studies differ in their conclusions about infants' understanding of means–end support sequences at this age. Schlesinger and Langer (1999) concluded that infants of this age demonstrate sensitivity to causal features of these sequences in action, but not in perception. In contrast, Baillargeon et al.'s (1992) findings suggest that infants of this age should demonstrate sensitivity to the causal features of these sequences in perception.

A second goal of Study 2 was to assess whether infants were sensitive to causal structure of the sequence both as measured via a habituation paradigm and an action task. The same group of 10-month-old infants participated in the fixed-toy condition of the visual habituation paradigm used in Study 1 and also received an action task in which they were given an opportunity to pull a cloth to attain a toy. During the action task, the toy sat on the cloth for half of the trials and the toy sat

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[4]Infants' looking preferences are governed by a variety of factors. As such, it is always possible that infants' preference for one type of test event over another is governed by an ancillary factor (e.g., perceptual novelty) rather than reflecting a sensitivity to the conceptual violation in question. Under one interpretation, infants may look longer to the inconsistent event in our study because it is more perceptually novel than the consistent event. In fact, infants may not even have noticed the change in the location of the toy in the consistent event.

We do not believe that such an interpretation accounts for our data for several reasons. First, we believe that the consistent event is actually more perceptually novel than the inconsistent event. Whereas the inconsistent event involves a change in the location of the toy, the consistent event involves a change in the location of the toy, and the movement status of the toy in comparison to habituation trials. Second, infants' recovery from the final habituation trial to the consistent test event can be used as an indicator of their ability to notice the change in the toy's location in consistent test events. We undertook a series of one-tailed paired t tests comparing looking on the last habituation trial to looking on the first consistent test trial. In all conditions except one (the fixed-toy condition of Study 1), infants demonstrated significant recovery to the consistent test event—Study 1, moving-toy condition, $t(7) = 3.6$, $p < .004$; Study 2, $t(20) = 2.7$, $p < .01$; Study 3, $t(19) = 1.7$, $p < .03$—indicating that infants were sensitive to the change in toy location. As such, we suggest that our findings indicate sensitivity to the causal violation in question rather than merely reflecting a preference for a perceptually novel event.

adjacent to the cloth on the other half of the trials. To gauge infants' sensitivity to the causal structure of the sequence, we compared infants' implementation of planful strategies as a function of the degree of contact between the toy and the cloth. Planful strategies were operationalized as those trials on which infants' actions were apparently directed toward the attainment of the toy (cf. Sommerville & Woodward, 2005; Willatts, 1999).

Method

Participants

Twenty infants between the ages of 8 months 29 days and 10 months 29 days participated in the experiment (*M* age = 10 months 3 days). Eleven of the infants were female, and 9 were male. The recruitment procedures and testing location were identical to Study 1. Three additional infants began the habituation task but were not included in the final sample because they became upset during the task (*n* = 2) or because there was an experimental error (*n* = 1). All infants participated in the fixed-toy condition (see Figure 1).

Materials and Procedure

Infants took part in the action task followed by the habituation procedure. A fixed-order methodology is standard practice in individual differences research to ensure that individuals are exposed to identical stimulus contexts (for a discussion of this issue, see Carlson & Moses, 2001). Moreover, pilot work suggested that action task order had no effect on overall habituation performance and that infants were more likely to complete both tasks if they received the action task prior to the habituation task. Finally, previous work demonstrated that action–perception linkages were independent of task order (Sommerville & Woodward, 2005).

Action task. Infants were tested in a room adjacent to the habituation room. Infants sat either on their parent's lap or in an adjustable high chair, behind a white table (64 cm × 51 cm) that was positioned at waist height. At the beginning of the task infants were given a yellow duck (9 cm × 9 cm) to play with, until they appeared to be comfortable with the setting. On odd-numbered trials the toy was placed on the far end of a red felt cloth (approximately 33 cm from the infant; contact trials). On even-numbered trials the toy was placed the same distance from the infant, adjacent to the cloth (9 cm to the [infants'] right of the cloth; no-contact trials). Trials lasted until the infant acted on the cloth or until 30 sec elapsed. A number of different toys were used (including an orange porcupine, a pink plastic cat, a blue plastic bear, etc.) to maintain infants' interest. A gray corduroy cloth (43 cm × 28 cm) was used on some of the trials. Both the toys

and the cloth used in the action task differed in color, size, and texture from the habituation toys and cloths. Infants received between 8 and 12 trials, depending on their willingness to participate.

Coding.   Because we were interested in whether infants varied their use of goal-directed strategies as a function of the location of the toy (e.g., across contact and no-contact trials), infants' implementation of planful solutions was coded. The trials on which the infant focused on the toy, maintained focus on the toy while pulling the cloth, and quickly and immediately grasped the toy once it came within reach were scored as planful. However, because on the no-contact trials pulling the cloth could not bring the toy within reach, trials were scored as planful if the infant focused on the toy prior to and while pulling the cloth and either reached for or leaned toward the toy while doing so. The coder was unaware of the infants' habituation responses.

Reliability.   A second independent coder, who was also unaware of infant habituation performance, coded 20% of the infants' action task performance from videotape. The primary and secondary coder agreed on 92% of trials.

*Habituation task.*   The habituation task was identical to the fixed-toy condition of Study 1 (see Figure 1).

Coding and reliability.   Coding of infants' looking time was identical to that of Study 1. A secondary observer, unaware of the condition in which the infants participated, coded the infants' eye gaze from videotape. The primary and secondary observer agreed on the ending of 85% of test trials. The direction of disagreements was randomly distributed, $\chi^2(1, N = 16) = 1.5, p > .22$.

Results

Habituation Responses

Infants' looking times to the test events are depicted in Figure 4. Infants averaged 7.8 ($SE = .5$) habituation trials.

The data were log transformed to reduce positive skew. Preliminary analyses revealed a marginal effect of trial pair, $F(2, 19) = 3.33$, $p < .06$, indicating that looking declined across trial pairs but no Trial Pair × Trial Type interaction. Therefore subsequent analyses were collapsed across trial pair. To explore infants' responses to the test events, an ANOVA on infants' looking times to the test events with test event shown first (consistent event vs. inconsistent event) as the between-subjects variable, and trial type (consistent trial vs. inconsistent
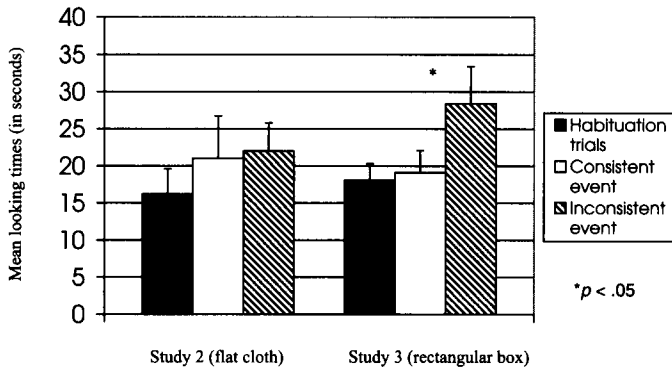
FIGURE 4   10-month-old infants' mean looking times (standard errors) to the habituation and test events (Studies 2 and 3).

trial) as the within-subjects variable, revealed no reliable effects. Planned comparisons revealed that infants' looking to the two test events did not differ significantly ($t < 1.0$). Nine of the 20 infants looked longer at the inconsistent test event ($p > .82$).

Action Task Performance

Figure 5 presents the proportion of planful strategies that infants produced on the action task. To test whether infants were sensitive to the conditions necessary to bring the toy within reach, the frequency with which infants implemented planful strategies as a function of whether or not there was contact between the toy and the cloth was investigated. Planned comparisons revealed no difference in the proportion of planful strategies as a function of trial type: Infants produced planful strategies on an average of 51% ($SE = .09$) of contact trials and 46% ($SE = .08$) of no-contact trials ($t < 1.0$). In addition, only 5 of 19[5] infants produced a higher frequency of planful strategies when there was contact between the toy and the cloth than when there was no contact ($p > .99$).

Discussion

The results from Study 2 provide no indication that 10-month-olds, as a group, were sensitive to the causal structure of the cloth-pulling sequence as measured via a habituation paradigm. As such, these findings (taken in conjunction with those of Study 1) are consistent with the looking time data of Schlesinger

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[5]One infant refused to participate in the action task.
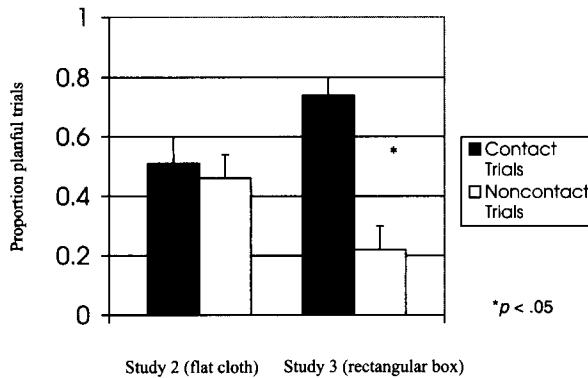
FIGURE 5   10-month-old infants' mean proportion of planful strategies in the action task (Studies 2 and 3).

and Langer (1999) and seem inconsistent with the findings of Baillargeon et al. (1992). Study 3 was designed to further investigate this apparent contradiction.

The results of the action task suggest that 10-month-olds are no better at deploying planful strategies as a function of the toy location than they are at appreciating the need for contact between the toy and the cloth when watching another person act. These findings stand in contrast to those of Schlesinger and Langer (1999), who reported that by 8 months of age infants use different strategies to retrieve the toy depending on whether or not there is contact between the toy and the cloth. One reason for this discrepancy may have to do with the coding scheme that was used by Schlesinger and Langer to classify infants' behavior on the task. In this experiment, we classified infants as discriminators or nondiscriminators based on whether or not they used a higher frequency of planful strategies on contact versus no-contact trials. Schlesinger and Langer reported that 81% of 8-month-old infants were at the objective stage (e.g., used goal-directed strategies on the contact trials but not the no-contact trials). However, the criterion used to make this distinction was not reported. For instance, infants may have been classified as at the objective stage based on the mere appearance of a different strategy to solve the task on a single no-contact trial.

STUDY 3

At face value, it is difficult to reconcile Baillargeon et al.'s (1992) findings with those of Schlesinger and Langer (1999) and this experiment. Although there are superficial differences in all of the tasks (for instance, the perspective

that the baby had on the event, whether the event was live or recorded, and whether the paradigm was a visual preference paradigm or a habituation paradigm), these differences do not appear to account for the reported discrepancy in results.

One factor that may account for the age at which infants can demonstrate sensitivity to the causal structure of the sequence is the type of support that is used in the display. Both Schlesinger and Langer (1999) and the experiments reported here used flat cloths in their displays, whereas Baillargeon et al. (1992) used a box. It may be the case that the latter display provided a more compelling instance of support. For instance, removing a supported toy from a box involves both vertical and horizontal displacement, whereas removing a supported toy from a cloth involves primarily horizontal displacement. In addition, a support relation involving a flat support may have a different causal history than that of a more substantial support. Consider, for example, a brick supported by a piece of tissue paper versus a brick supported by a two-by-four. It is clear that pulling the two-by-four will reliably bring the brick within reach, but that pulling the tissue paper may not. As Baillargeon (1995) suggested, infants' ability to reason about aspects of their physical world is probably dependent on a variety of task-specific variables.

To determine whether the type of support used influences 10-month-olds' sensitivity to the causal structure of the sequence, 10-month-old infants in Study 3 participated in a habituation task and an action task that featured rectangular boxes rather than flat cloths. The question in this study was whether replacing the cloth with a box would facilitate 10-month-olds' ability to detect violations to the causal structure of the means–end support sequence, and whether it would do so similarly in action and perception. In addition, by pooling data across Studies 2 and 3, we examined infants' looking times to the habituation event as a function of their action task performance, to see if performance across the tasks was related at the individual level.

Method

Participants

Twenty-one infants between the ages of 9 months 1 day and 11 months 6 days participated in the experiment (*M* age = 9 months 29 days). Six of the infants were female, and 15 were male. The recruitment procedures and testing location were identical to previous studies. Ten additional infants began the habituation task but were not included in the final sample because they became upset and were unable to complete the procedure (*n* = 4), there was an experimental error (*n* = 3), or their eye gaze was not visible on the camera for part of the task (*n* = 3). All infants participated in the fixed-toy condition.

Materials and Procedure

All infants participated in the action task, followed by the habituation paradigm.

Action task.   This task was identical to that of the action task of Study 2 except that boxes (23 cm × 15 cm × 6 cm) were used in place of the red and gray cloths. These boxes were covered with the red felt cloth and gray corduroy cloth that the cloths in early experiments were tailored from. In addition, these boxes had a slight lip made out of cloth that extended from one end of the box, to ensure that the boxes were no harder to grasp than the cloths used in Study 2.[6]

Coding and reliability.   The coding scheme was identical to that used in Study 2. A secondary coder, unaware of infant habituation performance, coded 20% of the infants' action task performance from videotape. The primary and secondary observer agreed on 91% of trials.

Habituation paradigm.   The habituation paradigm was identical to that of the fixed-toy condition of Studies 1 and 2 with one minor exception. Instead of using a cloth to support the toy, a rectangular box was used (30 cm × 15 cm × 10 cm). This box was the same color as the blue cloth that had been used in Studies 1 and 2.

Coding and reliability.   Coding of infants' looking time was identical to that of Studies 1 and 2. A secondary observer, blind to the condition in which the infants participated, coded the infants' eye gaze from videotape. The primary and secondary observer agreed on the ending of 92% of test trials. The direction of disagreements was randomly distributed with respect to trial type, $\chi^2(1, N = 9) = 1.84, p > .17$.

Results

Habituation Responses

Figure 4 depicts looking times to the test events. Infants averaged 8.4 habituation trials ($SE = .6$).

Because there was positive skew in the looking time data, the data were log transformed. Preliminary analyses revealed a main effect of trial pair, $F(2, 19) = 7.33$, $p < .01$, indicating that infants' looking time declined across trial pairs but no Trial Pair × Trial Type interaction. Therefore all subsequent analyses were collapsed

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[6]One participant did not have sufficient usable trials to score action task performance.

across trial pair. To explore infants' responses to the test events, an ANOVA on infants' looking times to the test events with test event shown first (consistent event vs. inconsistent event) as the between-subjects variable, and trial type (consistent vs. inconsistent) as the within-subjects variable, revealed a main effect of trial type, $F(1, 19) = 12.75$, $p < .01$, and a Trial Type × Test First interaction, $F(1, 19) = 11.37$, $p < .01$. Post hoc comparisons revealed that whereas infants who saw the inconsistent test event first looked longer to the inconsistent event than the consistent event, $t(10) = 6.1$, $p < .001$, infants who saw the consistent test event first looked equally to both types of test events, $t < 1.0$. All 11 infants who received the inconsistent test event first looked longer to the inconsistent test event than the consistent test event ($p < .001$), whereas 7 of 10 infants who saw the consistent test event first looked longer to the inconsistent than the consistent test event ($p > .34$).

Previous research suggests that initial sensitivity to knowledge tapped by habituation tasks may be easily disrupted by task demands, such as the order in which test events are displayed (e.g., Baillargeon, 1987). To circumvent this problem, researchers often use a between-subjects design in habituation studies (e.g., Huettel & Needham, 2000). Given the order effects in our data, we next compared infants' looking on the first test trial as a function of whether infants received the inconsistent event first or the consistent event first. An unpaired one-tailed t test indicated infants who saw the inconsistent event first looked significantly longer on the first test trial than those who saw a consistent test event, $t(19) = 1.9$, $p < .04$.

To compare looking times to the test events with those of Study 2, infants were categorized according to the experiment in which they participated and their habituation task preference. Infants' individual looking preferences varied significantly according to the experiment: Whereas 9 of 20 infants in Study 2 showed a preference for the inconsistent test event, 18 of 21 infants in Study 3 showed a preference for the inconsistent test event, $\chi^2(1, N = 41) = 7.55$, $p < .01$.[7]

Action Task Performance

Figure 5 presents the proportion of planful strategies that infants produced as a function of trial type (contact vs. no-contact) for Studies 2 and 3. Infants produced significantly more planful strategies when the toy sat on the box ($M = .74$, $SE = .06$) than when the toy sat adjacent to the box ($M = .22$, $SE = .08$), $t(18) = 6.4$, $p < .0001$. To compare infants' performance on the action task to that of performance in Study 2, the proportion of planful strategies that infants produced were entered into an ANOVA with study (Study 2 vs. Study 3) as the between-subjects factor and trial type (contact vs. no-contact) as the within-subjects factor. This

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[7]Infants across Studies 2 and 3 did not differ significantly in age ($t < 1.0$), suggesting that age cannot account for the differences in looking times and action task performance across the two studies.

analysis revealed a main effect of trial type, $F(1, 37) = 29.64, p < .0001$, which was qualified by a Study × Trial Type interaction, $F(1, 29) = 20.62, p < .0001$. Infants in Study 3 produced significantly more planful strategies on contact trials $(M = .74, SE = .06)$ than did infants in Study 2 $(M = .51, SE = .06)$, $t(37) = 2.1, p < .04$, and significantly fewer planful strategies on no-contact trials $(M = .22, SE = .08)$ than did infants in Study 2 $(M = .46, SE = .08)$, $t(37) = 2.1, p < .04$. In addition, whereas 5 of 19 infants discriminated between contact and no-contact trials in Study 2 (e.g., produced a higher frequency of planful strategies on contact than on no-contact trials), 17 of 20 infants did so in Study 3 $(p < .001)$.

The Relation Between Action Task Performance and Habituation Task Performance

To investigate the relation between action task performance and habituation task performance we pooled data across Studies 2 and 3. Our first set of analyses focused on whether infants' ability to discriminate contact versus no-contact trials was associated with their sensitivity to the inconsistent test event (as measured by the extent to which infants recovered attention from the last habituation trial to the first inconsistent test event). To investigate this question we categorized infants in terms of performance on the action task. Those infants who produced a higher proportion of planful strategies on contact trials were dubbed discriminators $(n = 22)$, and those who did not were dubbed nondiscriminators $(n = 17)$. We next entered infants' recovery scores (difference in looking time to the first inconsistent test event from the last habituation trial) into an ANOVA with action task performance (discriminator vs. nondiscriminator) and test event shown first (inconsistent vs. consistent event) as the between-subjects variables. This analysis revealed a main effect of action task performance, $F(1, 35) = 10.1, p < .003$, and no other reliable effects. In addition, whereas discriminators demonstrated significant recovery to the inconsistent test event, $t(21) = 7.1, p < .001$, nondiscriminators did not, $t(16) = 1.2, p > .22$ (see Figure 6).

We next explored the impact of infants' action task performance on their assessment of the test events in the habituation task (Figure 7). Because we had previously demonstrated an effect of test event seen first on infants' looking times to the test events for the Study 2 data, we entered infants' looking times on the first test trial into an ANOVA with test event shown first (inconsistent vs. consistent) and action task performance (discriminator vs. nondiscriminator) as the between-subjects variables. This analysis revealed a main effect of test event shown first, $F(1, 35) = 6.0, p < .02$, a main effect of action task performance, $F(1, 35) = 4.7, p < .04$, and no other reliable effects. However, planned comparisons revealed that longer looking to the inconsistent test event than the consistent test event was only significant for discriminators, $t(20) = 2.4, p < .04$, and not for nondiscriminators, $t < 1.0$.
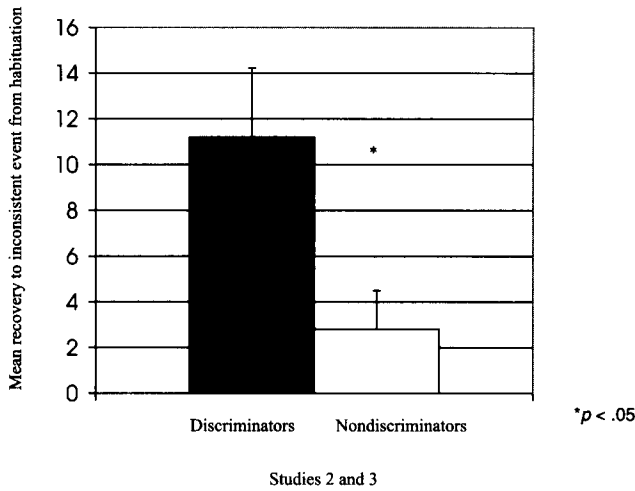
FIGURE 6   10-month-old infants' mean looking time recovery (standard errors) to the inconsistent test event as a function of action task performance (Studies 2 and 3).
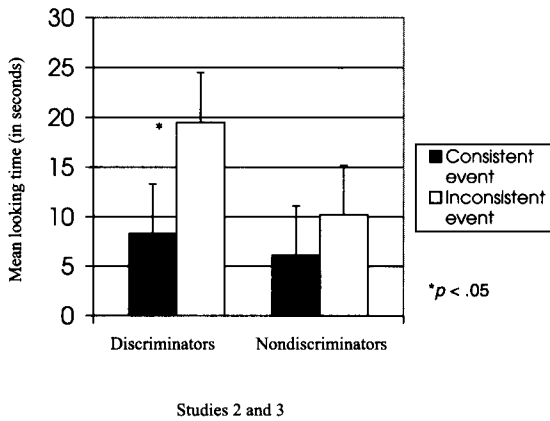
FIGURE 7   10-month-old infants' mean looking time to the test events as a function of action task performance (Studies 2 and 3).

GENERAL DISCUSSION

The findings from these studies suggest age-related changes in infants' ability to appreciate the causal structure of means–end support sequences that are closely linked to the identity of the supporting object and infants' own action capabilities. We demonstrated that 12-month-old infants appreciate the causal structure of

a cloth-pulling sequence in their perception of the actions of others. Taken in conjunction with previous research on infants' ability to solve this task in their own actions, it appears that infants of this age have a robust sensitivity to the causal structure of such sequences in both action and perception.

In contrast, 10-month-olds as a group did not appear to be sensitive to the causal structure of a means–end support sequence featuring a flat cloth, either in action or perception. However, when a rectangular box was substituted for a flat cloth, infants demonstrated sensitivity to the causal structure of the sequence across both tasks. These findings, in part, help to reconcile the disparate observations on infants' ability to detect perceptual support violations using flat versus substantial supports (Baillargeon et al., 1992, vs. Schlesinger & Langer, 1999). A remaining question concerns why infants are more sensitive to the causal structure of a means–end support sequence when a rectangular box is used but not when a flat cloth is used. It may be that support events involving substantial objects provide more compelling instances of the relation between the object and the intermediary that it rests on than sequences involving flat objects. Specifically, displacement of the toy from its supported position involves both vertical and horizontal movement in the case of a rectangular box, but primarily horizontal displacement in the case of the flat cloth. Furthermore, means–end sequences involving substantial objects may have a richer and more reliable causal history than do those involving flat objects.

One way in which this study presents an improvement over previous work (Schlesinger & Langer, 1999) is that the same infants were tested on both action and perception tasks, allowing us to directly compare performance across both tasks. Our findings demonstrate a relation between performance on the action task and the habituation paradigm in two ways. Our data suggest that changing the identity of the intermediary has similar effects on both action and habituation performance. Furthermore, irrespective of the intermediary featured, successful performance on the action task was associated with infants' sensitivity to violations of the causal structure in the habituation paradigm. Although we administered the action task and habituation paradigm in a fixed order, based on previous work with a similar task (Sommerville & Woodward, 2005) we suspect that such action–perception linkages would be found irrespective of task order. Future work, however, should empirically examine the role of task order on the action–perception relations.

Assessing the Association Between Action Task and Habituation Task Performance

What explains the relation between perception of the causal constraints of a means–end support sequence and infants' ability to appreciate these same constraints in their own actions? One possibility is that infants' action and

habituation performance may be underwritten by a third variable that may or may not be central to infants' causal reasoning about means–end support sequences. A good candidate for such a variable is inhibitory control: Diamond (1991) noted that 8 to 12 months of age is a time during which infants develop the ability to inhibit prepotent response tendencies in the context of object search, object retrieval, and detour-reaching tasks. Whereas the action task requires inhibiting a prepotent response (pulling the cloth), the habituation task may require inhibiting a prepotent representation (e.g., inhibiting a representation of the toy moving when the cloth is pulled). Although perseveration, or a failure to inhibit a prepotent response, is typically reserved for tasks that require an active response, some researchers have recently suggested that perseveration may apply to representations as well as actions, and specifically, that performance on habituation tasks may sometimes reflect perseverative tendencies (Aguiar & Baillargeon, 2000, 2003). However, it is unclear from this account why perseveration would be more likely when a cloth was used as a support versus a box, suggesting that inhibitory control may account for some, but not all, of the relation in performance across action and perception tasks in this context.

Another possibility is that action and habituation performance in this context are related and co-occur in development because they both rely on a similar type of causal reasoning. Specifically, to appreciate causal violations to the cloth-pulling and box-pulling sequences, infants must be sensitive to event features that specify adequate support conditions. Infants must recognize that one object must be in contact with another object to (a) be adequately supported by that object, and (b) move as a result of movement of the first object. Although Needham and colleagues (Huettel & Needham, 2000; Needham & Baillargeon, 1993, 1997) have demonstrated that infants have a fairly sophisticated understanding of static support relations by roughly 8 months of age, understanding dynamic support displays may require a more advanced or integrated understanding of support. Huettel and Needham distinguished among three types of support knowledge: understanding primary support relations (that an object may rest on the ground that supports it), understanding secondary support relations (that one object may support another), and understanding animate support (that objects may move freely from place to place if guided by an animate form of support, but not an inanimate form of support). To interpret dynamic support events, infants must appreciate and integrate all three of these types of support knowledge.

Finally, it is likely that these explanations for infants' performance on the means–end support sequences are not mutually exclusive. It is possible that the ability to inhibit prepotent responses is heavily dependent on infants' understanding of the causal or underlying forces operating in a given situation. In one study

(Aguiar & Baillargeon, 2000), after 9- and 11-month-old infants were trained to pull a cloth that supported a toy (over one that was unconnected to the toy), the toy–cloth pairs were reversed and infants were given the opportunity to choose which cloth to pull. Whereas 9-month-old infants perseverated in pulling the initial cloth, which was now unattached to the toy, 11-month-olds were able to switch strategies and pull the cloth now supporting the toy. Aguiar and Baillargeon interpreted these data as evidence that increasing problem-solving expertise results in greater depth of processing of problem features, enabling infants to detect critical differences about the problem once it has changed, and thus to implement novel problem-solving strategies. Under one account 10-month-old infants, who are relative novices at solving the problem, may be attending to the concrete entities involved in the problem, whereas 12-month-old infants may be focusing more on the deeper causal structure of the problem (e.g., the relation between the toy and the cloth; cf. Aguiar & Baillargeon, 2000). These findings suggest that the ability to inhibit a given response may go together with infants' understanding of object knowledge and causal relations.

The Effect of Context on the Development and Demonstration of Cognitive Competence

Our findings suggest that contextual factors, such as the type of objects involved in support sequences, exert an influence on infants' ability to acquire and demonstrate knowledge both in action and perception. Research on infants' problem solving and object knowledge has yielded similar results. Infants' ability to search for a hidden object is affected by the hiding method (Clifton et al., 1999; Meltzoff & Moore, 1998) and the identity of the hidden object (Bigelow, MacDonald, & MacDonald, 1995; Slaughter & Boi, 2001), infants' ability to individuate objects is reliant on the type of objects that infants see (e.g., Kaufman, Mareschal, & Johnson, 2003), and infants' success at tool-use tasks is dependent on the identity of the tool (Bates et al., 1980; Piaget, 1953). Furthermore, infants' ability to reason about object events is category specific: Infants use specific rules to reason about different types of object events. For instance, whereas 4.5-month-old infants can reason about height in a hiding by occlusion event, they cannot yet do so in a hiding by containment event (Hespos & Baillargeon, 2001). These findings and our results are consistent with proposals that suggest that infants' event knowledge may be initially contextually malleable and highly situated and is increasingly filled in by experience (e.g., Baillargeon, 2004). Such a possibility points to the need for continuing work on the investigation of the role of stimulus and context on the acquisition and demonstration of cognitive competence across domains of cognitive development (cf. Fischer & Bidell, 1991).

Associations and Dissociations in Development Broadly Construed

The results of this study add to the growing body of literature examining infants' object knowledge across response modalities and call for a shift from making blanket claims about dissociable or integrated systems to investigating factors affecting the presence or absence of across-task dissociations. Although some studies document dissociations in object knowledge as assessed via looking behavior and action tasks (e.g., Hofstadter & Reznick, 1996), the results from this study and other studies (Bell & Adams, 1999; Hespos & Baillargeon, in press; van de Walle, Carey, & Prevor, 2000) provide evidence that associations in infants' object knowledge across looking time and action tasks also exist. As such, these findings raise the possibility that presence of associations and dissociations across tasks may be mediated by a variety of task variables. In particular, we suggest that the absence or presence of such dissociations may depend as much on the demands of a given task as on the response modality that is used to gauge infants' understanding per se (cf. Munakata, 2001; Munakata & Yerys, 2001). Future work should address factors that mediate the presence or absence of dissociations in infants' performance across tasks with different response modalities.

ACKNOWLEDGMENTS

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