Infants reason about functional information embedded in means-end sequences

by

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For young infants, knowledge of physical objects and animate agents seems highly rigid, with no information combined across domains. Adult cognition, however, is more flexible. In this thesis, I use a special category of object—a tool—that can only be reasoned about appropriately if information is combined across domains. Using this special case, I examine whether older infants are capable of integrating functional information about the tool while making inferences about the intent of the tool-user. Experiment 1 shows that infants can reason about complex means-end sequences involving tools; and Experiments 2 and 3 both show that under some circumstances, infants can take into account functional information about the tool when making these sorts of inferences. Together, these studies extend previous findings about how infants understand complex means-end sequences, and demonstrate that by 13 months, infants are already combining knowledge across domains.
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Chapter 1: Introduction

In a *The New Yorker* cartoon, a woman complains to her mechanic that her car is “often sullen and withdrawn, and then suddenly, it becomes hostile and vengeful.” With that caption, the cartoonist points out a phenomenon of human minds: that from computers to cars to many other everyday objects, we often read intentions into the behavior of purely mechanical entities. Even though we know that our computer does not intend to frustrate us when it notifies us that an application has unexpectedly quit, and we know that our car does not need our encouragement when it sputter-coughs early on a cold morning, we automatically act as if our computers or cars are animate. Yet despite this intention reading, we would never expect our car to answer us back; on a basic level, we do not misjudge the car as truly being alive.

Recently, Paul Bloom and others (Bloom, 2004; Kuhlmeier, Bloom, & Wynn, 2004; Spelke, 1994) have suggested that one aspect of human cognition is a tendency to split the world into two categories: things that are animate, and things that are inanimate. Within each category, the argument goes, there are rules or constraints for how we process information. People and animals, once categorized as animate, are thought about in terms of their goals, desires, or intentions. In contrast, objects categorized as inanimate are thought about in terms of their underlying physical constraints. The line between categories (or domains) is often thought of as hard-and-fast. Once an infant categorizes something as being an object, they use all sorts of rules to describe how that
object ought to behave. This gives the infant a deep understanding of any object nearly instantaneously. However, once that item is categorized as an object, the infant cannot also treat that thing as having goals, desires, or intentions. These categories, at least for very young infants, are considered rigid and encapsulated; that is, no information exchanges across them. The infant can re-categorize something into a different domain if given enough evidence that their initial assumption was wrong—such as when what appeared to be a toy bug suddenly scurries towards the corner. However, once the infant has re-categorized the bug as ‘animate’, all previously held constraints, such as how it ought to behave in a physical world, are no longer accessible (Bloom, 2004). Something about this rigidity changes across development, with adults not as restricted in their cognition as young children. Adults are able to assign animate traits to inanimate objects, and vice versa, suggesting that for them, domains are more fluid or can combine more easily than for young infants. The cartoon above works because the car is inanimate: the cartoon would not be nearly as funny if the woman were discussing the temperament of her horse.

If we start out with such a rigid, encapsulated sense of animate entities and inanimate objects, then how do we get to the flexible state of the woman in the cartoon? There is evidence that infants recognize that some rules do not apply equally well to both animate entities and inanimate objects (Kosugi & Fujita, 2002; Kosugi, Ishida, & Fujita, 2003), and in some cases may even fail to consider rules that do apply to both (Kuhlmeier, Bloom, & Wynn, 2004; but see Saxe, Tzelnic, & Carey, 2006). However, little research has addressed whether infants are capable of deploying two sets of rules at once, in order to reason about a single event. My thesis addresses one special case—tool-
use—in which infants must combine their knowledge of animate and inanimate entities in order to make sense of an event. I use tools because in order to reason about tool-use events correctly, infants must be able to combine physical information (such as the tool’s function) with intentional information (what the tool is being used for) while taking into account causal features of the interaction (how people can act on objects, and how objects can act upon other objects). With this special case, I examine the abilities and limitations of infants to combine knowledge across these domains. That is, I test whether changing physical aspects of the tools involved in an action modifies infants’ interpretation of the intent behind those actions. If so, it would provide increasing evidence that infants can combine their knowledge of animate entities with their knowledge of inanimate objects, and therefore begin to map out what kinds of information infants seem particularly attuned to when combining their knowledge.

**Infants’ understanding of inanimate objects**

Infants’ knowledge of inanimate objects, rather than developing around what infants can easily perceive, instead seems to be organized around the constraints that constitute the most reliable information about an object’s physical properties (Spelke, 1994). The organization of these constraints is considered to be innate because the constraints are not easily deducible from experience, and the infant literature suggests that within the domain of objects, infants’ own experiences could not be sufficient to explain this early-developing knowledge.¹ Additionally, infants’ sensitivity to these constraints within the

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¹ There are two versions of the nativist hypothesis: the strong version and the weak version. The strong version argues that the boundaries between domains, as well as the contents of them are pre-determined. The weak version argues that only the boundaries
domain of objects, but not across all domains, suggests that this type of knowledge may be organized in an encapsulated fashion (Fodor, 1983; Spelke, 1994; Spelke, 2003).

In particular, young infants seem to be sensitive to three principles of objects: cohesion, continuity, and contact. The first one, cohesion, states that objects are defined by their bounding edges, and that those edges must always move in unison. For example, infants find it surprising if part of an object separates when pulled, and therefore are likely to infer that what they saw was two, not one, cohesive objects (Spelke, Phillips, & Woodward, 1995). Similarly, infants are capable of tracking cohesive, but not non-cohesive substances across occlusion (Huntley-Fenner, Carey, & Solimando, 2002).

Infants also expect that objects cannot be discontinuous, blinking in and out of existence. For example, if infants see a box moving back and forth behind two screens, they infer that they are seeing one box if it is visible in the gap between the screens, but two boxes if they never see anything move between the screens (Kuhlmeier, Bloom, & Wynn, 2004; Spelke, Kestenbaum, & Simons, 1995). That is, they make an inference about the number of objects based on continuity: if the movement of the boxes is suggestive of discontinuity, infants infer two; if the movement suggests a continuous whole, infants infer one. This inference is part of a related constraint: that two objects cannot occupy the same space at the same time. Infants only apply this constraint to objects: outside the domain of physics, they are unsurprised at the intersection of two lines, but are surprised when a ball appears to fall through a solid shelf or a rotating screen seems to pass through a solid block (Baillargeon, Spelke, & Wasserman, 1985; Spelke, 1994; Spelke, 1983).

between domains are pre-determined, and experience generates within-domain rules: regularities in knowledge merely reflect universal experiences (Carruthers, Laurence, & Stich, 2005). Either version of the nativist hypothesis is in accordance with the data presented here.
Breilinger, Macomber, & Jacobsen, 1992). Young infants also have sophisticated expectations about contact, understanding that an object can only be set in motion by an external force, and thus are surprised by self-starting objects for which the external force is not immediately obvious, such with a robot (Paulin-Dubois, LePage, & Ferland, 1996) or a mysteriously self-moving chair (Golinkoff, Harding, Carlson-Luden, & Sexton, 1984).

While infants demonstrate sophisticated knowledge about the physical world in areas beyond these core principles, this knowledge develops somewhat later. For example, while the youngest infants can make inferences about support, initial inferences are rather crude. Three-month-old infants only show surprise when an object appears wholly unsupported. Understanding of support develops across the first year of life, with infants ultimately coming to a more adult-like understanding of support by approximately 6.5 months. At this point, infants finally show surprise only if an object’s heaviest edge remains unsupported. By this later age, infants have developed an understanding of how much of an object’s weight must be supported in order for it not to fall, and further, infants seem quite sensitive to an object’s balance point (Baillargeon, 1995; Baillargeon & Hanko-Summers, 1990). However, even by 6 months, infants’ understanding of gravity, a crucial component of support, remains fragile and is easily disrupted (Spelke, Breilinger, Macomber, & Jacobsen, 1992). This gradual development of understanding support, gravity, and balance stands in contrast to Spelke’s principles, to which even the youngest infants will show sensitivity without direct experience, and of which infants show no developmental progression. In general, infants’ early knowledge of objects seems to set the stage for the later emergence of adult-like concepts.
Similarly, young infants possess a sophisticated knowledge of causality. For example, infants recognize that simple co-occurrence do not explain causation across a gap or with a delay (Leslie, 1982; Oakes & Cohen, 1990, 1994). Ball (1973) showed infants several types of contact events and found an asymmetry that matches adult perception of the same events (Ball, 1973; Michotte, 1946/1963): infants automatically assign the causative role to the object that hits and the receptive role to the object that is being hit. That is, adult subjects always report causal events as A setting B into motion, and never that B stops A’s motion, despite that both explanations are equally true (Leslie, 1982; Michotte, 1946/1963). This designation of roles is so powerful that adults can not resist perceiving it, even when they know the effects they see could not be caused by the agents involved (such as when seeing a wooden ball appear to set a circle of light into motion). This rigid feature of adult causal perception is what led Michotte (1946) to anticipate Fodor (1984) in claiming an encapsulated, fast, and domain-specific cognitive mechanism.

Young infants can also make sophisticated qualitative inferences about cause, taking into account the other properties of an object, such as its size, when generating predictions about how it should affect a second object in a causal event. Kotovsky and Baillargeon (1998) demonstrated this elegantly in a series of studies with 6.5-month-old infants (Kotovsky & Baillargeon, 1998). Infants in this study were habituated to a medium sized cylinder rolling down a ramp and hitting a bug-shaped, wheeled toy. Due to the force of the impact, the toy was propelled a certain distance across a stage. Once infants habituated, infants saw two types of test events: a smaller cylinder hitting the bug and propelling it a longer distance away (all the way to the end of the ramp), and a large
cylinder hitting the bug an propelling it a long distance away (also to the end of the ramp). Infants were surprised when the smaller, but not the larger cylinder propelled the bug farther than the medium object had during habituation events, suggesting that they were capable of using a previously seen event to predict cause and effect with new cylinders. A separate group of infants saw a different habituation event: one in which the medium cylinder always propelled the bug to the end of the ramp. This group of infants, when tested on the small and large cylinders, had no preference for how far the other cylinders should propel the bug. This suggests that the infants in the second group had assumed the ramp was too short to reveal the effects of the medium cylinder and therefore the infants could not generate an expectation for how far the other cylinders should propel the bug. Infants in these studies looked longer when the size of the objects mismatched the distance the toy was propelled. This inference was highly specific: infants did not assume, for example, that any impact ought to propel the toy far away—once given a calibration point, or an example of how far a cylinder of a certain size ought to propel the bug, infants were able to infer how far novel cylinders of difference sizes also ought to propel it\(^2\). Therefore, they were capable of using information provided to them in habituation to generate inferences about a novel causal interaction.

Infants’ earliest understanding of inanimate objects, then, appears to be based on domain-specific reasoning that captures the most regular, and non-obvious constraints on

\(^2\) Interestingly, for the youngest infants tested, a sex difference appeared in their understanding of these collision events: the youngest boys, at 5.5 months, could not reason about the interaction, while the youngest girls, at 4.5 months, could. Kotovstya and Baillargeon ruled out attentiveness and working memory as explanations for the difference. From their data, it seems that youngest boys simply have not yet figured out how to reason about these sorts of collision events. Whether this is due to lack of experience (motor abilities) or just later-maturing cognitive abilities remains unanswered.
objects, such as the properties of cohesion, continuity, and contact. This knowledge is not fully encapsulated, as infants exhibit learning about (or maturation of) some of these properties within the domain of objects; however, this knowledge does not seem to be extended to other, non-object domains. Infants’ causal understanding of objects similarly matures during the first six months of an infants’ life, ultimately becoming its own domain of knowledge.

*Infants’ understanding of agents and their actions*

From early infancy, infants treat animate agents differently than they treat objects (Woodward, 1998). Animate agents are treated as having goals, beliefs, intentions, and desires, and these epistemological states are not extended to everyday physical objects. From 4 months, infants will respond differently to the disappearance of an object (by touching the item that is occluding it) than a person (by vocalizing) (Legerstee, 1994). Once an entity is established as being agentive (e.g., by interacting contingently) infants will follow its ‘eye-gaze’, even if it is an eye-less green blob (Johnson, 2003; Johnson, Slaughter, & Carey, 1998). Additionally, infants form specific expectations about the nature of an agent’s behavior. Young infants understand that while agents may engage in many types of actions, only a subset of these actions is goal-directed. Woodward (1998) pioneered a way of testing how infants perceive actions by pitting one type of action (goal-directed) against the other (non-goal-directed). Infants are habituated to an actor performing an action towards one of two objects. Once the infant habituates, the locations of the two objects are switched, and the actor performs the same action again, this time towards the new toy, now located where the old one used to be, or the old one, now
located where the new one used to be. By measuring infants’ looking time to these events, infants are “asked” if they perceived the events as being “about” the object the actor was acting upon (e.g. grasping the toy), or rather, if they perceived the events as being about the actor’s motion (e.g. moving to the left). If infants interpret habituation events as being about the actor’s goal, they should find it surprising when the actor reaches for a new object, despite the fact that the actor’s arm moves in the same manner it did throughout habituation. If infants interpret the habituation events as being about the actor’s path of motion, the infants should be surprised when the actor moves differently, even if this different motion is directed towards the same old toy the infants were habituated to. This design elegantly pits two salient features of a reach against each other, and can tell if infants have encoded any sequence of actions as goal-directed.

Woodward has demonstrated that by 6 months, infants differentiate between actions that are goal-directed, such as a grasp, and actions that are ambiguous, such as touching an object with the back of one’s hand (Woodward, 1999). Additionally, by 7 months, infants understand and can reach for someone’s likely goal, even if that person’s action remains unfulfilled (Hamlin, Hallinan, & Woodward, in press). By 12 months, infants have added pointing and looking to the types of actions that qualify as intentional and goal-directed (Woodward, 2003; Woodward & Guajardo, 2002). Even the youngest infants tested show that they can differentiate between intentional and unintentional actions; 3-month-olds, if given grasping experience with the aid of Velcro mittens, will eventually treat grasping as goal-directed. Infants of this same age do not appear to understand grasps without this experience (Sommerville, Woodward, & Needham, 2005). What remains unexplained by the Velcro mittens study, however, is whether this early
experience provides enough input to fire up a pre-existing domain of knowledge, or whether it helps organize experience into such a domain. Regardless, as soon as infants demonstrate this sensitivity to goal-directed actions, their knowledge appears domain-specific: when infants see the same actions performed by a mechanical arm, they treat the arm differently, now seeing its path of motion as more salient than its goal. Other studies have suggested that infants can sometimes be fooled by perceptual tricks: gold lamé gloves are treated like mechanical objects, and self-moving boxes can be treated like agents (Guajardo & Woodward, 2004; Luo & Baillargeon, 2005). Here the distinguishing factor seems to be about the cues exhibited by the actor. If enough aspects of the actor are animate and the action meets specific constraints, the action is treated as goal-directed. However, if the actor presents with a dearth of agentive cues, or the action itself does not fall within the domain of goal-directed actions, the action is classified as ambiguous.

Recent research has suggested that infants are also sensitive to complex means-end sequences, understanding that an agent’s goal might lay at the end of a sequence of smaller actions organized around that ultimate goal (Woodward & Sommerville, 2000). For example, 12-month-old infants are capable of pulling a cloth to bring a toy within reach, and understand that the purpose of lifting a cover off of a box is to obtain the item inside (Sommerville & Woodward, 2004; Woodward & Sommerville, 2000). Understanding these complex actions requires a suspension of the interpretation of “goal” until the final action in a hierarchy is fulfilled. How infants come to integrate multiple smaller goals into an action sequence, organized around an ultimate goal is unknown. Nonetheless, when infants first show an understanding of these actions, they seamlessly
integrate sub-goals together in just such a hierarchy, and can even reason about the ultimate goal after viewing only a sub-goal within the sequence (Sommerville & Woodward, 2004; Woodward & Sommerville, 2000).

Combining outputs, an easy or hard problem?

According to the idea of these encapsulated systems, processing in one domain should be entirely cordoned off from all other mental functions (Fodor, 1983). Further, natural language seems to be the only mechanism that can flexibly combine outputs across these domains (Carruthers, 2005; Spelke, 2003; Sperber, 2005). This idea is implicit in research investigating how young infants reason about objects and animate agents: most of the evidence thus far points to a division between these two domains, suggesting that processing within one domain is nothing like processing in the other (Woodward, 1998). For example, it makes no sense to think of intentions or goals when assessing how bounded a surface is; nor does it make sense to think about cohesion when making a judgment about what type of food a classmate prefers. What remains to be explained is how knowledge within one domain can sometimes be combined with processing in the other. Adults clearly can combine some knowledge across the domain of objects and the domain of animate agents; however, adults also have already acquired natural language. The outstanding question, then, is how and when infants can accomplish this feat.

In some cases, what appears to be combination can be as simple as a set of rules dictating when to apply or not to apply certain constraints. For example, infants suspend Spelke’s contact causality principle for any causal interaction involving people. Infants are not surprised when one person seems to set another person into motion without
contacting them (Kosugi & Fujita, 2002; Kosugi, Ishida, & Fujita, 2003; Spelke, Phillips, & Woodward, 1995). However, infants do not think simply that animate agents do not have to contact each other, but that animate agents are more likely to move because of some other event, such as being spoken to (Kosugi & Fujita, 2002). This reversal of the usual constraints seems more than a mere suspension: instead of treating animate agents as outside the realm of objects, and therefore outside the constraints of any object principles, a separate set of constraints seems to be guiding infants’ reasoning. Similarly, infants will resist developing an association to explain the cause of a person’s motion, but not an object’s. For example, Carlson-Luden (1979), as cited in Golinkoff (1984), showed that infants as young as 10 months could easily learn to press a button to make a picture appear in a window, but never learned that pressing a button could cause a person to smile and wave.

Not everything, however, fits neatly within a particular domain of reasoning, or can be explained by the simple rules guiding inferences within a domain—some things belong to a grey area, and the infant mind seems capable of assessing these middle cases. Recently, Pauen and Trauble (under review) have shown that when infants are presented with a situation in which they have equal and symmetrical experience with two items (one of which appears agent-like, and one which is an object), infants assume that the agent causes the motion of the object. Bhojani and Saxe (in prep) extended this to show that infants at 7 months treat an animate agent as causal in respect to an object only when the agent and object are in contact, apparently appreciating that while agents may cause other agents to move across a gap, an agent must contact an object in order to affect it (Bhojani & Saxe, 2006). Similarly, Meuntener (2006) has shown that while infants
respect Michottean constraints for physical causal events with objects (such as only reasoning about collision or entraining events), they allow far more flexibility in events involving people. For example, while infants do not see a color-change event as causal when it involves two objects, they do see it as causal when a hand is playing the causal role (Muentener & Carey, 2006).

These cases suggest that infants have some way of sorting perceptual input correctly into the appropriate domains, and they know that the rules of one domain might sometimes trump the rules of another (i.e., when seeing both an animate and inanimate thing moving together, assume the animate one is the cause of motion). This sort of hierarchical application of rules may be a simple form of combination. More complex combination, however, would involve context-sensitivity, for which infants would need to recognize that some rules apply only to some specific situations, and other rules to other situations. For example, infants recognize both that contact is necessary for one object to launch another into motion, and not necessary for one person to launch another into motion; when dealing with an object and an agent, two different types of rules might apply. First, infants should recognize that an agent still must contact an object to set that object into motion. Second, infants should also recognize that agents do not need to be contacted in order to be set into motion: a person might start running away from a falling tree branch long before the branch could contact the person. Another type of situation that may demand context-sensitivity is tool-use. Tools, after all, are objects, and therefore must conform to object rules; yet tools are special in that what they are being used for often involves the intent or goal of the user. Due to the complexity inherent in tool-use, simple rules for combining information across domains should not apply.
Infants’ understanding of tools (tools as means-end sequences)

Early research on infant’s understanding of tools investigated the developmental trajectory by which infants could reason about increasingly complex types of tools. These studies, more descriptive than experimental, sought to describe the system of schemas underlying infant’s understanding of tools (Bates, Carlson-Luden, & Bretherton, 1980; Brown, 1990). Brown (1990) describes infants’ understanding of tools beginning with simple tools, in which tool and goal object are contiguous (e.g., cloths), to complex non-contiguous tools such as sticks. Infants were presented with two possible tools at a time, one more difficult to use than the other. Therefore, infants’ choices on each pair provided Brown with a system of ranking infants’ understanding of how to use increasingly complex tools. Brown’s descriptions were framed in a Piagetian fashion, employing schemas to describe increasing developmental complexity, and claiming that infant’s own ability to use a tool set the stage of the acquisition of a more complex schema. This type of explanation closely matches Piaget’s own descriptions of his children’s developing ability to use more complex tools. (Brown, 1990). Unfortunately, what Brown’s descriptions lack is an explanation for what underlying concept develops as children gain insight into how to perform complex means-end sequences. There are two candidates for what develops: infants may be able to make increasingly difficult inferences about goals (e.g., what people intend to accomplish by using a tool), or they may be able to make increasingly difficult inferences about objects (e.g., their understanding of a tool’s possible uses becomes more robust as infants begin to incorporate concepts such as balance and support into their understanding).
Recently, Sommerville and Woodward (2004) have investigated the extent to which an infant’s ability to reason about sequences of goals informs their understanding of actions performed on objects. These authors have claimed that for complex means-end sequences, the only thing tying the individual actions together under the heading of one uniform sequence is the concept of an overarching goal. These authors have demonstrated that infants can reason easily about these overarching goals (such as obtaining a toy), without mistaking any of the steps on the way (such as opening the cupboard or pulling out the toy-box) as being the goal of the sequence. For example, 12-month-old infants recognize that when an actor reaches towards a box containing a bear, the actor’s goal is the bear, not the box (Woodward & Sommerville, 2000). Similarly, 10 and 12-month-old infants recognize that when an actor pulls a cloth closer in order to obtain the toy resting upon the cloth, the actor’s goal is the toy, not the cloth that they actually acted upon (Sommerville & Woodward, 2004). Interestingly, these authors also find that an infants’ own ability to perform a means-end sequence correlates with the infant’s understanding of that sequence (Sommerville & Woodward, 2004). Such a correlation suggests that infants cannot initially understand how an action works if they themselves are not capable of mastering that same action.

What has received little attention, however, are the constraints on goal hierarchies, and how an infant’s own experience relates to both their underlying understanding of objects, and their ability to make sense of these hierarchies. Tools are always objects, and therefore ought to always be constrained by physical principles. However, tools are unique objects in that an agent’s intent determines what a tool is being used for, and the tool’s structure imposes constraints on what types of goals are possible.
In order to successfully reason about tools, infants must somehow combine their knowledge of agents with their knowledge of objects, determine which of the many available principles ought to apply, and do this while keeping in mind the overarching goal of any tool-use sequence of actions. If infants can not combine their understanding of agents and objects, then the question ends here: unless an action is fully situated within one domain of reasoning, infants ought to have only a shallow understanding of how tool-use works. However, if infants can combine knowledge across domains, it should be possible to detect this by adjusting aspects of the object to see how that affects infants interpretations of the agent’s intent, and vice versa. This is a bit akin to tugging on a loose thread in order to see where the cloth initially got snagged: the organization of these two domains ought to leave telltale patterns in infant’s reasoning, and by investigating these patterns, we may be able to trace whether infants can combine outputs across two different domains.

In my thesis, I investigated infants’ underlying representation of objects and agents by examining how they can reason about tools. In particular, I adjusted aspects of a tool’s functional properties, and asked if that modulated infants’ interpretation of the agent’s intent. Given that previous work on action understanding has found that an infant’s own ability to perform a specific action correlates with that infant’s understanding of the action, I also included a task in which infants were given an opportunity to use the tools themselves.
Chapter 2: Experiment 1

Introduction

There is little empirical work examining at what age infants can understand that complex tools, such as canes, are used in a goal-directed manner. Therefore, in Experiment 1, I tested whether infants would treat cane-use as goal-directed. I chose 12- to 15-month-old infants for this task since the available literature suggested that by 12 months, infants understand a point of contact is necessary to pull an object (Brown, 1990), and that by 18 months, all infants will choose a cane over a rake or stick (Brown, 1990). I tested infants using a habituation paradigm modeled after Woodward (1998), and described in Chapter 1. Infants were habituated to an actor picking up a cane, and then using the cane to pull one of two toys within reach. Due to the lack of empirical data on how infants might reason about tool-use, many possible functional and causal cues were included: the experimenter always hooked the cane around the target object, and always succeeded in pulling it closer. However, because previous research has suggested that 12-month-old infants can use eye-gaze alone to predict an actor’s goal (Woodward, 2003), in Experiment 1 and all subsequent experiments, I removed this possible cue (i.e., the actor always wore a cap that hid her eyes from view). On test trials, the locations of the objects were switched, and infants were then presented with the actor using the cane to pull in a new object (situated now in the old location of the initial target object) or the old object (now in a new location). I reasoned that if infants understand canes as tools that are used intentionally to achieve a goal, they would look longer when the actor used the cane to
reach for the new object (signifying a change in goal) then when she used the cane to reach for the old object (changing the cane’s path of motion).

Previous research suggests that infants’ understanding of an action develops in concert with their own ability to perform the action (Sommerville & Woodward, 2004). In this study, therefore, infants also participated in a reaching task immediately following the looking time task. However, since it is unknown at what age infants can use canes themselves, I reasoned that some infants might be too young to spontaneously use the cane themselves. In order to address this concern, infants received modeling trials in addition to a spontaneous reach trial, in which they saw an experimenter use the cane. They were then given 4 chances after the modeling to use the cane themselves.

Methods

Participants. Sixteen 13-month-old infants (range 12.6 to 15 months, 7 males) participated in Experiment 1. An additional 11 infants participated, but were excluded from analyses; 4 due to fussiness, 2 for experimenter error, 2 for maternal interference, 1 for technical difficulties, and 2 for failing to reach habitation criteria\(^3\). Infants were tested at the Infant Cognition Lab at Queen’s University, and recruited from a database of participants. Infants received a small gift and a certificate to thank them for their participation.

Procedure: Looking-time task. For the looking-time task, infants sat on a parent’s lap, approximately 1m away from a stage. During the study, parents were asked to close their

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\(^3\) See (Cohen, 2004; Houston-Price & Nakai, 2004) for a discussion of habituation paradigms.
eyes or direct their gaze downwards at the infant’s head. One camera, behind the infant, registered the experimenter’s actions, while the other captured the infant’s eye movements.

Trials began when the curtain-operator raised the stage curtain. The experimenter was seated behind the stage and visible from the waist up. For all trials, she was wearing a visor so that the infants could not use eye gaze as a cue to infer her goal. Once the curtain was raised, she looked at the baby, and said: “Hi, [baby’s name], look at this!” and then looked down. She then picked up the cane. The cane was resting in a holder at the back of the stage, at the midline between the two possible goal objects: a red and white swirl, 13 cm in height, or a purple and yellow cylinder, 13 cm in height (figure 1). The experimenter held the cane by the stick end and positioned the curved end such that it could hook the toy, and then pulled one of the two objects closer. The object the experimenter reached for during habituation was counterbalanced between subjects.

For each trial, once the experimenter finished acting on the cane, she sat motionless, cane still in her grasp, for the rest of the trial. A computer beep signaled the end of trial; at this point the curtain-operator lowered the curtain. With the curtain down, the experimenter reset the stage, returning the cane to the holder, and if necessary, moving the objects back to their starting positions. The experimenter always reset the stage between trials. Infants were given a minimum of 6 trials and a maximum of 14 trials in which to habituate\(^4\). Trials ended after infants either looked away for 2 consecutive seconds or looked at the display for a maximum of 120 seconds.

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\(^4\) Habituation is reached when the sum of looking time across three consecutive trials is equal to or less than half of the sum of the looking time across the first three trials.
Once infants habituated, the experimenter switched the location of the two goal objects. The curtain operator then raised the curtain. The experimenter said, “Look, [baby’s name], something’s different!” and then looked down. This “reveal” trial lasted for 10 seconds, allowing the infant to observe the new locations. At the end of the 10-second period, the curtain operator lowered the curtain.

Test trials began in the same way as habituation trials, but the experimenter reached the cane either to the new goal or the old goal, hooking the object and pulling it towards her. She alternated her goal on each trial. Infants were given 2 pairs of test trials (one old goal and one new goal trial in each pair), and the order (new goal or old goal) was counterbalanced across infants.

![Figure 1. Experiment 1: (a) Habituation, (b) New Goal, and (c) Old Goal events](image)

*Reaching Task.* Infants who participated in the looking time task also participated in a corresponding reaching task. Again, infants were seated on their parent’s lap, directly across the table from a camera. A second camera filmed the infants from above so as to record all arm movements. The experimenter sat beside the infant (figure 2). The reaching task consisted of four phases:
(1) Familiarization: In order to allow the infant to explore the novel items, and to ensure all infants were motivated to participate, the experimenter placed both the toy and the cane in front of the infant, giving the infant exposure to both items. This initial exposure period lasted 10 seconds.

(2) Baseline/Spontaneous reach: Infants in this trial were given an opportunity to use the cane to pull a toy within reach, prior to any modeling experience. For this trial, the experimenter placed the cane on the table in front of the infant. The cane was always positioned stick end close to the infant’s hands, with the curved end oriented such that a slight lateral movement and a straight tug back would bring the toy within the infants’ reach. Infants were given 10 seconds to attempt to bring the toy within reach.

(3) Modeling: The experimenter placed the toy on the table, out of her reach, and then positioned the tool such that its orientation matched what the infant previously saw in the looking time task. She then grasped the cane and pulled towards her. The experimenter performed this modeling action twice, each time exclaiming “Wow!” at the end of her action.

(4) Test trials: The experimenter placed the toy so that it was out of the infant’s reach. The experimenter then always placed the tool on the table, oriented correctly for the infant’s use, but offset from the goal such that the infant had to engage in a lateral pull to hook the toy before pulling it within reach. Infants were given 4 trials, 10 seconds each, to pull the toy within reach.
Figure 2. Experiment 1: Reaching Task: Toy/Cane arrangement for Spontaneous Reach (a), Modeling Trials (b), and Test Trials (a).

**Coding and Reliability.**

*Looking time.* Infants’ looking times were coded online by two coders. One experimenter was always blind to experimental condition. Reliability for a single trial was calculated as a percentage agreement between coders, every 1/10th of a second. Percentage agreement was then averaged across all trials. For any infant, if on-line reliability was less than 90%, two trained coders then recoded the data off-line. If the two coders still could not agree, the infant’s data was dropped from the data set. The average reliability for all infants in Experiment 1 was 92%.

*Reaching.* Reaches were coded for “planfullness” (Sommerville & Woodward, 2004). Each trial was coded for whether the infant: 1) touched the cane and toy together; 2) hooked the cane around the toy without watching their own actions; 3) hooked the cane around the toy while watching their own actions; and 4) picked up the toy once he or she pulled it within reach. A reach was only categorized as planful if the infant directed his or her eye gaze at the toy while using the tool, and then grasped the toy once it was within reach. All infants were coded off-line by a trained coder; 50% of infants were
also coded for reliability by a second observer. Reliability was calculated as the percentage agreement for the number of reaches per trial. Reliability was 85.7 %.

Results and Discussion

Looking Time. Infants habituated in an average of 7.57 trials (SE = .57).

Preliminary ANOVAs were conducted investigating the effect of Sex (Male or Female), and test order (New/Old or Old/New). No main effects or interactions were detected, so all subsequent analysis collapsed across these variables.

I conducted a 2 x 2 repeated measures ANOVA on infants’ looking times, with test trial type (New or Old) and pair (First or Second) entered as within-subjects variables, and habituation stimulus (Red or Purple) entered as a between-subjects variable. The only main effect was of test trial type, \( F(1,14) = 7.75, p = .015 \), reflecting that infants looked longer at test events in which the actor reached for the New goal using the old path of motion (M = 10.74s, SE = 1.7), as compared to events in which the actor reached for the Old goal using a new path of motion (M = 6.59s, SE = .66). No other main effects or interactions were detected (figure 3).

Non-parametric tests also confirmed this finding. Two different non-parametric tests were conducted: a Binomial test and a Wilcoxon’s signed-rank test. Binomial tests confirmed that the 13 out of 16 infants who looked longer at new goal rather than old goal events was significantly above chance, \( p = .021 \), two-tailed. The Wilcoxon signed-rank test revealed that infants looked significantly longer at new goal test events \( p = < .05 \), two-tailed, Wilcoxon signed-rank test).
Figure 3. Infants Looking Time in Experiment 1. Error bars represent standard error.

*Reaching.* In order to assess the relationship between individual infants’ performance on the looking time task and the reaching task, a correlational analysis was performed. Infants were given a score reflecting the total number of planful reaches they executed. Following Sommerville & Woodward (2004), these scores were correlated with a score reflecting infant’s sensitivity to the disruption in the means-end relations in the looking-time cane-pulling sequence (i.e. the looking time difference between the average of their looking time on new goal trials – the average of their looking time on old goal trials).

The correlational analysis revealed no relationship between infants’ own ability to use the canes and understanding of whether canes could be used in a goal-directed manner $r(15) = -0.110, p = .686$, two-tailed (figure 4).

An additional correlational analysis was also run, using more liberal criteria for the infants’ reaching. In this case, infants’ detection of the means-end relationship during
the looking time trials was correlated with whether the infants touched the toy and cane together at all. Because the coding scheme did not count eye-gaze as a factor in this category, any tapping of the cane against the toy was included in this measure. Results revealed that even with this liberal criterion, infants’ own ability to use the cane was not related to their understanding of cane use $r(15) = -.434, p = .093$, two-tailed.

![Figure 4](image)

**Figure 4.** The relationship between infants’ planfulness and their looking behaviour in Experiment 1. The line represents the line of best fit.

The results from the looking time task in Experiment 1 indicate that infants in understood the actor’s actions as being directed to the target toy, demonstrating that these infants could reason about a goal-hierarchy involving a cane. This suggests that by 13 months of age, infants already understand that a cane can be used as a means to fulfill an overarching goal. However, what remains unclear is if infants see the cane only as a means to fulfill a goal, or if they are aware that the cane itself has certain physical
constraints, and that those constraints affect what the actor can and cannot do with the cane.

Infants’ own implicit understanding of the cane-pulling (as demonstrated in the looking time task) did not correlate with their own abilities to use the cane themselves. Given that Somerville and Woodward (2004; also see Iacoboni et al., 2005; Rizzolatti & Craighero, 2004) have found that action experience generally correlates with action understanding, it seems odd that that is not the case here. One possible explanation is that infants use their own experience to bootstrap their understanding of simple actions such as reaches, pulls, or grasps. However, once a tool is involved, infants may be able to draw on their underlying knowledge of objects in order to solve the “understanding” problem, and they might be capable of doing this a few months before they can coordinate their own bodies to perform these more complicated goal hierarchies. If this is the case, it should be that infants can draw on their understanding of object physics to solve other tool-use problems. This question is examined in Experiments 2 and 3, through looking time only, by testing infants whether they can reason about physical or functional information when making inferences about whether cane-pulling is goal-directed. Due to the lack of correlation between an infants’ own ability to use a cane and that infants’ performance on the looking time task, the reaching task was not included in Experiments 2 and 3.
Chapter 3: Experiment 2

Introduction

Infants in Experiment 1 could have been making an attribution of the actor’s goal without taking into account at all the functional features of the cane. It could be, for example, that infants know enough about tools to infer that whenever they see an adult holding an object, that adult is intending to act upon something. If this were the case, then it might be that infants would extend their interpretation of goal-directedness even to tools whose functional properties are inappropriate for solving the particular task for which they are being used. In Experiment 2, I tested this by having the actor hold the cane backwards, with everything else identical to Experiment 1. In this case, the cane was oriented such that it could not pull the toy because no surface of the cane contacted the toy in a way that could afford pulling. If infants were assuming any action with any object towards another object has an overarching goal, they would look longer when the actor used the backwards cane to act on the new goal (at the old location) then when the actor used the cane to act upon the old goal (in its new location).\(^5\)

Methods

Participants. Seventeen 13-month-old infants (range 12.53 to 14.30 months, 6 males) participated in Experiment 2. An additional 9 participated, but were excluded

\(^5\) Experiment 2 also serves to control for the possibility that the effect in Experiment 1 was driven by an association between seeing the cane and object in close proximity on the stage.
from analyses: 5 due to fussiness, 1 for technical difficulties, 2 for maternal interference, and 1 for failing to reach habituation criteria.

Procedure: Looking-time Task. All procedures were identical to Experiment 1, except that once the actor picked up the cane, she turned it around such that the stick-end was facing towards the toys on the stage. She then placed the cane, stick-end forwards next to one of the two toys. After a brief pause, she deliberately pulled straight back on the cane, stopping when the cane was pulled all the way back. The cane never contacted the toy, although she always placed the cane such that it passed no more than two centimeters away from the target toy (figure 5).

![Figure 5](image-url)

Figure 5. Experiment 2: (a) Habituation, (b) New Goal, and (c) Old Goal events

Coding and Reliability.

*Looking time task.* Infants’ looking times were coded online by two coders, reliability was measured in the same manner as Experiment 1. One experimenter was always blind to experimental condition. The average reliability between coders was 93%.
Results and Discussion

Looking Time Task. Infants habituated in 6.94 trials (SE = .36). Preliminary ANOVAs were conducted to investigate the effects of sex (Male or Female), and order (New/Old or Old/New). No main effects or interactions were detected, so all subsequent analyses collapsed across these variables.

2 x 2 repeated measures ANOVA was conducted on infants’ looking times, with test trial type (New or Old) and test pair (First or Second) entered as within-subjects variables, and habituation stimulus (Red or Purple) entered as a between-subjects variable. There were no main effects or interactions, reflecting that infants in this Experiment did not look longer at either type of test event (figure 6). In contrast to Experiment 1, there was no effect of trial type, \(F(1,9) = 1.008, p = .342\), reflecting that infants did not look longer at test events in which the actor reached for the New goal using the old path of motion (\(M = 5.93\)s, \(SE = .82\)), as compared to events in which the actor reached for the Old goal using a new path of motion (\(M = 6.8\)s, \(SE = .68\)). No other main effects or interactions were detected.

I conducted non-parametric to confirm and further elaborate on these results. Only 5 out of 16 infants (31%) looked longer at New Goal rather than Old Goal events, and this was not different from chance, \(p = .21\), two-tailed. A Wilcoxon signed-rank test was also conducted, revealing that infants did not look significantly longer at New Goal events \((p > .05\), two-tailed, Wilcoxon signed-rank test).
Infants in Experiment 2 did not see the use of the backwards cane as being goal-directed, suggesting that infants can differentiate between a tool that is functionally appropriate and one that is not when reasoning about goal-hierarchies. An alternative but related possibility is that infants did not perceive the cane, when held backwards, as a cane. From the infants’ perspective, the cane in this orientation could easily have been construed as a stick with an oddly shaped handle. I address this concern in Experiment 3.

Taken together, Experiments 1 and 2 suggest that infants are capable of reasoning about goal-hierarchies involving tools, and functional or causal information about those tools at the same time. However, it is possible that these results can be explained if infants have learned a simple rule about canes: that the hooked end “goes with” goals. If infants were following such a rule, then they would perceive as goal-directed any cane use in which the hooked end is facing the right general direction, but not would not extend that inference to a cane held backwards, and should not extend that inference to a
situation in which the hook is not completely encompassing the target toy. This concern is also addressed in Experiment 3.
Chapter 4: Experiment 3

Introduction

For Experiment 3, I reasoned that if infants were using a simple association between the hooked end of the cane and the toy in order to reason correctly about the actor’s goal, then infants ought to mistakenly perceive as goal-directed a situation in which the hooked end is held close to the toy, but turned outwards such that the hook is oriented away from the toy. In this configuration, the cane could not be used to pull the toy closer, and so it does not afford pulling. However, if infants are operating on a rule such as “hook-end near toy means that the toy is the goal”, then they should perceive this as a goal-directed action about the toy, and a looking time pattern similar to that in Experiment 1 should be obtained. If, however, infants recognize that a turned-out cane is not an effective tool, despite the proximity of the hook-end and the toy, they should not look significantly longer at new goal versus old goal events, suggesting that they do not consider actions involving a turned-out cane as part of a broader goal-hierarchy.

Methods

Participants. Sixteen 13-month-old infants (range 12.66 to 14.53 months, 8 males) participated in Experiment 3. An additional 10 participated, but were excluded from analyses; 3 due to fussiness, 1 for experimenter error, 1 for maternal interference, 1 for an off-camera error, and 4 for failing to reach habituation criteria.
Procedure

Looking-time Task. All procedures were identical to Experiment 1, except that once the actor picked up the cane, she turned it such that she was facing the hooked end towards the toys on the stage. She then placed the cane, hooked end next to but facing away from one of the two toys. After a brief pause, she deliberately pulled straight back on the cane, stopping when the cane was pulled all the way back. The cane never contacted the toy, although she always placed the cane such that it passed no more than two centimeters away from the target toy (figure 7).

![Figure 7](image.png)

(a)                             (b)                                (c)

Figure 7. Experiment 3: (a) Habituation, (b) New Goal, and (c) Old Goal events

Coding and Reliability.

Looking time. Infants’ looking times were coded online by two coders using. One experimenter was always blind to experimental condition. Reliability was calculated in the same manner as Experiment 1, and overall reliability was 92.3%.
Results and Discussion

Looking Time Task. Infants habituated in 7.81 trials ($SE = .49$). Separate ANOVAs were conducted to investigate the effects of sex (Male or Female), and order (New/Old or Old/New). No main effects or interactions were detected, so all subsequent analyses collapsed across these variables.

A 2 x 2 repeated measures ANOVA was conducted on infants’ looking times, with test trial type (New or Old) and test pair (First or Second) entered as within subjects variables, and habituation stimulus (Red or Purple) entered as a between subjects variable. There were no main effects or interactions, reflecting that infants in this Experiment did not look longer at either type of test event, $F(1,7) = .268, p = .621$, reflecting that infants did not look longer at test events in which the actor reached for the New goal using the old path of motion ($M = 6.38s , SE = .84$), as compared to events in which the actor reached for the Old goal using a new path of motion ($M = 6.08s , SE = .79$) (figure 8).

Only 7 out of 16 infants (44%) looked longer at New Goal rather than Old Goal events was not different from chance, $p = .804$, two-tailed. A Wilcoxon signed-rank test was also conducted, revealing that infants did not look significantly longer at new goal test events over old goal test events ($p > .05$, two-tailed, Wilcoxon signed-rank test).
Infants in Experiment 3 also did not see the actor’s action as goal-directed, suggesting that they were not reasoning about the actor’s goal using a simple association. Taken together, the results of all three experiments suggest that infants’ reasoning about cane-pulling events is complex, with infants able to take into account functional information when making inferences about the actor’s goal. Infants are not fooled by sequences of actions in which the tool selected is unable, due to causal or functional constraints, to act upon an object. Infants then, must be able to integrate information about a tool’s affordances on-line while they simultaneously make inferences about an actor’s overarching goal.
Chapter 5: General Discussion

Infants in these three experiments were able to reason appropriately about the actor’s goal, treating the actor as having an overarching goal only when the tool’s functional properties afforded acting on the toy. In order to do this, infants had to combine their knowledge about the cane’s functional properties with their knowledge of goal hierarchies, in effect suspending an inference about the overarching goal until they were able to assess whether the cane was a plausible tool to use to achieve a particular goal. Taken together, these data suggest that by 13 months, infants are able to combine some knowledge across domains, changing their interpretation of an action as goal-directed or not goal-directed based on functional information embedded within the event. This suggests that infants already are aware that intentions are not the only piece of information to consider when making inferences about overarching goals. Rather, this pattern of findings suggests that infants are aware that functional information also constrains what someone’s goal might be. This suggests that by 13 months, the rigid distinction between domains found in early infancy is already beginning to take on some of the flexibility of adult cognition.

Interestingly, the infants in Experiments 1 were able to correctly reason about another’s tool-use despite their own inability to use canes. This suggests that some aspects of tool-use might develop independently from experience, with infants able to draw upon their understanding of physics in order to generate plausible hypotheses for what a tool might be used for, even if they themselves cannot yet use it. While this pattern of findings appears to contradict Sommerville and Woodward (2004), it may be
that infants rely upon experience in order to understand simple tools (e.g. cloths), where functional information is ambiguous. A cloth, after all, has many uses, only one of which is to pull something closer. Canes, however, are not as ambiguous, because the construction of a cane affords pulling only when the hook-end is correctly positioned. This high level of functional specification might provide infants with enough information that they do not have to rely solely on their own experience in order to understand what someone is doing when they are using a cane to pull something within reach.

An outstanding problem remains, however. Experiment 1, the only experiment in which infants reasoned that the actor’s actions were directed towards a goal, is also the only experiment in which the cane contacted and moved the toy. These two confounding variables are related, and may have impacted infants’ interpretation of the causal sequence involved in the goal-hierarchy. In order to correctly reason about the sequence of events involved in a goal hierarchy, infants must perceive each part of the sequence as causally related to the next. A disruption in the causal sequence of events may disrupt infants’ abilities to reason about the overarching goal hierarchy. Since both movement and contact are typical aspects of a causal sequence, the fact that these were lacking in Experiments 2 and 3 could explain why infants did not treat the actor’s actions as goal-directed.

Movement

In most causal interactions involving objects, the causal agent sets the receptive agent into motion, either through launching or entraining. It may be that infants attend to this motion as an indication that a causal interaction took place. This interpretation seems
unlikely, however, given repeated demonstrations that infants do not rely on motion alone when making causal inferences across a gap (Kotovsky & Baillargeon, 2000; Leslie, 1984; Oakes & Cohen, 1990, 1994). In Kotovsky (2000) infants witnessed collision events similar to Kotovsky and Baillargeon (1998). However, in this study, infants were shown that at the contact point, a full wall either obstructed the track, or a half-wall was suspended under the track. This half wall was high enough off the track that a cylinder could roll by unimpeded. Once infants were familiarized with the display, the experimenter flipped up an occluder, hiding the contact point from view. The cylinder was then rolled down the hill, sometimes displacing the wheeled bug and sometimes failing to move the bug at all. Infants’ reactions to the test events depended on which type of familiarization event they received: infants who were familiarized to the full wall were more surprised when the wheeled bug was displaced than when it was not, suggesting that they had expected the wall to stop the cylinder from contacting the bug. However, infants who had seen the half-wall familiarization events showed the opposite pattern: they were more surprised when the wheeled bug did not move than when it did, suggesting that they had expected the cylinder to roll under the half wall and contact the bug. Since the critical part of the wall was hidden in all test trials, infants had to make an inference about whether the bug should move based on whether contact was possible or not, and this depended on which type of wall the infant had seen in familiarization.

Infants were able to match bug’s displacement (or lack thereof) with whether contact was possible or not, and were only surprised when the bug should have moved and did not, or the bug should not have moved, but did. This suggests that these infants were not relying on motion alone as a heuristic for inferring contact. Similarly, it is unlikely that infants in
Experiment 1 mistook the sequence of actions as causally related simply because the cane set the toy into motion.

Contact

Another possible confound is that of contact. It may be that while infants know enough to exclude motion as a possible cue to a causal interaction, they base their inference of cause on the amount of contact between two objects. In this case, lack of contact between the cane and the toy could mean that no causal interaction took place. For experiments 2 and 3, this could explain infants’ inability to reason about the sequence of actions involved in the goal hierarchy, and therefore, infants would have concluded that the actions were not directed towards any goal in particular. In order to address this concern, I am currently running a fourth experiment, in which the actor, with the cane oriented correctly and hooked end towards the toy, pulls the cane and makes contact with the toy, but does not them move the toy any closer. Data from this ‘contact only’ condition suggests that contact alone is not enough of a cue for infants to understand the sequence of actions as goal-directed (5/7 infants look longer to the old goal, rather than new goal events). This suggests, in fact, that the motion of the toy in Experiment 1 was a cue that infants relied upon in order to draw an inference about the actor’s overarching goal. It may be that while neither contact or motion alone are sufficient to make inferences about the actor’s goal, the combination of contact and movement in Experiment 1 provides infants with a gestalt sense that allows them to interpret the action as goal-directed, possibly because the perceptual salience of the moving toy draws their attention the relationship between the cane, the toy, and the actor.
Both of these concerns will be addressed in a further condition, in which the cane breaks as the actor hooks it around the toy. If infants in this condition infer that the actor has a goal, and expect her to act accordingly, then they should treat her actions as goal-directed, despite that she does not succeed in moving the toy. If so, infants would show a new goal effect, looking longer when she changes her goal than when she changes the manner of her motion. However, if infants are not reasoning about the functional properties of the cane whatsoever, or depend on motion as a cue when reasoning about functionality, then they should treat the broken tool condition as ambiguous, and look just as long at both new goal and old goal outcomes.

Infants in Experiment 1 could have used several available cues, including motion and contact, in order to make sense of the actor’s actions. Their ability to do so, coupled with the results of Experiments 2 and 3, suggest that when observing someone else use a tool, 13-month-old infants are capable of suspending an inference of the actor’s actions until they calculate, on-line, whether the tool is functionally capable of fulfilling the intended goal. That infants are capable of reasoning about someone else’s tool-use even when they are incapable of using that same tool themselves suggests that some representational capacity might be at work. Given that by 13 months, infants already have experience reasoning about goals, but are just beginning to reason about tools, they are likely representing what the actor’s goal is, while relying on more rudimentary systems to figure out how the tool works. If so, then these infants are combining their knowledge of physical objects with their understanding of agents, and doing so flexibly. This ability to flexibly combine domains or flexibly reason about embedded actions is a hallmark of adult cognition. As Sommerville and Woodward state (p. 2, 2004):
As discussed by Searle (p.98, 1983), our construal of the murder of Archduke Franz Ferdinand in Sarejevo by Gavrilo Princip can exist at a number of different levels of analysis (e.g., pulling the trigger, firing the gun, shooting the Archduke, killing the Archduke, striking a blow against Serbia, avenging Serbia), each of which is embedded in the subsequent higher-level intention….Indeed, as Searle writes, we can recognize that ‘Princip moved only his finger, but his Intentionality covered the Austro-Hungarian Empire’ (p.99).

This example of the murder of Archduke Franz Ferdinand illustrates the progression from a simple, physical understanding of actions (e.g., what happens when one pulls a trigger) to an increasingly integrated and higher-level understanding of intentions (e.g., intending to kill the Archduke). 13-month-olds certainly are incapable of construing motives as complex as ‘avenging Serbia,’ but by combining knowledge flexibly across domains, they have already gotten part of the way there.
References


