ACTION, AGENTS, OBJECTS, AND OUTCOMES:

HOW INFANTS LEARN ABOUT THEIR WORLD

A Dissertation

by

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ABSTRACT

There is a large body of work demonstrating that infants are sensitive to the distinction between human and mechanical agents from the early months of life, with different expectations for how those agents move and interact with the world around them. Further, infants are able to understand scenes in which objects engage in functionally-relevant events. Lastly, this functional information can enhance how infants determine the number of objects in a scene.

Infants aged 9 months watched two kinds of hands (human or mechanical) engage in functionally-relevant priming events, which allowed the infants to link surface color of the object to the distinct function (wherein color becomes of predictive value). Then the infants watched two kinds of event-mapping test events (color change or control), to assess object individuation. We assessed total duration of looking to the color change and control test events. Results revealed that infants use color as predictive value after watching the human hands perform functionally-relevant events, but not if infants watched mechanical hands perform the same functionally-relevant events. The discussion examines the importance of this finding, and how this fits into and adds to existing work with infants in object cognitive area.

DEDICATION

For my Pepa, who always encouraged my curiosity. And to every other young woman who wants to be a scientist: keep learning, keep working, keep honoring the women who came before you and keep paving the way for the other women who will come after you.

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1. INTRODUCTION

If you saw your roommate pick up a book, what would you think would happen next? Witnessing this action on an object, the most likely scenario is that she will open the book and begin reading. Or, what if you saw your roommate take a glass out of the cabinet and pull a jug of milk from the fridge – what would happen next? Adult humans can figure this puzzle out with ease, without much conscious effort. You would assume your roommate is going to pour herself a glass of milk and drink it, in large part because adults see and participate in these kinds of events.

Infants are also capable of parsing complex scenarios, which combine agents, objects, actions, and outcomes. Research has demonstrated the progression of how infants learn about their world, and how this changes over their development, which informs researchers about what infants learn and how they apply that knowledge to future events they witness.

This dissertation will examine theories and present research around the topic of object individuation and priming with functionally relevant events in infants. However, since this topic is broad and complex, I will discuss related points in finer detail. Developmental researchers capitalize on infant's novelty preference (Reynolds, 2015). By showing infants objects first hidden from view and then measuring infants' response to a reappearing object, we can better understand the expectations that infants have about how objects move through space and time. First, I will cover object individuation and the features of objects that infants use to tell one object from another. These may be features like shape, size, color, or other features like sound, labels, or category membership. Second, infants are sensitive to the functional aspects of objects, and consider the relationship between objects, actions, and outcomes, while considering perceptual and conceptual information. Third, function priming is one way to increase an infant's sensitivity to specific characteristics of an object, which can help them during the object individuation process. Fourth, agency is important for infants: who is performing an action or event, and what are the goals of the action in question?

Why does this matter? We live in an increasingly automated world. How will interaction with avatars, robots around the home, or automation influence how infants learn from their environment? Infants may encounter agents that are not human. Thus, it is critical to understand how infants respond to different agents and how that influences what they learn and know. In the educational setting, we have already seen changes, where children are learning from avatars or animated entities.

A major aspect of importance in studying the developing infant is that infant will inevitably grow and change throughout adolescence and adulthood. Infants engage with and learn from their environment, which ultimately affect their course of development. Further, some infants are not on a typical developmental track – for instance, infants with intellectual disabilities or autism spectrum disorders. What makes these infants distinct from others at the same age? How can we find early markers for intellectual disabilities, and thus, provide earlier care and interventions to ensure a more successful outcome?

These topics – object representations, agents and their goals, and infants' ability to discriminate how many objects are in a scene – are at the heart of the "core knowledge systems" proposed, with their existence supported by strong evidence from experimental research (Spelke & Kinzler, 2007). These topics work in coordination and are related to the study of how infants learn about their world and acquire knowledge.

2. BACKGROUND AND LITERATURE REVIEW

2.1 Object Individuation and Object Features

To understand our world, we must keep track of the objects that constantly enter and leave our field of vision. Although it sounds simple and automatic, object tracking is quite complex, relying on a series of networks and hierarchies that grow and change from birth. For example, the ability to use particular features of objects change throughout an infant's development and appear to be hierarchically organized (Káldy & Leslie, 2003; Wilcox, 1999). These organizational networks influence how we learn about our world, understand our surroundings, and determine what is important and what requires attention.

Even infants a few months of age can recognize that an object retains its identity, even if it leaves their immediate sight. It has been shown that infants do have ability to identify and track objects across space and time (Wilcox & Schweinle, 2003). An infant must be able to hold in mind an object's features, location, and trajectory in order to determine later whether it is distinct from another object seen.

Object individuation is the process by which we determine whether one object is distinct from another. This process involves the use of spatial and temporal cues, object categories, perceptual information like features, and conceptual information like labels. In short, object individuation answers the question, "how many objects are there?" On the other hand, object identification is the process of determining what an object is, using perceptual and conceptual properties of the object. Object identification answers the question, "which one is that?" Together, individuation and identification constitute the "what," "where," and "when" of perception (Naughtin, Mattingley, & Dux, 2014): object identification is the "what" component, and object individuation is the “where” and “when” component (or “how,” see Goodale & Milner, 1992). One way to study how infants understand objects is to use occlusion paradigms — when an object has left immediate sight and then reappears. This paper will focus only on object individuation – how many – and will not cover object identification – which one or what kind.

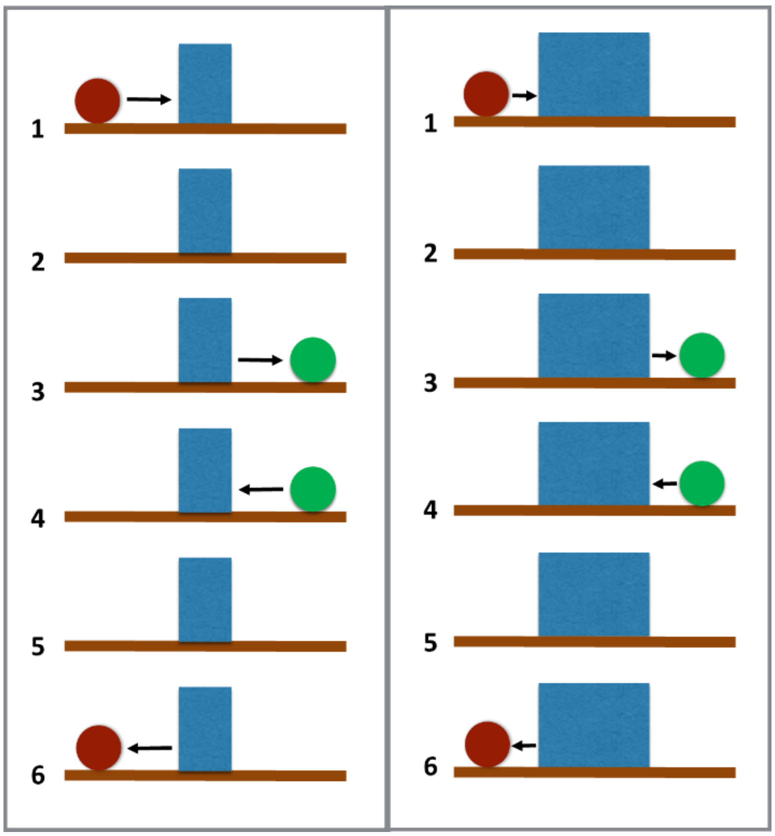

Figure 1. Event monitoring events featuring (a) narrow-screen and (b) wide-screen color-change events. The narrow screen cannot conceivably conceal two objects, while the wide screen can. If infants individuate these objects by color (e.g., interpret the scene as two objects), then infants will look longer at (a) than (b), since it will be a surprising result to hide two different objects behind the narrow screen.

In experimental settings, infant researchers use several types of occlusion events typically to test object individuation. Two main kinds of tasks used in the visual domain are: *event monitoring* and *event mapping* (Wilcox & Baillargeon, 1998a,b). **Event monitoring** involves an object moving from one side to another behind an occlusion screen that never changes or moves (Figure 1). This is in opposition to **event mapping**, which involves an object moving from one side to another behind an occlusion screen that eventually is removed to reveal the entire stage. (More about event mapping will be addressed in Methods. See Figure 2).

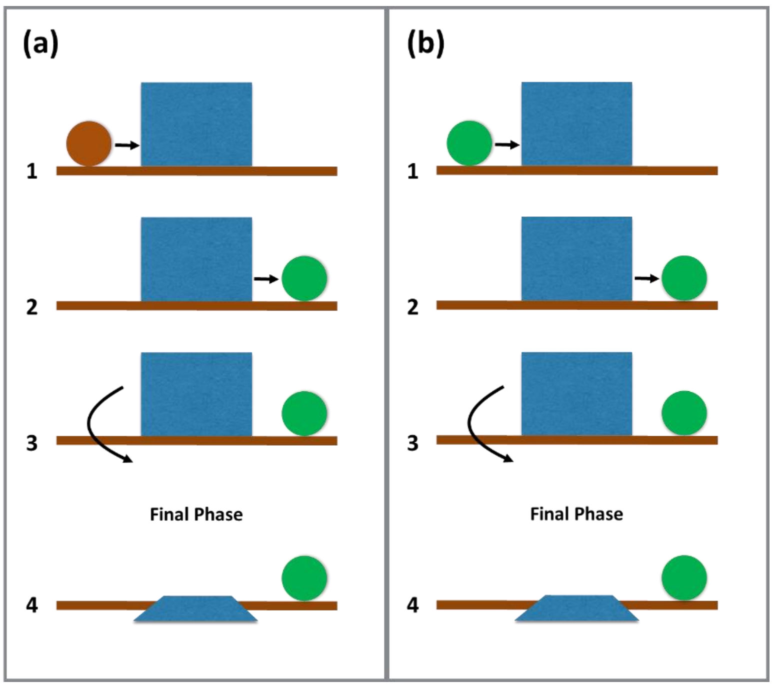

Figure 2. Event mapping: A red ball moves behind an occluder, and reemerges on the other side, as a green object (color-change condition), or (b) a green ball moves behind an occluder and emerges on the other side as a green ball (control condition). If infants individuate by color, then infants will look longer at final one-ball display in the color-change than the control condition, since they will expect to see two objects on the stage during the final phase of (a), but not (b).

Infants can also participate in occlusion search tasks, where objects are occluded and then infants are allowed to search for them (McCurry, Wilcox, & Woods, 2009), or other types of containment tasks (e.g., putting an object in a box, or covering it with a box, see (Baillargeon, Li, Gertner, & Wu, 2011). While these kinds of tasks contribute greatly to the understanding of how infants individuate objects, given the complexity of search tasks and the additional working memory demands associated with multisensory object exploration, those are not the focus of this paper.

2.2 Development of Object Individuation

If you see your roommate put a gallon of milk in the refrigerator in the morning, and pull out a gallon of orange juice in the afternoon, you know without much thought that the two gallon-sized jugs are different, since they contain different liquids. Or if you see a gallon jug of milk enter the refrigerator in the morning, and a half-gallon carton of milk comes out in the afternoon, you know the two objects are different since they differ in size and shape. Infants, like adults, are also sensitive to properties of objects, like size, shape, and category, and use these properties to individuate objects (Wilcox, 1999).

In another example, if you see your roommate put a gallon of milk in the refrigerator in the morning and then in the afternoon remove a gallon of milk to fill a glass, you can infer that it is the same gallon of milk in both instances. If you witness your roommate holding a gallon of milk three months later, however, or if she pulls a gallon of milk out of the refrigerator at her parent's house, you can likely infer that it is not the same gallon of milk. Milk does not travel by itself, and is susceptible to spoiling, making it unlikely to be the same gallon of milk months later. Infants, too, are sensitive to these kinds of spatiotemporal discontinuities during object individuation (Wilcox & Schweinle, 2003).

Previous object individuation research using event monitoring and event mapping paradigms with infants has helped determine (a) which features of objects infants use to tell whether objects are distinct, and (b) the developmental hierarchy of these abilities (Wilcox, 1999). Spatiotemporal information – that is, where is the object and when – is highly salient and often used by infants during the individuation process. For example, infants as young as 4.5 months can also use spatiotemporal information – namely, speed of disappearance and subsequent reappearance – to infer the presence of more than one object (Wilcox & Schweinle, 2003). However, objects contain a vast array of properties: size, shape, color, complexity, and usefulness. Infants can use many different object features during the individuation process – thus, the question asked was which features are used by infants, and does this change over the course of development?

In a seminal study investigating a developmental hierarchy of features used by infants during object individuation tasks, Wilcox (1999) exposed infants aged 4.5-11.5 months to scenarios involving event monitoring to test their object individuation capabilities with objects differing in shape, size, pattern, and color. The results indicated that the youngest group of infants aged 4.5 months used shape and size information to individuate objects. Infants aged 7.5 months, but not those aged 4.5 months, used surface pattern (e.g., striped versus polka dotted) to individuate objects. Further, infants aged 11.5 months, but not those aged 7.5 or 9.5 months, used surface color (e.g., red versus green) to individuate objects. Together, these experiments demonstrate a developmental hierarchy in the features that infants use to individuate objects. Younger infants use form features, like shape and size, while older infants can add more skills by using surface features, like pattern and color (Wilcox, 1999). While there are many of properties of objects infants use during the individuation process, this paper will focus mainly on surface feature properties, such as color.

2.3 Color-Function Priming

You and your roommate like different kinds of milk: you prefer 1% milk, which has a green cap, but your roommate drinks whole milk, which has a red cap. When you look in the refrigerator, you always search for the green cap, because you have linked the feature “green cap” with the corresponding object “1% milk.” Infants, too, can be (a) primed to attend to surface feature differences between objects, and (b) link surface features to objects, which researchers can capitalize on by using event-monitoring occlusion sequences (Wilcox, 1999). However, is this developmental hierarchy for how infants use form and surface information fixed, or is it malleable based on information received from the environment? Are infants sensitive to featural information if it is highlighted or shown to be important? If so, is it possible that infants will use this featural information to individuate object earlier in their development?

Previous research indicated that infants do not spontaneously individuate by color during an event-monitoring task until aged 11.5 months (Wilcox, 1999). In a series of experiments, infants aged 7.5-9.5 months watched events, which highlighted the importance of a surface feature – color. The purpose was to highlight surface features as important. The events consisted of a red cup scooping and pouring salt, and a green cup pounding a wooden nail. Infants watched multiple pairs of these events successively, pound followed by pour (or vice versa). The function of the objects differed, as did their color, and – most importantly – the function was intimately linked to the color: green always pounded and red always poured.

Infants then watched either a narrow-screen or wide-screen occlusion task (Wilcox & Chapa, 2004). By seeing these scooping and pounding events before the test trials, infants should

(a) link color to a specific function, using function as a salient feature of the objects, and (b) be primed, applying the highlighted color sensitivity to a separate occlusion task. Thus, infants should see the red cup scooping and pouring and link “scoop/pour” to “red.”

One additional factor was involved: one group of infants watched just one set of cups perform the priming tasks, while another group of infants watched two sets of cups. Infants all watched the same number of trials, but some infants saw two pairs of cups performing the tasks. We would not expect the same result for infants in the one exemplar condition, as those infants would believe that each cup performing the task was an individual, and not apply the color-function link to all green and red objects. In contrast, the infants who watched multiple cups perform the task would form a category, and apply the color-function priming link to *all red and green objects*.

The priming trials were first, followed by occlusion test trials to assess object individuation. The occlusion trials were narrow-screen and wide-screen event monitoring tasks (Wilcox & Baillargeon, 1998a,b), where infants saw a green ball move behind an occluder and emerge as a red ball (color-change). If the priming task was effective, then we would expect the infants in the two-exemplar conditions to evidence prolonged looking.

Infants aged 9.5 months who watched only one exemplar pair perform the tasks looked equally at the wide- and narrow-screen test trials (Figure 1). However, infants who watched *two* exemplar pairs looked longer during the narrow-screen occlusion test trials than infants who were in the wide-screen condition. This means that infants who saw two red cups scoop and pour, and two green cups pound a nail, could (a) link color to function, (b) form a category, and (c) apply that knowledge to a novel object individuation task. Additionally, 7.5 month olds also demonstrated individuation-by-color after color-function priming, if they were first shown three-exemplar priming trials, with three different cup pairs (Wilcox & Chapa, 2004). Infants aged 9.5 months linked *specific* colors to the function, but did not link the color differences to function more generally (Wilcox, Woods, & Chapa, 2008), illustrating that infants can use color differences to help them build categories.

Slightly younger infants aged 9 months benefit from additional comparison information during priming. For example, this comparison process consists of watching one colored spoon stir, while another different colored spoon sits to the side of the event in progress. The comparison process seems especially beneficial for younger infants, by “supporting the abstraction of commonalities and rules” that can be generalized to a broader set of situations (Wilcox et al., 2008). Benefits during the comparison process could also possibly reflect bolstering short-term memory in infants, gently reminding them that there are two kinds of objects, each performing different events.

Infants can (a) track regularities in the scenes they witness, (b) form relevant relations between these things, and (c) use these regularities to make predictions about what will happen next. For instance, when infants watch multiple different red cups perform the same action, and multiple different green cups perform the same action (distinct from the red cups), infants can learn to link things like “red-scoop” and “green-pound,” and draw from that information in novel contexts (like an occlusion task) to make decisions.

Interestingly, if color-function priming is disrupted by not having a physical functional link between the cups and the events (e.g., if the cups merely make the motions of the functional events, without scooping or pounding), there is no priming and thus no increased sensitivity to color during subsequent event-monitoring tasks (Wilcox & Chapa, 2004). It appears there is a special relationship that can be made to exist between an object property and an object action, if the action has a *functionally-relevant outcome*. Further, if surface features of objects are demonstrated to have predictive value, through a functional event, then infants can use that information to predict outcomes of later events. For instance, if the infant witnesses "red-scoop" multiple times, with multiple object exemplars, that color-function link has predictive value to potentially other action-object sequences. However, if this outcome is not functionally relevant, the surface features of objects are of no predictive value. (More about the importance of functional events will be described in the next section.)

These results indicate that there still exists a developmental hierarchy for the featural information infants use to individuate objects, but is malleable with additional information and training. When infants as young as 7.5 months watch priming pre-test events and can link color to functional property of an object, they will later evidence individuation-by-color. Sensitivity to the surface features of objects can be highlighted during a short task prior to an occlusion test event, leading to earlier use of the surface features to individuate objects than spontaneously occurs in infants (Wilcox & Chapa, 2004; Wilcox, Smith, & Woods, 2011; Wilcox et al., 2008). These results indicate that infants can learn information about objects from their environment, and give insight into the types of experiences to which infants are more sensitive.

2.4 The Functional Nature of Objects

In the previous section on color-function priming, we learned how the functional relevance of actions by objects is critical to infants' use of color as a predictive feature. But what does it mean when an object has a "function?"

Object function can be defined in many ways. One description is as "a simple action-object-outcome relation" (Kingo & Krøjgaard, 2012). Other definitions include "both perceptual (e.g., appearance, action, sound) and conceptual (e.g., goals of an actor, intentions of the creator) in nature" (Baumgartner & Oakes, 2011); or as "an agent-produced action on an object that the object affords and/or for which it was intended, either by design or conventional use" (Wilcox et al., 2008). These definitions consider the affordances (e.g., possible uses) of an object, an actor's goal, and actions that produce a specific outcome. While these definitions consider several aspects, the widely held definition of "function" varies among researchers who use it, and is still up for debate (Oakes & Madole, 2008). One critical feature may be argued, however, that function is an "emergent property" of an object, arising from a combination of perceptual features plus the use of the object (Oakes & Madole, 2008).

For example, adults easily understand that a cup is used to contain, scissors are used to cut, and so on. In the kitchen example, the function of a refrigerator is to contain and preserve a jug of milk. This function arises out of several components of the refrigerator: the materials used, how it is constructed, its capability to make and contain cold air inside of it, and that person can open the door to insert and remove items. These features combine to create an "emergent property," which is understood as refrigeration: to contain and preserve food. If the refrigerator did not have the ability to keep food cold, it would not function as expected. If the refrigerator was cold inside, but was not accessible via doors to contain and store food, it would not function as expected. Further, in these examples, there exist objects, actions upon those objects, outcomes of the actions, and agents – whether that is through implicit goals of an agent (e.g., want to keep the milk cold) or through tangible actions upon objects (e.g., opening the refrigerator door).

Infants have a more rudimentary knowledge of objects' functions than adults, but infants can learn quickly. The functional attributes of objects help guide infants in making decisions about what objects are, what they are used for, and how they are similar or different from other objects. For example, 9-month-old infants can grasp and use a handle of a brush or spoon in functional ways appropriate for the object (McCarty, Clifton, & Collard, 2001). Additionally, there has been research to determine the specific functional characteristics and relations that infants use during categorization and object individuation processes.

If function is considered an emergent property of an object, then to truly understand function, infants must be able to link multiple object properties together *and* understand the relationship between those object properties. Indeed, evidence of a developmental trajectory may exist for infants between 8 and 12 months of age, involving the change from "encoding individual features of events to encoding the relations between those features" (Baumgartner & Oakes, 2011). If a yellow object clicks when it is rolled, then the important aspects to encode are the relational links of appearance (yellow) – action (roll) – outcome (click sound). For instance, infants aged 8 months encode individual features of the objects presented – appearance (color), action, and sound the object makes. However, infants aged 12 months were more sensitive than the infants aged 8 month to the *relationship* between those features: if a yellow object always squeaked when it was rolled, infants were more surprised to see that yellow object squeak if it was squeezed (Baumgartner & Oakes, 2011). Those infants had linked *yellow-roll-squeak*, and found *yellow-squeeze-squeak* to be a surprising event. This also reflects an increase in sophistication in the parts of an event which infants use to individuate: younger infants aged 8 months use the properties of the object itself (appearance, action, sound) to individuate, but older infants aged 12 months link those properties together, and are more sensitive to the relations between those properties (Baumgartner & Oakes, 2011). As adults, we would be surprised if our refrigerator did not keep our food cold, per our expectations, and we would recognize there was a problem with the object itself.

Supporting this developmental trajectory, there is evidence that infants aged 10 months old encode the link between actions and outcomes, but do not encode a link between an object's appearance and an outcome (Perone, Madole, & Oakes, 2011). This seems to be an intermediate step in the action-object-outcome relation, which does not consider perceptual or object information as critical as the action-outcome component. Unlike the infants aged 8 months in Baumgartner & Oakes (2011), who only encoded individual object features, or the infants aged 12 months, who encoded the full appearance—action—outcome relationship, infants aged 10 months appear to be in the middle, by encoding the link of some relationships between multiple object features, but not all. This ability to link all object features, whether they are related to appearance, action, or the resulting outcome, seems to develop over the first year of life and is refined through further experience.

Further, when an object covaries on appearance *and* function, infants aged 12 months will link those two properties together (Kingo & Krøjgaard, 2012). Infants aged 12 months are also sensitive to the relationship between the action performed by an object, and the subsequent outcome – a "plausible cause-effect relation" (Träuble & Pauen, 2011). These studies, which demonstrate infants' ability to link together an object's properties and form relations between those properties, underscore their ability to understand function as an emergent property of an object.

Functional information can aid infants in categorization of objects. In the absence of other information, infants aged 11-12 months use overall perceptual similarity in objects to categorize them; however, after witnessing the functional nature of the objects, infants will categorize based on part similarity – that is, the part of the object used to demonstrate the functional event (Träuble & Pauen, 2007). However, these results are not due to just the mere demonstration of a functional event. A follow-up study indicated that infants aged 12 months old use the causally-relevant information from events to categorize objects based on their part similarity; this was not the case in a condition where the function of the object was demonstrated in the absence of a "plausible cause-effect relation" (Träuble & Pauen, 2011). Infants categorized objects based on overall perceptual similarity, unless they are shown an event with a functional outcome using a specific part of the object. For example, if infants see a t-shaped hook on the object can pull a loop, which causes a resulting sound, then infants will categorize other objects as similar if they have a t-shaped part. However, if the event highlighting the specific t-part of the object has no functional outcome during the event (e.g., no resulting sound), then infants again use overall perceptual similarity to categorize the objects. Thus, infants are sensitive to the relationship between the action performed by an object, and the subsequent outcome. These results indicate that merely highlighting a specific part of the object itself does not induce categorization, but demonstrating the functional link between action-object-outcome *does*. The functional nature of objects also facilitates categorization in infants aged 16 months; however, merely making a motion similar to the function does not allow infants to categorize. In order to effectively categorize objects, they must share functions across multiple exemplars, but infants only need to see a single exemplar to apply the same function category to a novel object (Booth, Schuler, & Zajicek, 2010).

Functional information can also help facilitate infants during object individuation tasks when there is differing appearance information. Infants aged 12 months will not use function (in this case, an auditory cue) alone or appearance alone to individuate objects, but when an object covaries on function *and* appearance, infants will link those two properties together and persist in a manual search task (Kingo & Krøjgaard, 2012). This seems to be evidence of early usage and understanding of function as an emergent property – one featural change is not sufficient, but multiple featural changes appear to signal a difference between the objects. Further, infants' ability to identify the link between the feature changes is also critical.

Functional uses of objects are also useful in priming infants to attend to specific object features (Wilcox & Chapa, 2004; Wilcox et al., 2008). For example, if a red cup always scoops and pours rice, and a green cup always hammers a wooden nail, then the action and object have an outcome, and are considered functionally-relevant. If the red cup just mimics the action of scooping and pouring, without physically contacting the container of rice (e.g., without an action outcome), then it is not functionally-relevant. Infants who watch functionally-relevant events can link properties of the object performing the action (e.g., color or pattern) with the action (e.g., scooping or pounding). Then on later object individuation tasks, they apply what they learned previously – that red objects are distinct from green objects – and can succeed in the individuation task and individuate by color. However, function priming only works when the event is (a) functionally relevant, and (b) when the object is only used for one specific function (e.g., an object cannot be used for multiple functions; red cups only scoop salt and green cups only pound the nail; Wilcox & Chapa, 2004). If the object just mimics the action without physically performing the action (e.g., in the absence of a causal link), there is no color-function link and no priming to sensitivity to color information in the later individuation task. Further, infants can use information about function more broadly to form categories, helping them make predictions about objects (Wilcox et al., 2008).

Object knowledge is comprised of what an object is and how it is used. The underlying assumptions of the affordance-matching hypothesis is that "manipulation and function knowledge about objects cannot only be used during action execution, but also for predicting and understanding the actions of others" (Bach, Nicholson, & Hudson, 2014). According to the affordance-matching hypothesis, object function is tightly coupled with object manipulation. Observed goals can predict object function; object function can also predict goals of an agent. Further, how an object is manipulated can predict an agent's behavior, but observed behavior can also predict how an object is used (Bach et al., 2014). For example, if you know your friend is packing to move and enters the room carrying a newspaper, you may not immediately infer that they are going to sit and down to read – instead, you might infer that your friend will use the newspaper to safely pack her dishes and glassware. The observed goal is moving, which informs the predicted function of the newspaper. If you see a person pick up a can opener, you can predict their goal is to open a can. The function of the observed object is to open cans, which informs the inferred goals of the agent. For infants, this object knowledge aids infants in both predicting and interpreting action movements.

2.4.1 The Function Equation

There are many components to what comprises a functional outcome. One previously mentioned definition of function is "a simple action-object-outcome relation" (Kingo & Krøjgaard, 2012). Based on other research, *agent* could also be considered in the following equation:

Action + Agent + Object + Outcome = Function

How important are each of these components to creating the "emergent property" of function? Consider the equation above. If one of the operands is removed from the equation, the outcome and emergent property of "function" may not exist. The action component includes motor behaviors and motor predictions. The agent component includes the agent (e.g., appearance, identity) and their goals. The object component includes characteristics and affordances (e.g., uses and purposes). The outcome component includes any relevant result from the action-object sequence. Let us take a closer look at evidence to support this concept.

How important is *action* to the emergent property of function? An event with an agent, object, and outcome, without any action on the object, seems unlikely to be considered functional. In fact, affordance matching tightly couples action and objects (Bach et al., 2014), where: (a) observed goals can predict object function, (b) object function can predict goals of an agent, (c) how an object is manipulated can predict an agent's behavior, and (d) observed behavior can predict how an object is used. Thus, action knowledge is critical for understanding and planning one's own actions on objects, as well as interpreting actions on objects by another. Further, infants form links between motor actions and the "sensory consequences" (e.g., outcomes) of these actions (Hunnius & Bekkering, 2014). Therefore, without action, it is unlikely that there is the perception of an object function.

How important is the presence of an *object* to the emergent property of function? Since "most human actions involve objects, either as the recipient to be acted upon, or as a tool to be acted with," the presence of an object is critical to function (Bach et al., 2014). Also, "infants represent actions as organized by the relation between agent and object" (Woodward, 2009). One example of action by an agent with an outcome could be communication, gestures, or language. However, it could be argued that language is privileged and not in the same category as a functional event. Therefore, without the presence of an object, there may not be the perception of an object function.

How important is an *outcome* to the emergent property of function? For example, without an outcome, an action on an object is merely an action. Indeed, while extant research indicates that while infants can be primed during functional events, infants are *not* primed by non-functional events (e.g., those without a functional outcome; Wilcox & Chapa, 2004). Thus, outcome appears to be critical to the equation, and without an outcome, there is no priming. Within the affordance matching framework, we witness the *outcome* of the actions on objects and store this knowledge for later, helping us infer how an object can be used in the future (Bach et al., 2014). For instance, scissors cut paper, and this knowledge comes, in part, from witnessing the action (cutting) upon an object (paper) to a desired outcome (the paper is cut). Further, infants expect actions to be associated with outcomes (e.g., "goal states"), as actions are a means to an end outcome (Gergely & Csibra, 2003). Therefore, without a plausible outcome, there may not be the perception of an object function.

How important is an *agent* to the emergent property of function? As previously demonstrated, if there is no object, action, or outcome, there is no function; therefore, these as those are at least perceptually crucial pieces. What can be said about the presence of an agent within a functional event?

Agent is typically an *assumed* part of a functional event, without being substantiated. If something has a function, but it not acted upon, it has *potential*, but has not fulfilled the potential – which is why action is critical to the formula. Infants are sensitive to agent-produced information; in fact, agent produced motions are beneficial for category formation with infants aged 14 months, because "the interactions between agents and objects play a special role in infants' discovery of new categories" (Booth, 2000). Agents are critical to the use of objects, as the links "allow objects to act as an interface between an actor's goals and their motor system"

(Bach et al., 2014). Infants can predict outcomes of actions and understand other's actions (Hunnius & Bekkering, 2014). (The next section further elaborates the discussion of agents.)

"Actions are defined by goals and not the specific procedures by which they are implemented. They are initiated from within by motives…" (von Hofsten, 2012). This demonstrates that goals and desires by an agent are the driving force for actions on objects. Actions don't exist in the absence of motives. Therefore, agency is tightly linked with objects, actions on objects, goals, and outcomes. However, it is unknown exactly how agency is truly related to the emergent property of function.

While it appears that agency may be a critical component of function, there is not extant work that exists to determine whether the presence of agent – which in prior research is typically human – is essential to the emergent property of function. It is also unknown whether the absence of an agent would eliminate the perception of function. Further, it is unknown what kinds of agents (e.g., human/non-human, animate/inanimate) are critical to the property of function. There are many assumptions that underlie researcher's definitions of "function." One possibility is that agent could comprise a sub-part of "action." Another possibility is that agent is a separate part of the equation, a necessary critical component of the perception of function.

One piece of evidence for the importance of agency to function is from a neuroimaging study with infants aged 8 months. Results indicated that an interaction of a human agent and an event with a functional outcome causes an increase in oxy-hemoglobin (HbO) in the left middle temporal region (Biondi, Boas, & Wilcox, 2016). This interaction was not present when (a) the agent was a mechanical hand, or (b) when the outcome did not have a distinct cause-effect relation (Biondi, et al, 2016). Thus, an increase in cortical response was only evident when the human hand performed functional events, and not in the other contexts, linking the importance of *agent* to *function*. Based on this neuroimaging research, it could be predicted that the component of agent stands alone as relevant to the perception of function, and whether infants easily understand the agent's goals is also linked to who (e.g., what kind of agent) is performing the action. This result shines some light on the neural underpinnings for how infants interpret agents within the context of functional events, and may possibly help to determine the role of agent in understanding of function. (This question of agency will be further addressed in the next section and as part of the predictions for the current proposal.)

2.4.2 Function: Considerations and Caveats

Several issues arise when dealing with the concept of object function. When researchers consider an object's function, they do so typically from their own perspective. And although we have data to suggest that infants are sensitive to the "functional" nature of objects, we do not really know what may constitute a true "object function" from the infant perspective (Oakes & Madole, 2008). An important consideration is that what adults think of as an object's "function" may not be apparent to infants (Baumgartner & Oakes, 2011). For example, should an object's resulting clicking sound after it is rolled across a table (Baumgartner & Oakes, 2011) be considered a true object function?

These discrepancies and questions may be due, in part, to the elusive, non-obvious nature of function. The understanding of "function" come from our history of watching others use these objects, using the objects ourselves, and drawing upon memories of past experiences even simply when we see objects. Conversely, the mere *passive* usage of an object in its functional capacity is simple to comprehend, since we have experience seeing people use objects, and using the objects ourselves, both of which we draw from without thinking. However, since adults may rarely *actively* consider why an object is used or how it is used, this may be more difficult, could prove elusive, and may contribute to the wide discrepancies in the definition of "function" we see in the literature. Thus, there seems to be an opportunity for more clarification within the philosophical debate of object function, as well as determination of what "function" means for the developing infant.

Researchers do have data to suggest that infants understand the relationship between multiple features of an object, including appearance and function (Baumgartner & Oakes, 2011; Kingo & Krøjgaard, 2012), action and outcome (Perone et al., 2011), and in general, understanding of the relationship between the features that give rise to the perception of function (Oakes & Madole, 2008). The function of an object helps infants learn information from new objects and that can be applied to already-known objects in novel contexts and situations (Wilcox et al., 2008). The function of an object can help infants categorize (Träuble & Pauen, 2007, 2011), individuate (Kingo & Krøjgaard, 2012; Wilcox & Chapa, 2004), and predict both actions and outcomes (Bach et al., 2014). The function of an object can also be one which highlights links between features, priming infants to use featural information during object individuation (Wilcox & Chapa, 2004; Wilcox et al., 2008). Finally, neuroimaging results have demonstrated the link between agent and function in the infant temporal cortex (Biondi et al., 2016).

2.5 Agency

What adults consider as an "agent" comprises of multiple components. First, the agent has a set of specific features and physical characteristics. For example, a human agent looks distinctively human, with a head containing two eyes and other sensory organs, and with hands that reach and apprehend objects. Human agents move with biological motion patterns, on their own, without assistance. Infants are sensitive to the differences between human agents and all other kinds of agents, be they mechanical, animal, or other (Chouchourelou, Golden, & Shiffrar, 2013; Gergely & Csibra, 2003; Woodward, 1998, 2009).

Second, agents have goals, and make specific actions to attain their goals. Infants can reason about an agent's goals (Király, Jovanovic, Prinz, Aschersleben, & Gergely, 2003; Luo & Baillargeon, 2010), and may have expectations that an agent will make rational decisions regarding attaining their goals (Gergely & Csibra, 2003). Action may even be considered a major component of goal processing (Sommerville & Woodward, 2010). These components interact to help infants form representations about agents and their goals.

Even very young infants can discriminate human versus non-human agents, are sensitive to the perceptual qualities that comprise a human agent, and have expectations for how agents should behave and act. For example, from the early days of life, infants prefer human faces as opposed to patterns, shapes, or other types of visual stimuli (Fantz, 1963).

Not only can infants discern the differences between human and other kinds of agents, but their skills to differentiate agents is refined throughout the course of their development. For instance, infants aged 6 months view biological motion is as animate (Schlottmann & Ray, 2010). By 9 months, infants can attribute reaching goals to a particular individual, with the understanding that different individuals can have different goals (Buresh & Woodward, 2007). Infants aged 10 months can individuate self-propelled agents from inert objects (Surian & Caldi, 2010). Infants aged 12 months expect agents to behave rationally based on the "situational constraints" in the environment, the action, and the agent's goal state or intentions (Gergely & Csibra, 2003). Like function, it appears that infants become more sophisticated in the features used to comprehend a complex scene, and include increasingly complex material in that understanding.

Research has shown that infants have different expectations about how human and non-human agents behave, and associate goals to them differently. For instance, infants at 6 months of age can differentiate between the goals of different kinds of agents (Woodward, 1998). Evidence exists that: (a) infants can discriminate human agents versus non-human agents, and (b) and infants assign goal-directed behavior to human agents, but do not reliably do so for non-human agents. Infants assume human agents have goals and can link those goals to individual people (Buresh & Woodward, 2007). Infants mirror their own actions to the goals they see and an infant's own action experience can influence how they attribute goals to agents (Longo & Bertenthal, 2006; Sommerville, Woodward, & Needham, 2005). On the other hand, infants may not act similarly if the agent is not human, say, a mechanical hand or an inert rod (Woodward, 1998). However, this is based on action cues, the environmental constraints, and amount of experience or training with the agent. Infants may have expectations about human agents and their goal-directed behavior, but these expectations may not be applied to non-human agents (Jovanovic et al., 2007). It is possible for infants to ascribe a non-human agent with goals, but there are specific conditions under which this occurs.

In a seminal study, infants watched a human hand reaching for one of two objects, followed by multiple trials of the same hand reaching to the same object. Then the positions of the objects were switched. If the infants looked longer when the hand reached for the new object in the old location with the same path, it would be taken as evidence that the infants were surprised to see the hand the reach for the new object, and attributed the hand to have a specific goal of the old object. Indeed, the infants aged 6 months who participated were more surprised, evidenced by increased looking, when the hand switched goals and reached for the new object (Woodward, 1998). However, when the human hand agent was replaced with an inanimate rod or occluder, infants looked equally when (a) the mechanical agent reached for the old object in the new location, and (b) when the mechanical agent reached for the new object in the old location. This signaled that the infants did not form expectations about whether the mechanical agent had a goal (Woodward, 1998).

Understanding other's action intentions is also linked with an infant's own action experience, as "active action experience is crucial for infants' developing action understanding" (Hunnius & Bekkering, 2014). Take, for instance, the A-not-B task. During the canonical A-not-B task, an infant typically watches an experimenter hide a toy in one of two locations. Then the infant is given an opportunity to search for the toy. Once it is discovered, the toy is hidden again. After hiding and subsequently removing the toy from location A multiple times, the experimenter then hides the toy at the alternative location B. Infants younger than 12 months of age will usually incorrectly continue to search for the toy at location A, although they have seen the toy moved to location B. Indeed, infants aged 9 months make A-not-B errors when given the opportunity to search for objects themselves. Infants even make these errors when simply watching an experimenter hide and retrieve the toy, in the absence of the infants' ability to act on objects themselves, as long as the action is one the infants themselves could perform (Longo & Bertenthal, 2006). However, infants aged 9 and 12 months do not commit these A-not-B search errors when the agent is a mechanical hand – an agent so dissimilar from the infant that there is no possibility of motorically matching the mechanical agent's movements onto their own (Boyer, Pan, & Bertenthal, 2011; Moriguchi, Matsunaka, Itakura, & Hiraki, 2012). This action experience seems to be a critical component of how infants understand an agent's actions and goals. Infants younger than 12 months may be "biologically tuned" to human agents as opposed to mechanical agents (Moriguchi et al., 2012), and infants' motor repertoire directly influences their action understanding during observation and execution (Boyer et al., 2011; Longo & Bertenthal, 2006).

Indeed, first person experience with actions and objects aids infants in understanding an agent's goals (Woodward, 2009). To support this claim, infants aged 3 months, who normally don't have the dexterity to grasp objects, were given training experience acting on objects (e.g., reaching and apprehending). Training and experience increased their sensitivity to another person's hand attaining a goal in the classic Woodward (1998) paradigm (Sommerville et al., 2005). Infants who did not have the training experience did not show goal inference for the human hand in the test trials. Therefore, the infants' experience with their own ability to achieve an action goal helped aid them in understanding a goal reach from another agent.

Similar to the reach training, infants are sensitive to short episodes of learning about objects (Wilcox & Chapa, 2004). Understanding agency is no exception, as experience, training, and other cues can change infants' perception of agency for non-human agents. Infants who simply watch the mechanical hands do not fail the A-not-B task (i.e., do not incorrectly persist in searching the wrong location). However, after prior experience with both the mechanical claw and its function, infants fail in the A-not-B task, showing performance akin to infants who watch a human perform the A-not-B task (i.e., incorrectly persist in searching the wrong location; Boyer et al., 2011). After experience with the mechanical hands, infants can assign a goal-orientation to the agent *and* demonstrate a "relation between the means and the ends" (Boyer et al., 2011). Not only can infants imitate mechanical agents, but training and experience seems to influence infants' goal attributions to mechanical agents, as evidenced by a study with 9- and 12-month-olds (Hofer, Hauf, & Aschersleben, 2005). The 12-month-olds, but not the 9-month-olds, attributed goal-intentions to a mechanical claw; however, when the 9-month-olds were given experience with the claw (e.g., showing the infants how the claw is operated), the infants then attributed goal-intentions to it. Although, an alternative argument is that infants, when given experience with a mechanical claw operated by a human, saw the claw as a tool, not a mechanical agent with its own goals (Hofer et al., 2005).

Conversely, in another study with infants of similar age, mere exposure to and familiarization of a mechanical claw did not aid 7- and 10-month old infants in imitating an action; only comparison also helps infants aged 7- to 10- month-olds attribute goals to mechanical claws. The important factor is if the infants can compare the tool action and align the claw's goals with their own. Similar to the action training of Sommerville and colleagues (Sommerville et al., 2005), for infants, the ability to compare between their own goals and another agent's goals (e.g., reaching for an object) is more beneficial to imitating the goals than merely watching (Gerson & Woodward, 2012). Thus, evidence supports the claim that an infant's own action experience influences how – and to whom – they attribute goals.

A further contrasting account demonstrates that infants as young as 6 months old can assign goal-orientation to a mechanical claw after witnessing specific agentive cues (such as "self-propelledness, action-effect, and equifinality"), regardless of experience with the agent (Biro & Leslie, 2007). A complementary account argues that infants as young as 6 months of age do not need experience with the agent, nor did the agent need to be human or familiar, but as long as an agent exhibited the "abstract cues of goal-directedness" (Király et al., 2003). These accounts highlight specific action cues that could be parsed from action sequences to which infants are sensitive and can use to attribute agency and goals. Further evidence suggests that infants aged 12 months, but not those aged 9 months, do assign goal-attributions to a mechanical agent. However, in this testing scenario consisted of watching a mechanical claw perform a “salient change in the objects’ state” (Hofer et al., 2005). One important point: this is a different paradigm than the Woodward (1998) study, which had a human hand or mechanical entity reach and touch an object, *without* moving or changing the object. Critically, it is possible that this “salient change in objects’ state” is, in fact, what we would call an *outcome,* which would then change how this event is interpreted. Regardless, these results have led researchers to the conclusion that (a) infants do understand the differences in kinds of agents, whether human, mechanical or other, and (b) differentially assign intentions and goals to human and non-human agents. Yet, these methods and subsequent results are complex and do not always measure the exact same thing. However, one point is clear: together, this research suggests that infants do not *reliably* attribute goals to non-human (or mechanical) agents.

One question that arises is whether infants assign a mechanical claw with true agentive goals, or think of it as just a tool used by a human agent. Infants may have an “automatic bias” to assign intentional agency to humans, but not mechanical devices (Fields, 2014). This interpretation is reasonable, since 10- and 12-month-olds believe a human hand to be a more plausible action agent than a toy train (Saxe, Tenenbaum, & Carey, 2005). Generally, it seems that infants have difficulty overcoming an “automatic bias” to assign goals solely to human agents (Fields, 2014), and they perhaps do not clearly understand mechanical agents. To assign goal-orientation to a mechanical claw, infants may need experience, training, ability to compare, agentive cues, or some combination of these factors – importantly, none of which is necessary in order to assign goal-orientation to a human agent.

Evidence exists that: (a) infants can discriminate human agents versus non-human agents, and (b) and infants assign goal-directed behavior to human agents, but do not reliably do so for non-human agents. Infants assume human agents have goals and can link those goals to individual people. Infants mirror their own actions to the goals they see and an infant's own action experience can influence how they attribute goals to agents. On the other hand, infants may not act similarly if the agent is not human, say, a mechanical hand or an inert rod. However, this is based on action cues, the environmental constraints, and amount of experience or training with the agent. Infants may have expectations about human agents and their goal-directed behavior, but these expectations may not be applied to non-human agents (Jovanovic et al., 2007). However, it is possible for infants to ascribe a non-human agent with goals, but there are conditions under which this occurs.

Therefore, the evidence is not clear-cut and we need additional research to clarify how infants understand human and non-human agents, whether infants assume any kind of agent has goals, and how these concepts change throughout the course of infant development. Further, it is unknown how infants respond to a non-human agent in a scenario involving color-function priming.

2.6 Summary

Infants use specific features of objects to individuate them, features ranging from differences in shape, size, color, sound, labels, or category membership. Occlusion tasks are one way to test how infants individuate objects. Further, infants are sensitive to the functional aspects of objects. An object's function considers the relationship between objects, agents, actions, and outcomes, while considering both perceptual and conceptual information. Infants will use objects according to their function, as well as categorize and individuate objects based on demonstrated function. One caveat in the use of function during experiments with infants is the consideration of how the research defines function, versus how an infant interprets function.

Priming is one way to increase an infant's sensitivity to specific characteristics of an object, which can help them during the object individuation process. Infants also need specific information linking a specific color to a specific function, as infants will not rely on mere color differences generally (Wilcox et al., 2008). For example, an object's color can be highlighted by engaging objects in different functions (like scooping/pouring or pounding a nail; Wilcox & Chapa, 2004). If an infant links the object's function to its color, they will rely on color as a salient object property, and then can use that information to an object individuation task. If a priming event has highlighted the importance of color, and then the infant will use color as a feature upon which to individuate the object.

Agency is an important attribute for infants: who is performing an action or event they are watching? Agents perform actions with goals, and the interaction between the kind of agent and the action and goal is important. Infants have a possible bias toward human agents. At a young age, infants will assign goals and intentions to human agents, which could simply be a human hand. Infants have different expectations for non-human agents and do not necessarily assign non-human agents with intention or goal directed behavior.

3. PREDICTIONS AND CURRENT RESEARCH PROPOSAL

How important is an agent to the emergent property of function? Function relies on the presence of an object and an action upon that object by an agent, resulting in a substantive outcome. If there is no object, action, or outcome, there is no function; thus, these are at least perceptually crucial pieces. What can be said about the presence of an agent within a functional event?

Infants are sensitive to agent-produced information; in fact, agent produced motions are beneficial for category formation with infants aged 14 months (Booth, 2000), because "the interactions between agents and objects play a special role in infants' discovery of new categories" (Booth, 2000). Agents are critical to the use of objects, as the links "allow objects to act as an interface between an actor's goals and their motor system" (Bach et al., 2014). Infants can predict outcomes of actions and understand other's actions (Hunnius & Bekkering, 2014). Therefore, agency is tightly linked with objects, actions on objects, goals, and outcomes. However, it is unknown exactly how agency is truly related to the emergent property of function.

These topics set the stage for this research to examine the roles of human and non-human agents within functional events. This research will contribute to the understanding of how agents – both human and non-human – contribute to the "emergent property" of function, as infants understand it. This research of familiarizing infants with the goals of human and non-human agents converges with the function research: agency is a critical piece of the function equation, especially if it is a human agent. If infants do not assign a goal or intention to a non-human agent, it is possible that the perception of function degrades. This brings to bear the importance of agent to a functional event. We will examine both concepts: (a) what kind of agent is important to infants and (b) how important is agency within the functional framework. I predict that agent – who is performing an action – plays an important role in the overall percept or emergent property of a functional event.

This study has provided evidence to determine the influence of the agent performing an event to the priming scenario. Further, this study demonstrated how the agent (e.g., who/what entity is performing an event) contributes to how infants perceive object function. Specifically, this hypothesis tested whether infants evidence individuation-by-color after watching priming trials performed by a mechanical hand agent. There are several reasons why we predicted they will not. First, as previously discussed, infants do not reliably assign goal orientation to mechanical entities. In this testing scenario, were not provided the visual cues necessary for infants to attribute goal orientation to our mechanical agent, namely self-propelledness, action effect, or equifinality (Biro & Leslie, 2007). In absence of these cues, infants should interpret the mechanical hand as a non-self-propelled, inert agent, and not ascribe intentionality or goal-directedness to it. Second, based on previous neuroimaging research with infants in the same age range, we have found that the infant brain distinguishes agents while using a functional object (Biondi et al., 2016). Specifically, the left hemisphere showed increased cortical activation to the human agent, but only in the context of the functional event. After infants watched the priming trials performed by a mechanical agent, the infants then watched an event-mapping task to assess object individuation based on surface color.

This experiment an extension of previous work (Wilcox & Chapa, 2004; Wilcox, Hirshkowitz, Hawkins, & Boas, 2014): in both previous studies, an event-monitoring task was employed, using narrow- and wide-screen occlusion events, where the occluder was never removed during test trials. In the current proposed study, we employ a one-trajectory event-mapping task, where after the occlusion interval, the occluder is removed and stage is revealed. Event mapping requires the infant to match the first object position with the second object position. However, the occlusion event was followed by a non-occlusion event, the final phase, where the screen is removed to reveal the stage behind it. Typically, the occlusion screen is wide enough to conceal both objects, but when it is removed, it may reveal other objects behind it, or nothing at all.

If the infant successfully individuates by color, they will expect to see two objects in the color-change condition and will be surprised to see only one object on the stage when the occluder is removed. Infants would then look longer at the final phase of the test trial during the color change trials, as compared to the control trials. The object of this study is to determine how infants individuate based on the agent type they watched perform the priming events. Infants in the human hand condition should evidence color-function priming and should individuate by color during the test trials. However, infants in the mechanical hand condition should not evidence color-function and should not individuate by color during the test trials. We chose this methodology for several reasons. First, the one trajectory event-mapping task has been demonstrated to be simpler to comprehend in infants, as compared to multi-trajectory event-mapping tasks (Wilcox & Baillargeon, 1998b). As our age group is aged 8-10 months, we predict that this one trajectory event-mapping task will be effective and provide similar results as previous work using the event-monitoring tasks. Previous research has indicated that infants aged 9.5 months can succeed in an event-mapping task with one trajectory change (Wilcox & Baillargeon, 1998a). Further, within this research, the objects different on multiple dimensions:

shape, pattern, and color. The current work proposes use of surface color change only. Thus, we will be able to extend previous results with a modification in the methodology.

3.1 Research Methods

3.1.1 Participants

Eighty infants healthy full-term aged 9.5 months participated in this study (*M* = 288 days, *SD* = 21 days; range = 241-330 days). The gender, ethnic, and racial representation of our sample consisted of 39 females and 41 males; 15 infants identified as Hispanic/Latino, 62 infants identified as not Hispanic/Latino, and 3 infants chose not to identify ethnicity; 60 infants identified as white, 6 infants identified as Asian, 1 infant identified as Black/African American, 11 infants identified as more than one race, and 2 infants chose to not identify race.

Parents were recruited primarily by commercially available lists, social media, or word of mouth, and given $5 and a t-shirt for their participation. Exclusionary criteria included: procedural problems during any part of the study[1] (n = 14), inability to complete at least 1 test trial (n = 1), parental interference/environmental distractions (n = 8), or infant fussiness (n =5). Infants were randomly assigned to one of two agent conditions: human hand (n = 40) or mechanical hand (n = 40). Further, infants within each condition saw either color-change test trials (n = 20 for each condition) or control test trials (n = 20 for each condition).

[1] While this might seem like a high number of infants excluded, it is important to consider the context of the entire study environment. We had seven undergraduate students manipulating multiple objects across two blocks of trials, during which if there were any timing or movement errors, the study could possibly be excluded from final analysis.

3.1.2 Apparatus & Objects

All events were performed in a wooden puppet stage apparatus, with real, 3-D objects. The apparatus was 213 cm high x 105 cm wide x 43.5 cm deep. Video recordings were taken of all events, plus the infants' affect and attention to the apparatus, for review if necessary. A fabric-covered screen, concealing the stage, was raised to begin and lowered to end each priming trial and test trial. Two naïve observers observed the infant's visual behavior through a hole in fabric-covered screens on either side of the infant.

Figure 3. The three pairs of cups used in all conditions by both the human and mechanical agents. The pairs were always presented in the same order, though it was counterbalanced whether the green or red pairs were presented first. Reprinted from Biondi et al., 2016.

Three pairs of cups were used in the priming events. Each pair had one green cup and one red cup, each of which were identical to the other. The three pairs were all similar in appearance but had slightly different shapes and handles (Figure 3). These three pairs were always presented in the same order. The green cups engaged in pounding a wooden nail, and the red cups engaged in a scooping and pouring action with a container of rice. The green cups always pounded a nail box and the red cups always poured from a rice box, so the object color predicted the event in which the object engaged.

Two natural-colored wooden boxes, each with four wooden legs, were used as the function containers. The size of both boxes was 23.5 cm (width) x 13 cm (height) x 15.5 cm (depth), including the 12 cm legs. Both boxes had an open side facing up to form a container. Rice filled this opening for the pour events, and it was empty for the pound events except for an additional 12 cm wooden nail that protruded from the top.

The balls used in the test events were 10.25 cm in diameter, made of Styrofoam, and painted the same hue of green and red as the cups from the priming trials. The occlusion screen was 30 cm (width) x 19.5 cm (height), and connected to a wooden dowel, which was used to flip it down to reveal the contents behind it.

3.1.3 Testing Events

Priming Trials

Each experimental session began with six priming trials, followed by four test trials. The same experimenter performed both the priming and test events. A metronome set to 60 beats per second softly clicked during the experimental session.

The six priming trials were set up as three pairs of trials, and each pair consisted of a pound trial and a pour trial (Figures 4 and 5). Infants were randomly assigned to watch the priming events performed by either the human hand or a mechanical hand. All priming events were performed by either a human hand covered with a black glove (human hand condition), or a mechanical grabber tool painted black (mechanical hand condition).

Trials (pound or pour) were counterbalanced between infants. Each priming trial was 30 s in duration, during which infants watched four complete cycles of each event. Each pair of pound and pour trials were seen with a different pair of green and red containers (Figure 3). The priming events and test trials were similar to events seen in previous work (Biondi et al., 2016; Wilcox & Chapa, 2004; Wilcox et al., 2014).

Each eight-second event cycle for the pour trials showed the cup in a still neutral position above the rice container (2 s), moving down to scoop the rice for (2 s), returning to a neutral position above the rice box (2 s), and finally pouring the rice out and returning to neutral position (2 s). This cycle was then repeated until the infant looked away for two consecutive seconds, at which point the trial ended and a pound trial began.

Each eight-second event for the pound trials showed the cup being held in neutral position above the nail box (2 s), pounding the nail twice on the beat (2 s), returning to neutral position (2 s), followed by two more pounds on the nail twice on the beat (2 s). The cycle was then repeated until the infant looked away for two consecutive seconds, at which point the trial ended and a pour trial began (until six priming trials had been completed). Review Figures 4 and 5 to see still images depicting the stages of this dynamic event.

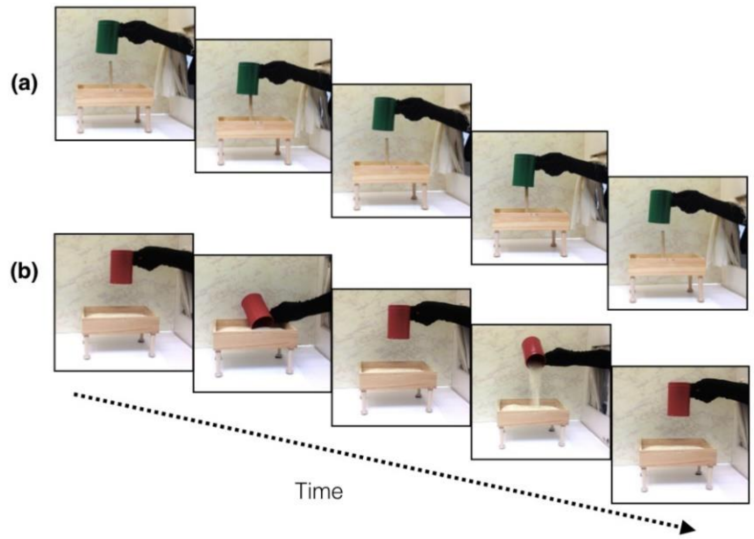

Figure 4. (a) Pound and (b) pour events, performed with a human hand obscured by a black glove. Reprinted from Biondi et al., 2016.

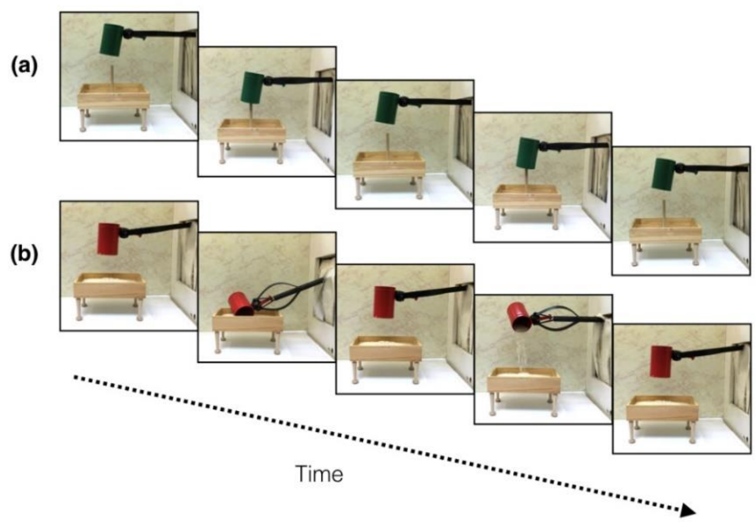

Figure 5. (a) Pound and (b) pour events, performed with a mechanical hand painted black. Reprinted from Biondi et al., 2016.

Test Trials

All test events were performed by human hand covered with a black glove. Each infant saw only one of two test trial types: color-change or control. In the control condition, a green ball began on the left side of an occluder screen, moved behind the screen, and a green ball emerged on the right side of the occluder screen. In the color change condition, a red ball began on the left side of an occluder screen, moved behind the screen, and a green ball emerged on the right side of the occluder screen (Figure 2)[2]. The occluder then was removed to reveal an empty stage behind it.

Each test trial began with the colored ball to the left (infant's point of view) of the occluder screen. In the pre-trial phase, the ball "danced" in a stationary position, where the ball bounced left and right on the beat, until the infant looked at the ball for two seconds. Then the trial began, where the ball slid right (2 s), became occluded (2 s), slid out on the right side of the occlusion screen (2 s), then stopped at an equidistant point to resume "dancing" on the beat until the trial ended. The occlusion screen flipped down (seven seconds after the initiation of the ball slide) and the ball continued dancing until the infant looked away for two consecutive seconds, at which point the trial ended and another test trial began (until four test trials had been completed).

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[2] There are, of course, four possible combinations of objects that we could use in the event-mapping test trials: 1) red-red, 2) green-green, 3) red-green, and 4) green-red. Ideally, we would use all four combinations, but for simplicity sake (in data collection and analysis), we chose red-green for color change trials and green-green for control trials. This was done so the result of both final phases was a green ball, and that increased looking to the final phase could not be interpreted as the result of increased looking to different colored objects.

3.1.4 Procedure

Infants sat in their parents lap in a quiet room and watched the events on a puppet-stage apparatus. The infants sat on their parents lap approximately 75 cm from the stage. Trained experimenters produced the events with a precise, timed script (see above section for specific timing of all events). One experimenter performed the priming trials, and two experimenters performed the test trials (all human hands were disguised using black gloves, to obscure changes in identity during the test trial events). During the priming trials, the infant watched events appropriate to their condition on six successive trials. Each trial ended when (a) the infant looked away for two consecutive seconds, after watching for at least 12 cumulative seconds; or (b) after 30 seconds. The looking time data was coded by hand via the two observers in real time. The computer signaled a tone when the trial should end and the curtain was lowered, ending the trial.

During the test trials, infants watched events appropriate to their condition. Each trial ended when (a) the infant looked away for 2 consecutive seconds after watching the event for 8 seconds, or (b) after 60 seconds. Each infant was presented with the same number of familiarization and test trials. Similar to the priming trials, the computer signaled a tone when the trial should end and the curtain was lowered, ending the trial.

Two observers, naive to the condition infants are assigned, monitored infants’ looking behavior through peepholes in the frames on either side of the apparatus. Each observer used a game controller connected to a Dell computer and depressed a button when the infants attended to the event. The looking times by the primary observer was used in data analysis. Inter-observer agreement was calculated and averaged 94.45% (SD = 0.03). Total duration of looking (i.e., cumulative looking) to each test trial was obtained, and was the dependent variable of interest.

4. RESULTS

4.1 Priming Trials

Preliminary analyses were performed to determine whether male or female infants responded differently to the priming events. First, looking time to the six priming trials was averaged (across all six priming trials) and analyzed via a multivariate 2 (gender) x 2 (agent type) x 2 (test type) ANOVA. The following main effects were not significant: gender, $F(1,79) = 1.599$, $p = 0.210$, $\eta p^2 = 0.022$; agent $F(1,79) = 0.123$, $p = 0.727$, $\eta p^2 = 0.002$; test type, $F(1,79) = 0.054$, $p = 0.817$, $\eta p^2 = 0.001$. The following interactions were not significant: agent x test type, $F(1,79) = 0.802$, $p = 0.374$, $\eta p^2 = 0.011$; agent x gender, $F(1,79) = 0.887$, $p = 0.349$, $\eta p^2 = 0.012$; test x gender, $F(1,79) = 1.384$, $p = 0.243$, $\eta p^2 = 0.019$; agent x test x gender, $F(1,79) = 0.000$, $p = 0.990$, $\eta p^2 = 0.000$.

In summary, we found no statistically significant differences between looking times to any of the priming trials by gender, agent type, or test type, nor were there any statistically signifant interactions. Thus, we collapsed across gender for the remaining priming trial analyses. However, due to relatively small sample sizes, we interpret null results with caution.

Next, infants' mean looking times (averaged across all six priming trials) were analyzed by means of 2 (agent type) x 2 (test type) ANOVA. The main effect of agent was not significant, $F(1,79) = 0.026$, $p = 0.264$, $\eta p^2 = 0.000$, nor was the main effect of test type significant, $F(1,79) = 0.00$, $p = 0.997$, $\eta p^2 = 0.000$. The interaction between agent and test type was not significant, $F(1,79) = 0.428$, $p = 0.515$, $\eta p^2 = 0.005$. Infants in all four conditions looked almost equally at the priming events (Table 1). Therefore, we did not add priming trials as a covariate during our primary data analyses.

	Test Condition	
Agent	Color-Change	Control
Human	24.99 (4.02)	24.37 (4.66)
Mechanical	24.22 (4.56)	24.83 (3.53)

Table 1. Total looking time to the priming trials, by agent and test condition. Means and standard deviations (in parentheses) are shown.

4.2 Test Trials: Initial Phase

Next, infants' mean looking times (averaged across test trials 1 and 2) to the initial phase (occlusion event) were analyzed by means of a 2 (agent type) x 2 (test type) ANOVA. The main effect of agent was not significant, $F(1,79) = 0.064$, $p = 0.801$, $\eta p^2 = 0.001$, nor was the main effect of test type significant, $F(1,79) = 1.600$, $p = 0.210$, $\eta p^2 = 0.021$. The interaction between agent and test type was not significant, $F(1,79) = 1.638$, $p = 0.205$, $\eta p^2 = 0.020$. Infants in all four conditions looked almost equally at the scene during the initial phase (Table 2).

	Test Condition	
Agent	Color-Change	Control
Human	6.75 (0.52)	6.75 (0.52)
Mechanical	6.90 (0.27)	6.52 (1.07)

Table 2. Total looking time to the initial phase of the test trial (occlusion interval), by agent and test condition. Means and standard deviations (in parentheses) are shown.

4.3 Test Trials: Final Phase

First, looking time to the first two test trials was averaged and analyzed via a multivariate 2 (gender) x 2 (agent type) x 2 (test type) ANOVA. The following main effects were not significant: gender, $F(1,79) = 0.083$, $p = 0.774$, $\eta p^2 = 0.001$; agent $F(1,79) = 1.089$, $p = 0.300$, $\eta p^2 = 0.015$; test type, $F(1,79) = 2.743$, $p = 0.102$, $\eta p^2 = 0.037$. The following interactions were not significant: agent x gender, $F(1,79) = 1.643$, $p = 0.204$, $\eta p^2 = 0.022$; test x gender, $F(1,79) = 0.255$, $p = 0.615$, $\eta p^2 = 0.004$; agent x test x gender, $F(1,79) = 0.038$, $p = 0.845$, $\eta p^2 = 0.001$. The following interaction was significant: agent x test type, $F(1,79) = 4.227$, $p = 0.043$, $\eta p^2 = 0.055$. Due to the very small size of each cell for gender, this should be interpreted with caution.

In summary, we found no statistically significant differences between looking times to any of the priming trials by gender, agent type, or test type, nor were there any statistically signifant interactions, except for one. Thus, we collapsed across gender for the remaining test trial analyses. However, due to relatively small sample sizes, we interpret null results with caution.

Next, infants' mean looking times (averaged across test trials 1 and 2, using the two-second look away times) to the final phase (after the occlusion event, when the occluder was removed) were analyzed by means of a 2 (agent type) x 2 (test type) ANOVA. The main effect of agent was not significant, $F(1,79) = 1.267$, $p = 0.264$, $\eta p^2 = 0.015$, nor was the main effect of test type significant, $F(1,79) = 3.323$, $p = 0.072$, $\eta p^2 = 0.040$. The interaction between agent and test type was significant, $F(1,79) = 4.243$, $p = 0.043$, $\eta p^2 = 0.051$. Infants looked longest at the final phase of color-change trial events if they had first seen the priming trials performed by a human hand (Table 3).

	Test Condition	
Agent	Color-Change	Control
Human	29.68 (12.82)	20.34 (10.65)
Mechanical	22.01 (9.69)	22.58 (9.34)

Table 3. Total looking time to the final phase of the test trial (after the occlusion interval), by agent and test condition. Means and standard deviations (in parentheses) are shown.

Follow up analyses were set to perform three follow-up comparisons using independent samples *t*-tests: 1) human hand priming trials, color change vs. control test trials; 2) mechanical hand priming trials, color change vs. control test trials; 3) human hand priming trials, color change test trials vs. mechanical hand priming trials, color change test trials.

First, when the priming trials were performed by a human hand, infants looked longer to the final phase of the test trial if they were in the color change condition ($M = 29.68$, $SD = 12.82$) than if they were in the control condition ($M = 20.34$, $SD = 10.65$), $t(38) = 2.492$, $p = 0.017$; Cohen's $d = 0.79$. The effect size for this analysis ($d = 0.79$) was found to be in Cohen's (1988) convention for medium effect size, but very close to being classified as a large effect size.

Second, when the priming trials were performed by a mechanical hand, infants looked equally at the final phase of the trial whether they were in the color change test condition ($M = 22.01$, $SD = 9.69$) or the control test condition ($M = 22.58$, $SD = 9.34$), $t(38) = -0.189$, $p > 0.05$; Cohen's $d = 0.06$. The effect size for this analysis ($d = 0.06$) was found to be below Cohen's (1988) convention for small effect size.

Third, infants looked longer to the final phase of the test trial during the color change condition, when the priming trials were performed by a human hand ($M = 29.68$, $SD = 12.82$)

than if the performed by a mechanical hand (*M* = 22.01, *SD* = 9.69), *t*(40) = 2.185, *p* = 0.35; Cohen's *d* = 0.67. The effect size for this analysis (*d* = 0.67) was found to be in Cohen's (1988) convention for medium effect size.

In conclusion, infants looked longer at the final phase of the event if they 1) were watching the color change test trials, and 2) they had first seen the human hand performing the priming trials.

5. CONCLUSIONS

There is extant behavioral work demonstrating that infants can individuate objects by surface features, such as color. Further, the features that infants use as basis for individuation is malleable with experience, such as color-function priming. Infants respond differently to human vs. non-human or mechanical agents. Most critically to this work, infants regularly attribute goal-orientation to human agents but do not reliably do so for mechanical agents. Finally, infants use an object's functional properties to glean information about what they see and can apply what they learn to novel contexts.

The current study has investigated whether human or mechanical agents performing color-function priming events influence (a) how infants learn whether color has predictive value, and (b) whether infants apply what they have learned to a novel object individuation task. We had several predictions. First, we anticipated that infants in the human agent priming condition would evidence greater looking during the final phase of the event of the color-change test trials, as compared to infants in the control test trials. Next, we anticipated that infants in the mechanical agent priming condition would evidence equal looking during the final phase of the event during both the color-change and control test trials. Finally, we anticipated that infants in the human hand priming condition will evidence an increase in looking time to the final phase of the color-change test trials, as compared to infants in the mechanical hand priming condition during the color-change trials. Two main findings emerged.

First, the results have demonstrated that infants can be primed to attend to color-change events during object individuation tasks, using a one-trajectory event mapping procedure. Infants watched 6 pound-pour priming trials and could link color to object function, *only if they watched* *the human hand perform the priming events.* Then, on separate event-mapping occlusion tasks, infants who watched the human hand perform the priming events expected to see: a) one object during the control test trials, and were not surprised, as evidenced by short total looking time, and b) two objects during the color-change test trials, and were surprised to see only one object, as evidenced by prolonged looking. We found that infants aged 9 months are successful at individuating by color during an event mapping procedure. Previous color-function priming studies used event monitoring tasks to test object individuation abilities in infants 9 months of age (Wilcox & Chapa 2004; Wilcox, 2008). The current results demonstrate an additional object-individuation task type that infants can accomplish.

Second, this study demonstrated that infants *cannot* be primed to attend to color-change events during object individuation tasks, if the agent demonstrating the priming events is a mechanical hand. Infants watched 6 pound-pour priming trials and, since the agent performing the tasks was mechanical, were not able to link color to object function. Then, on separate event-mapping occlusion tasks, infants looked equally during the event-mapping trial, regardless if they saw the color-change or control condition. This finding is relevant for object occlusion research with infants, as we will outline restricted conditions under which infants can and cannot succeed during event-mapping object occlusion tasks. This finding also sheds light on how infants understand functional events and the agents that perform them. Further implications of this finding will be addressed.

These results fit within and support the existing literature. First, infants learned from the human hand, but not the mechanical hand, that color has predictive value and is linked to a specific and unique function – namely, red-pour and green-pound. Second, infants can then draw upon this knowledge on a separate, novel task – object individuation via event mapping paradigm. The data from this study shows that infants did in fact draw upon the information gathered during the priming trials and applied that knowledge to a completely novel experience of the individuation task, but only when the color-function priming trials were performed by the human hand agent.

Why would this be? In the priming trials, we taught the infants that color differences predict an object's function. For example, Cup 1 was colored red, and performed the action of scooping and pouring rice. Cup 2 was colored green, and performed the action of pounding the nail. Cup 3 was also red, like Cup 1, and also scooped and poured rice. We provided infants three exemplars, which is critical for category formation and color-function priming (Wilcox & Chapa, 2004; Wilcox, Woods, & Chapa, 2008). In this case, red objects scoop and pour while green objects pound the nail. Then, they could draw upon that color information when deciding on how many objects were in the scene during the test trial. Red and green objects look different, but more importantly they perform completely different functions. Therefore, it is vital to consider red and green objects as distinct entities numerically. These results have been demonstrated in previous studies with similar methods (Wilcox & Chapa, 2004; Wilcox et al., 2011, 2008; Woods & Wilcox, 2010)

The critical element in this study is the difference in looking time to the final phase of the test trials after watching the human or mechanical hand engage in the color-function priming events. The results of this study revealed significant differences in both the human hand color-change vs. control test trials, as well as the human hand color-change vs. mechanical hand color-change test trials. Infants who watched the human hand perform the color-function events learned from that agent that color has predictive value, as demonstrated by longer looking during the test events. However, infants who watched the mechanical hand perform the color-function events did *not* learn from the agent that color has predictive value.

One explanation is that infants do, in fact, ascribe intentions and goal-directedness to human agents, but not mechanical agents. Infants watched the two agents perform the pound-pour events, but only believed the human hand to be moving in a goal-oriented manner. Therefore, infants learned from the human hand but not the mechanical hand that 1) color is predictive of object function and 2) can be used as a reliable feature upon which to individuate objects. Why wouldn't the events themselves provide enough information to invoke color-function priming, regardless of the agent performing them? If this was the case, we would have seen equal looking times to the final phase of the test trials, regardless of the priming condition the infants were in. However, we did not. First, my working hypothesis underscoring the *Function Equation* is that action upon objects *by agents* with a specific outcome is what comprises the "emergent property" of function. Second, these results also highlight the goal-oriented nature of this action upon objects, the kind of actions that are only viewed as intentional when completed by a human agent. While the mechanical hand still performed the same pound-pour events, they were not viewed as intentional to infants. Therefore, infants did not view the events as functionally-relevant in nature and did not learn from them that color has predictive value. In sum, it is 1) the presence of agents (and based on these results, particularly human agents) engaging in the events, and 2) the intentionality of the events which allow for the infants to view the event as functionally relevant and enables the color-function priming.

Another explanation is that infants do (or can) ascribe intentions and goal-directedness to many kinds of agents, including mechanical agents, and action by *any type of agent* on an object with an outcome would be interpreted as a functional event. If this were the case, we would have likely seen no difference in looking time to the color change test trials whether infants first watched human or mechanical hands perform the priming trials. However, we did see a difference in looking time between those two groups, leading us to question this conclusion. There were two tasks involved in this study: a functionally-relevant event, followed by an event-mapping object individuation task. Two logical explanations follow: 1) in our case, the task demands were more challenging, and although the infants might have attributed goal-directedness to the mechanical hand, we did not see a transfer of knowledge to the second task; and 2) since the individuation task was not a functional event, perhaps that is where the translation failed. However, this seems unlikely, given that infants in this age range have succeeded in the same kind of color-function priming, as evidenced by object individuation, in other studies (Wilcox & Chapa, 2004; Wilcox et al., 2008).

In previous work, researchers found that infants need specific types of cues to view a mechanical agent as possessing goal-directedness – namely "self-propelledness, action-effect, and equifinality" (Biro & Leslie, 2007). The authors claim that the "specific appearance of the actor is not critical for infants' judgments of agency" (Biro & Leslie, 2007). However, in our study, the appearance of the actor was the only thing that changed. First, equifinial variations in the behavior likely occurred, as the infants watched the cups scoop and pour several times. Although the experimenters were trained well, one can assume small variations in movement along the XY axis of the stage during the scooping and pounding actions, as is typical when humans are engaged in many repetitive motor activities. Second, the action effect of scooping and pounding were sufficiently salient, as they resulted in outcomes of the hammering sound and pouring of rice (a change of state). Third, the agents moved in a self-propelled manner while performing all events. Thus, all three cues were present, and yet, based on the total looking time results, infants only demonstrated individuation by color after watching the human hands perform the priming events. In the original paper, the youngest group of infants at 6 months of age were able to attribute goal-directedness to the non-human agent when all three cues were present (Biro & Leslie, 2007). One final important note: although the mechanical agent appeared different than the human hand, it was still operated by a human experimenter and exhibited the three cues necessary to provide evidence of goal-directedness as based on the Biro & Leslie (2007) cue-based account. Since all three cues were present for both agents, and the only element that changed between conditions was the *appearance* of the agent, it seems that appearance of the agent is critical to infants' understanding of the priming events and extraction of color-function rules. Perhaps appearance of the agent is the cue that leads infants to form different expectations about the events they are watching.

One way to address this is by employing eye tracking technology. Corneal reflection eye tracking provides highly accurate assessments of looking patterns to complex scenes. Therefore, we would have a more complete sense of whether infants were looking at the agent, the container, or the object engaging in the event. If we saw group differences in looking to any part of the scene, we would have a better understanding of how the infants parsed the event, which may influence their later performance on the object individuation task.

Another question that arises is whether these results point to infants' familiarization with human hands. Human hands are involved in feeding, playing, comforting, and caring for infants daily. This could result in a framework for infants of evidence from prior experience. Could the current results simply indicate infants' ability to distinguish familiar agent vs. unfamiliar agent, or did the infants in the current study see the mechanical hand as unfamiliar? Other researchers have found that if infants are provided additional information about an unfamiliar mechanical agent, they have different expectations and responses to the event (Boyer, Pan, & Bertenthal, 2011). One way to test this possibility is to present and familiarize the infants to the mechanical agents, then perform the same color-function priming events, followed by the same event-mapping individuation tasks. This would help determine whether the current results were due to a difference in familiarity between the human and mechanical agents we used.

This all leads to a final question: is there a reason that infants appear to privilege human agents in this context? Is it appearance, familiarity, the agent's underlying goals, or something else? In our previous work, we showed similar pound-pour priming trials to infants while measuring hemodynamic response in bilateral temporal cortex using functional near-infrared spectroscopy (fNIRS) (Biondi et al., 2016). We found two main results: 1) increased HbO in the left temporal regions, only when infants watched the human hand performing functionally-relevant events, and 2) increased HbO to human vs. mechanical hands in the right temporal region of the brain (irrespective of functional relevance of the events). We attributed these differences in cortical response to the identity of the agent, but not the possible underlying goals or intentionality of the agent. In the current study, we are building on the fNIRS results, as the priming events are used as a learning mechanism to then test infants' knowledge of how many objects are in the final phase of the event-mapping trials. Since infants looked longest at the final phase of the test event *only* in the human hand color change condition, we can infer that the information gathered by these infants only in this condition was different and sufficient to induce priming. And the difference was simply the agent who performed the pound-pour priming events.

In the fNIRS work, the distinction between human vs. mechanical agents warranted further exploration; however, the main effect collapsed functionally-relevant and non-functionally-relevant events. In the current study, we only tested functionally relevant events. If we showed infants a mechanical hand engaging in non-functionally-relevant events, we would anticipate no color-function priming, based on previous results where human agents used objects to engage in non-functionally-relevant events (Wilcox & Chapa, 2004; Wilcox, Woods, & Chapa, 2008). Further, in our previous work with fNIRS, we found no activation in temporal regions to mechanical agents performing either functionally-relevant or non-functionally-relevant events (Biondi, Boas, & Wilcox, 2016). These results point to perhaps different cortical networks that are engaged when infants view 1) human agents, 2) functionally-relevant events, and 3) or both, signaling the importance of the relationship between them.

Together, this data further demonstrates that infants have different expectation for human vs. mechanical entities. Using an assessment of looking behavior, we found that infants were able to successfully individuate objects by color only if they witness the human hand agents engage in functionally-relevant priming events, but not if mechanical hand agents engaged in the same kind of event. These results shine a light on the developmental mechanisms of how infants learn about the world around them. Future studies will use looking time and measures of neural activation (e.g., fNIRS) to continue assessing infants' representation of functional events as influenced by the agents performing them, characteristics of the objects themselves, actions on the objects, and outcomes therein.

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