

**Perceptual-motor exploration and selection of objects in 11-month-old infants**

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Rebecca Faith Wiener  
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## DEDICATION

This dissertation is dedicated to each and every member of my family. Thank you for being my cheerleaders, supporting and loving me through every step toward this degree.

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## ABSTRACT

This project investigated how perceptual-motor exploration of two objects in 11-month-olds influenced subsequent selection of those objects. In study 1, seventeen 11-month-olds were presented with two objects initially out of reach to obtain eye-tracking for about 5s. Then, the objects were moved within reach to allow for 30-40s of manipulation. This procedure was repeated for up to 16 trials, including baseline, discovery, and generalization phases. In each pairing of stimulus objects, one object was filled so it would provide auditory-tactile feedback when manipulated. I predicted that if infants discovered this property, they would select that object more on subsequent trials via looking, reaching, and manipulation. I also predicted that these behaviors would be related across trials. In study 1, I found that infants discovered the auditory-tactile property by shaking/banging the filled object more than the unfilled object, but this discovery did not impact selection via other behaviors. Additionally, perception-action matching occurred within visual and manual modalities, but not between those modalities. Study 2 included eighteen 11-month-olds. The only difference from study 1 was that the unfilled object had visual details. I predicted that initially infants would look at, reach for and manipulate the unfilled/detailed object more. If they discovered the auditory-tactile property, they would subsequently select the filled object more; however, if saliency of the visual property prevailed over this motor discovery, infants would continue to select the unfilled/detailed object. Results from study 2 showed that infants looked at the unfilled/detailed object more than the filled object, but did not show any averaged group differences for reaching or manipulation. Additionally, higher proportions of perception-action matching occurred for looking variables regarding matches with the unfilled/detailed object, but higher proportions of matching occurred for reaching and manipulation variables regarding matches with the filled object. Results from both studies suggest that 11-month-olds can discover an auditory-tactile property of one object

when presented with two objects, but when there is a competing visual property, the effect is overridden. Additionally, it seems that perceptual modalities are still coordinating at 11 months, as exhibited by the disconnection between visual and manual types of object exploration.

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## CHAPTER 1: INTRODUCTION

### 1.1 Background and theoretical considerations

Throughout the first 12 months of life, infants are presented with the challenging task of making sense of the plethora of information with which they are bombarded on a daily basis. They must use cues about regularities in their environments to make associations between the raw sensory and perceptual information they encounter, so that within this first year of life they can become autonomous interaction partners with the objects and people in their surroundings. One prominent way infants learn to make sense of their worlds is by interacting with them. Initially during infancy, infants explore their environments in rudimentary ways, using vision (Haith 1980; Banks & Salapatek, 1983; E. J. Gibson & Spelke, 1983), sucking (Rochat, 1983, 1989), self-touch (White, Castle, & Held, 1964; Thomas, Karl, & Whishaw, 2015) and moving their extremities (Wolff, 1959; Thelen & Fisher 1983). However, even these behaviors provide a wealth of foundational information about properties of the environment and their own bodies, which sets the ground work for some of the first goal-directed interactions with the environment, such as reaching and grasping for objects.

To become skilled at reaching takes a lot of practice, but infants master the skill by exploring the repertoire of their own movements and selecting the actions that are successful (Thelen & Corbetta, 1994). Eventually, with practice, all of the necessary motor components become coordinated enough to reach and grasp successfully. Being able to reach and grasp for objects then allows infants to explore objects in their environment in new ways (Lobo & Galloway, 2013; Bhat & Galloway, 2006; Lobo, Kokkoni, de Campos, & Galloway, 2014). Each time infants explore objects, feedback is provided about the objects in the environment, but also about their own actions and perceptual systems (E. J. Gibson, 1988). This feedback loop

influences future perception and action, and, thus facilitates continued learning about the world and the infant's role within it. The current research investigated whether infants could discover certain properties of objects and how discovery of these properties influenced their subsequent exploration of the objects.

**1.1.1 Perceptual development via exploration and selection.** J. J. Gibson (1979) described the ambient optic array, in which individuals move through their environments and detect properties of their environments revealed by the structured arrangements of light. The invariant properties of the environment exposed by the optic array yield ample information that allows individuals to differentiate properties of objects and structures in their surroundings, and, thus, navigate through them. This description refers to J. J. Gibson's ecological view of perception, specifically visual perception. In his book regarding the topic, J. J. Gibson (1979) is very clear that the *information* to which he refers is provided externally by properties of the environment and movement of individuals within their environments. Though this *information* is related to the sensations that are produced internally from a person's sense organs and receptors, they are separate experiences. Additionally, he purports, this *information* is not synonymous with knowledge and it is not something that is communicated to the individual—it simply exists, and it is limitless. In describing the information as external, J. J. Gibson refers to a bottom-up process of perception, although he does not explicitly state it as such in the 1979 publication. In bottom-up processing, the perception of a stimulus is created by the sensory input, or sensory *information*, provided by the environment.

Eleanor J. Gibson elaborated on the work of J. J. Gibson, but took a developmental approach to understanding perception. Due to the nature of studying development, E. J. Gibson's work focused largely on perceptual development in infancy. The focus of E. J. Gibson's research

was to understand how infants learn about the features, properties, and events that occur around them by way of self-discovery (E. J. Gibson, 2000). She referred back to J. J. Gibson's description of the array of information that surrounds an infant in her environment. She then explained a process called differentiation, in which infants explore the environment via various behaviors and interactions with their surroundings, and then select relevant information provided by the array.

In E. J. Gibson's perspective, this process of exploration and selection elicits perceptual learning. She described infants as active perceivers from birth (E. J. Gibson, 1988), wherein infants engage in exploratory behaviors to obtain information about themselves and their environments. Exploration serves to survey the repertoire of possible behaviors and outcomes, followed by a process of selection, which allows the infant to choose parameters of the action that best complete the behavior (Thelen & Corbetta, 1994). According to E. J. Gibson (2000), selection of a pattern of behavior is determined by the fit between an infant's actions and the consequences of that action. When an infant explores her environment, her behavior causes an outcome that provides feedback to the infant about the stimulus, as well as her own action on the stimulus. The infant then observes those consequences and uses the feedback to inform her future actions on the environment.

Rovee and Rovee (1969) illustrated the role of conjugate reinforcement in infant exploratory behavior in their classic mobile study. In this paradigm, infants lie in a crib with a mobile hanging above. A soft string connects the infant's ankle to the mobile. In this study, Rovee and Rovee found that when infants received reinforcement from the movement and sound of the mobile in response to leg kicks, infants increased their rate of kicking. The authors

concluded that the conjugate nature of the reinforcement influenced the infants' increased exploration of leg movements.

Angulo-Kinzler (2001) further illustrated the process of exploration and selection, using the mobile paradigm and expanding on Rovee and Rovee's original study. She had 3-month-old infants lying supine with a string tied around their ankle, which connected to a mobile hanging above them, just as in the previous study. However, in this study, only a certain angle of their leg kick would move the mobile and make a sound. Initially, infants did not know this and, naturally, the 3-month-olds would kick their legs at spontaneous angles. When the infants coincidentally kicked at the angle that made the mobile move, they would receive reinforcement from the movement and sound of the mobile that was contingent on their own kicking behavior. This visual and auditory reinforcement provided feedback about the angle of their leg kicks. Through the process of exploring leg movements and receiving feedback from the mobile, the 3-month-old infants were able to select the leg movements that would activate the mobile increasingly more over the course of the trials. This study illustrated that young infants naturally explore their motor repertoires and can respond to feedback and reinforcement from the environment to select a motor pattern that helps them accomplish a motor goal.

**1.1.2 Dynamic systems theory.** Esther Thelen's dynamic systems theory recognized the role of exploration and selection, particularly for the development of motor skills, but provided a different perspective on how such behaviors develop. According to her theory, there are a plethora of systems within an organism (biological, physiological, physical, etc.) that interact with one another to promote development (Thelen, 1995; Thelen & Smith, 1998). These systems can interact in an infinite number of ways, and in different amounts throughout the lifespan. One defining feature of this theory is that these systems are self-organizing, which means there is no

single initiating force for different aspects of development. The interactions of the systems are dependent on the states of those systems at a given time. The theory rests on the premise that all of these systems are constantly in flux between instability and stability, creating a complex landscape of development (Thelen, 1995; Thelen & Smith, 1998). The systems respond to various perturbations from the environment or from the flux of other systems in various ways. Sometimes, the perturbations disrupt the activity of the systems which facilitates developmental change—this is during a state of instability. If the state of the systems is stable, it will take larger perturbations to disrupt the systems.

For instance, early in the development of reaching, infants' movements are ballistic and uncoordinated (Halverson, 1933; von Hofsten, 1991; von Hofsten & Rönqvist, 1993)—the motor systems appear to be in chaos. During this period of instability, one properly coordinated arm movement can get the infant to contact the target to push the motor systems into a new state. This selected motor pattern becomes an attractor state and ultimately becomes the preferred pattern of action because it is the organism's most stable state. The systems can make small adjustments away from this pattern of action, but will ultimately return to this stable state in most cases because it requires the least amount of effort. Thus, it takes exploration and selection of motor behaviors to move the infant's systems dynamically through states of stability and instability as the infant develops new motor skills.

Thelen and Corbetta (1994) further recognized the role of exploration and selection in the development of infant reaching in observing the differential trajectories of reaching development in four infants. They concluded that infants actively explore the force dynamics of their own movements with every jerky, uncoordinated movement they make from birth; then, they actively select the parameters that successfully accomplish their movement goal. They saw that the four

infants they followed explored the range of motor patterns their arms produced, including the speed and trajectories necessary to get their arm to the target. Through this exploration, pre-reaching infants often contact the target accidentally, but this contact provides feedback, which allows them to narrow down and select the forces, speeds, and trajectories that will get their arm to the target more frequently. Eventually, those selected motor patterns prevail over the jerky, uncoordinated movements and become typical patterns of movement.

**1.1.3 Role of action history.** Dynamic systems theory's description of the pattern of selection in a system pulls from Edelman's theory of neuronal group selection (Edelman, 1987). According to Edelman's theory, repetition of a behavior in an organism strengthens connections in the brain, such that ultimately a particular pathway of neurons becomes the selected pattern of action. This theory, in conjunction with dynamic systems theory (Thelen & Smith, 1998) highlights the importance of the organism's action history. The selection of a behavior depends on repetition of that behavior in a system, which strengthens the neural connections related to the behavior, and, eventually, that motor pattern becomes selected from the range of other, less useful behaviors. In dynamic systems theory, the action history matters because it directly influences future behaviors. While the process of learning to reach may appear chaotic and random, it provides the necessary exploration that results in those first few contacts. Those first accidental contacts provide the necessary feedback to reinforce the selection of motor patterns that direct the infant's arm to the target increasingly more, until they are successful every time.

One study by Corbetta and Snapp-Childs (2009) illustrated the sequence of exploration, feedback, and selection when infants were tasked with reaching for objects of different sizes. They highlighted that an individual infant's motor history predicted their preferred motor patterns when presented with the stimulus objects. In this study, infants' reaching preferences

were first identified by presenting infants with an object to see if they would reach unimanually or bimanually. Depending, on their reaching preference, they were presented with either a larger or smaller object to investigate whether their manual preference could be manipulated.

Corbetta and Snapp-Childs (2009) emphasized the cyclical process of object exploration, including looking at the object, reaching, grasping, and manipulating, behaviors which in turn influence subsequent looking, reaching, grasping, and manipulating (see Figure 1). The results of this study showed that 6- to 7-month-old infants did not alter their preferred reaching style to match the size of the objects, 8-month-olds altered their grasp only after contacting the object, and 9-month-olds showed more varied responses, sometimes altering their manual preference and sometimes not. These results highlight that an individual infant's reaching history can predict their future reaching patterns. Additionally, this study showed that 8 to 9 months old appears to be a transitional period for adapting motor patterns to properties of objects. For the younger infants tested in this study, the motor history was very predictive of future motor behavior. For the older infants, behaviors with the objects were sometimes predicted by the motor history and sometimes predicted by the object properties. The current research involved many of the factors illustrated in Corbetta & Snapp-Childs (2009) study, including a focus on a loop of exploratory behavior adapted from Corbetta and Snapp-Childs involving looking behavior, reaching behavior, and manipulation behavior. The history of behaviors was tracked from trial to trial to see how they predicted subsequent behaviors for individual infants and selection when given a choice of two objects.

**1.1.4 Developmental constraints on perceptual-motor integration.** Perhaps one reason the younger infants in Corbetta & Snapp-Childs (2009) struggled to adapt their reaching patterns to the objects sizes were motor constraints on their motor system that inhibited them from changing

reaching strategies. This explanation was suggested by Corbetta, Thelen, and Johnson (2000) following a study that, similar to Corbetta and Snapp-Childs, attempted to alter the preferred motor patterns of infants between the ages of 5 and 9 months. In this study, Corbetta and colleagues found that 9-month-old infants were able to use haptic information from prior reaches to inform their subsequent reaches with either one or two hands for larger or smaller objects. However, infants aged 5, 6, 7, and 8 months old were unable to do so, and instead, were constrained by motor tendencies for either unimanual or bimanual reaching.

This explanation fits with explanations of motor behavior from dynamic systems theory, in which the preferred unimanual or bimanual reaching strategies were perhaps those young infants' stable, attractor states, and at those ages there was not enough energy to perturb the system out of its preferred patterns. Additionally, several studies have emphasized the phenomenon of infants perseverating in motor patterns and being inhibited from altering their patterns to meet the needs of the experimental task (Smith, Thelen, Titzer, &McLin, 1999; Diedrich, Thelen, Smith, & Corbetta, 2000). These studies reiterate that there is a transitional period occurring around 8 to 9 months where developmental constraints prohibit infants from altering their motor patterns based on perceptual object information.

E. J. Gibson, et al. (1987) also showed that motor skill ability can influence how infants explore and integrate perceptual integration into their action plans. In four studies, E. J. Gibson, et al. tested crawlers and walkers on a variety of surfaces, which provided varying amounts of visual and tactile information. The goal of the study was to see how infants would explore the surfaces based on the available information, and, ultimately, how they would choose to navigate the surfaces. The study showed that walking infants were more hesitant of crossing a non-rigid surface than crawling infants, which suggests developmental differences in willingness to

traverse uncertain, and possibly unstable, surfaces. Overall, infants tended to rely more on haptic information than visual information; however, visual exploration increased when there was more visual information available, such as texture or agitation of the surface, compared to when a non-textured surface was offered. These results emphasize how infants differentially explore and utilize haptic and visual information for subsequent action, which will be relevant to the current research.

**1.1.5 Intersensory redundancy.** The intersensory redundancy hypothesis is a theoretical perspective that aims to explain a phenomenon called intersensory redundancy, which facilitates perceptual learning. This perspective focuses on synchrony between multiple perceptual properties, which recruits infant attention to amodal properties and reinforces the information provided (Bahrick & Lickliter, 2000, 2002, 2012; Bahrick, Lickliter, & Flom, 2004). For instance, in a first study proposing the intersensory redundancy hypothesis, Bahrick and Lickliter (2000) utilized the amodal property of rhythm, providing 5-month-old infants with visual and auditory information of rhythm presented either bimodally or unimodally. The authors found that 5-month-olds were able to learn and identify multi-element rhythms better when they were presented bimodally than when they were presented unimodally. The same was also later shown for tempo (Bahrick, Flom, & Lickliter, 2002). The authors attributed these findings to the saliency and redundancy of sensory information that is provided to infants when such information is presented synchronously in multiple modalities, which engages their selective attention and facilitates better perceptual learning. Specifically, when intersensory redundancy occurs, amodal information becomes more salient and more easily learned than modality-specific information. However, the hypothesis also predicts that when sensory information is presented only in one modality, modality-specific information becomes more salient. Thus, the prediction

could be made that when there is competition between intersensory redundant amodal information and unimodal modality-specific information, attention will be recruited to the former and reduced to the latter.

Evidence for the intersensory redundancy hypothesis was initially found with young infants, aged 3 to 5 months old (Bahrick & Lickliter, 2000; Bahrick, et al., 2002; Bahrick, Lickliter, & Castellanos, 2013), and it was unknown how the hypothesis would hold with older infants, children, or adults. Later studies showed that the predictions of the intersensory redundancy hypothesis were not supported for simple tasks as perceptual development progressed, but as task difficulty increased, intersensory redundancy continued to facilitate perceptual learning in older infants and children (Bahrick, Lickliter, Castellanos, Vaillant-Molina, 2010; Bahrick, Krogh-Jespersen, Argumosa, & Lopez, 2014) and was predicted to be the case across the lifespan.

In the current research, older infants were encouraged to explore both modality-specific and amodal properties of objects. The modality-specific information was presented unimodally and was visually obvious, while the amodal information was presented in multiple modalities, providing intersensory redundancy, and needed to be discovered by manipulating the objects. Since object selection was measured following visual and manual object exploration, it was necessary for the infants to associate the modality-specific information with the information provided in multiple modalities in order to be selective of one object over the other.

## **1.2 Experience and its effect on developmental trajectories**

Given that one way to predict an infant's future behavior with objects is to look at their past exploratory behaviors, another way to describe this cycle is that an infant's experience with the environment influences their future interactions with the environment. The word *experience*

has been inconsistently defined by developmental researchers. For instance, in some studies experience involves directive instruction or demonstration (Lobo & Galloway, 2008; Lobo & Galloway, 2013), where a mature partner, such as an adult, models or teaches a behavior to an infant, from which the infant learns a new way to interact with or interpret her environment. In other studies, experience is considered a process of self-discovery (Thelen, Corbetta, & Spencer, 1996; Bojczyk & Corbetta, 2004; Williams & Corbetta, 2016), through which an infant manipulates something in her environment, without instruction, to learn about its properties, about her own actions, and about her relationship with what she is manipulating. In either use of the word, several studies have shown that experience influences developmental trajectories and can even advance the onset of motor milestones (Bojczyk & Corbetta, 2004; Lobo & Galloway, 2008; Williams & Corbetta, 2016).

For example, Bojczyk & Corbetta (2004) showed how continued experience can eventually override developmental constraints and result in the emergence of a behavior not usually seen until later in development. Prior to 12 months, infants are generally unable to coordinate their arms to open and retrieve an object concealed in a container. Bojczyk & Corbetta investigated whether repeated exposure to such a task and varied visual information would result in advanced acquisition of this skill than what is seen in typical development. Infants received weekly exposure to an object retrieval task with either a semi-transparent or opaque container starting at 6.5 months old. Infants with exposure to the semi-transparent container first successfully retrieved the object around 8 months of age, while infants exposed to the opaque container were first successful around 9 months. Control infants who did not receive such exposure were still unsuccessful at this task when tested at the same ages (8-9 months). The authors concluded that the repeated exposure to the task provided increased motor and cognitive

experience, which allowed infants to explore their perceptual-motor repertoires and select successful patterns of behavior that would not have emerged so early, were it not for the advanced, intensive experience. Additionally, it seems that having the added visual information promoted faster development of the retrieval skill (for infants who had exposure to the semi-transparent container), as compared to infants who were lacking the added visual information (for infants who had exposure to the opaque container).

In another example of experience advancing motor milestones, Lobo and Galloway (2008) provided pre-reaching infants with intensive interventions of either postural experience, object exposure, or a social control, and saw earlier reach onset and exploration of objects with the advanced experience than with controls. Infants were recruited to the study around 2-3 months of age and prior to reach onset. In one group, caregivers were instructed to provide these young infants with 15-minute daily practice in postures that the infants could not yet sustain on their own (such as pushing up on arms, sitting upright, standing, and clapping hands) for three weeks. In a second group, caregivers were instructed to provide infants with object interactions (such as moving the hand midline toward an object and encouraging haptic exploration) 15 minutes, daily for three weeks. In a third, control group, caregivers were instructed to provide 15 minutes of added daily social interaction to control for the increased social interaction infants in the first two groups would have with their caregivers.

Lobo and Galloway (2008) found that infants who received the postural and object experience had advanced reaching ability and increased object exploration, as measured by experimenters in the home at five visits, separated by three week intervals. Even though caregivers only provided enhanced experiences for the first three weeks of the study, the researchers saw improvements in reaching ability and object interactions for weeks to months

after the intervention ended. These results support the idea that various types of advanced experience provided to infants altered their developmental trajectories for reaching and exploring objects.

**1.2.1 Role of object on reaching trajectories.** The most relevant finding from Lobo and Galloway (2008) for the current research comes from the object experience group that enhanced exposure to objects led to more advanced and more frequent exploration of objects. A second paper from the same authors expanded on the findings from this first study and showed that the specific types of exploratory behaviors infants performed on objects changed following the advanced object experience intervention (Lobo & Galloway, 2013). Specifically, the authors saw that the emergence of reaching changed how infants explored and interacted with objects. For one, infants did not explore objects as much prior to reach onset. Additionally, the amount of mouthing and fingering objects, as well as looking at the objects during combinations of those behaviors increased following the object intervention. The authors concluded that their findings support the fact that development is not merely the result of maturation alone, but is facilitated by typical perception-action experiences. The current research investigated how infants' experience with objects over a series of trials affected subsequent exploration of objects.

Williams and Corbetta (2016) also found that enhanced exposure to objects increased the frequency of object contacts, specifically when contingent sensory-motor reinforcement was provided. In this study infants were recruited at about 3 months old. The infants were provided with up to ten 1-minute trials of object presentations in the home, for fourteen consecutive days. Infants were seated upright at a table, and objects were presented directly in front of them, within reaching distance. One group of infants was provided with contingent reinforcement for object contacts, such that the object would move and make noise each time it was contacted. In a

second group, the reinforcement was continuous, such that the object moved and made noise continuously on its own, and thus, the reinforcement was not dependent on the object being contacted. Lastly, a third group served as a control, such that the object would not move or make sound at all, even when contacted. Williams and Corbetta (2016) found that the contingent reinforcement resulted in the most frequent contacts from these young infants. The current research focused on the relationship between sensory and motor exploration of objects, and how the production of perceptual properties contingent on the infants' exploration influenced subsequent sensory and motor exploration of the objects.

**1.2.2 Object properties impact perceptual-motor exploration and selection.** Aside from enhanced experience with objects, research has shown that the way infants interact with objects naturally changes with age, as infants progress through motor milestones (Bhat & Galloway, 2006; Lobo, et al., 2014). Furthermore, object properties have been shown to influence how infants interact with them in terms of perceptual and motor interactions. For instance, visual properties of a stimulus, such as size and complexity/detail have been shown to influence how infants fixate them and how much visual attention they pay to them (Fantz & Fagan, 1975; Ruff & Turkewitz, 1975, 1979; Kidd, Piantadosi, Aslin, 2012; Guan, 2013). Additionally, object size has been shown to influence accuracy of reaching between 4 and 6 months (Rocha, Silva, & Tudella, 2006), such that larger objects require fewer movement units, although accuracy of reaching generally improves during this time period anyway.

Furthermore, looking and reaching preferences for objects have been shown to be impacted by object size (Newman, Atkinson, Braddick, 2001). When 5- to 15-month-old infants were presented simultaneously with objects of varying sizes, which presumably also varied in graspability based on the age and reaching ability of the infant participants, the older infants

reached more to the objects that were the most graspable, something that changed linearly with age. The youngest infants, however, tended to reach for the first object on which they fixated, regardless of utility. Eight and a half to 12-month-old infants—the middle range of the ages tested—also spent more time fixating the objects prior to reaching for them.

Although studies have shown that the reaching skill becomes more efficient kinematically by 8 to 9 months (von Hofsten, 1991; Thelen et al., 1996), it would seem that it takes until closer to the end of the first year (8.5 to 12 months) before infants can integrate information about object properties into their motor plans. This is consistent with the results Corbetta & Snapp-Childs (2009) found with 9-month-olds, such that at 9 months infants are only just starting to integrate information about object properties, namely size, into their motor plans. The current research investigated whether 11-month-old infants could associate visual and non-visual perceptual properties of objects, and whether this information would be incorporated into subsequent perceptual-motor exploration of the objects.

**1.2.3 Role of perceptual-motor feedback on object exploration.** In addition to object properties alone influencing perceptual-motor exploration, many studies have examined the role of perceptual-motor feedback, specifically, on infant object exploration. Morgante and Keen (2008) investigated the role of visual feedback on 8-month-old infants' manual exploration of objects when provided with different auditory and tactile properties. These authors manipulated the visual information available using a lighted or dark room, whether or not the objects made noise, and the type of surfaces on which infants could manipulate the objects. They found that the different properties influenced the specific manipulation behaviors with the objects. Infants mouthed the non-sounding object more, but shook the sounding object more. They shook the sounding object more in the light than in the dark, and they banged objects more on hard-wood

than they did on carpet. These findings show that the infants were receptive to the different object and surface properties and that this information influenced which manual behaviors infants performed.

Additional studies have found, similarly to Morgante and Keen, that young infants discriminately explore objects based on the different perceptual information that the objects offer, and changes in exploratory behaviors can be seen with age (Ruff, 1984; Palmer, 1989; Rochat, 1989). Palmer (1989) found that 6- to 12- month- olds explore objects differently based on texture, sound, and weight. She also found that they treat the surface on which the objects are presented as an additional “object” that can be used in conjunction with the target object (such as banging, etc.). Rochat (1989) found that infants began exploring hand-held objects orally as young as 2-3 months and began exploring hand-held objects visually by 4 months, while alternating between visual and oral exploration at this age. Additionally, while infants were only able to explore objects haptically by grasping them between 2 and 3 months, fingering of the objects emerged around 4 months of age. Furthermore, Ruff (1984) found age-related changes among similar types of exploratory behaviors depending on the object properties. For instance, between 9 and 12 months of age, infants change how actively or passively they finger and mouth objects. Ruff suggested that these changes reflect differences in motor ability, as well as adjustments of behavior as a means of gathering information about the objects.

Baldwin, Markman, & Melartin (1993) investigated whether infants aged 9 to 16 months could make inferences about non-obvious object properties. To test this they first gave infants the opportunity to explore novel objects with non-obvious properties, such as a can that made a wailing noise when turned. Such a property could not be known from the visual information available and could only be discovered through manual exploration. Then, the infants were given

the opportunity to play with an object that appeared to be the same visually, but the non-obvious property had been removed. The researchers observed whether the infants would attempt to produce the expected non-obvious property via manipulation, when no information had suggested the property was removed. Infants were also provided with baseline controls to ensure that the observed effect was due to a violation of expectation of producing the perceptual property, rather than chance exploration of the object. The authors also included a second study, in which instead of presenting infants with the same object with the non-obvious property removed, they presented infants with a completely different object to see if they would attempt to perform the learned target behavior on a novel object. They found that infants were more likely to perform the target behavior when presented with a visually identical object with the non-obvious property removed than they were with a novel object. This confirmed that the target behavior was performed because it was expected to produce an effect, rather than just being part of the infants' normal exploratory repertoire. These results suggest that infants can use visual information about objects to infer a discovered non-obvious property and that discovery of this property can influence subsequent exploration of the objects.

Mash (2007) showed that infants as young as 9 months of age can learn to associate color and weight properties of objects following manual exploration of the objects. In the study, infants were given the chance to explore two objects presented individually. Each object was a different color and had a different weight. After exploring each object one at a time, the color and weight combinations were switched to see if infants would anticipate the previously learned association and exert the force appropriate for the expected object weight. Kinematics were collected to measure the force infants exerted to pick up each object. Mash (2007) found that infants did, in fact, use the force appropriate for the weight they were expecting for each object,

which shows that they did learn the association between the object's color and weight properties. Nine-, 12-, and 15-month-olds all performed similarly in this task. Mash concluded that infants as young as 9 months are capable of learning and utilizing object information to guide the force used in manipulation of objects. These results show that infants can make associations between visual and non-visual properties of objects and that such knowledge can influence how they further interact with the objects.

Building off of Mash's paradigm, Gottwald and Gredebäck (2015) manipulated the reliability of visual information of differentially weighted objects while assessing 14-month-olds' manipulative force. Their aim was to investigate what types of perceptual information infants rely on to make action decisions about how much force to use to lift an object. They found that infants can use both visual and tactile information to plan lifting actions, and that they are not solely reliant on either type in planning their actions. These findings lend themselves to further research as Gottwald and Gredebäck were not able to show the specific roles of visual and tactile information in action selection.

The design and predictions of the current research were heavily influenced by the studies reviewed above by assuming that 11-month-old infants can discover a property of an object that is not visually obvious via perceptual-motor exploration and that the feedback received would influence subsequent perceptual-motor exploration. However, in the current research infants were tasked with differentiating and associating perceptual properties when presented with two objects simultaneously.

### **1.3 Focus of the current research**

The literature reviewed above suggests that infants explore their surroundings perceptually and manually (E. J. Gibson, 1988) and use the feedback provided to select relevant

behaviors that produce an interesting outcome (Thelen & Corbetta, 1994; Angulo-Kinzler, 2001; Williams & Corbetta, 2016). The more infants repeat a behavior, the more it becomes part of their motor repertoire (Thelen & Corbetta, 1994). Although certain developmental constraints may prevent them from deviating from this pattern of behavior (Smith, et al., 1999; Corbetta, et al., 2000; Diedrich, et al., 2000), once infants are able to reach for and manipulate objects on their own, properties of the objects can influence how infants interact with them (Fantz & Fagan, 1975; Ruff & Turkewitz, 1975, 1979; Ruff, 1984; Palmer., 1989; Rocha et al., 2006; Morgante & Keen, 2008,). Additionally, infants are able to discover properties of objects and use that information to inform how they continue to explore the objects (Baldwin et al., 1993; Newman et al., 2001; Mash, 2007; Gottwald & Gredebäck, 2015). Furthermore, research has shown that perceptual-motor behaviors are inextricably linked, such that they influence each other in sequence (Corbetta & Snapp-Childs, 2009), and the feedback received from each modality impacts subsequent perceptual-motor interaction with stimuli. The focus of the current research was to investigate the relationship between discovery of perceptual properties of objects and subsequent perceptual-motor exploration of those objects as measured by looking, reaching, and manipulation of objects.

In all of the literature reviewed, except for Newman et al. (2001), researchers observed perceptual-motor exploration and selection of one object presented in isolation. Mash (2007) and Gottwald and Gredebäck (2015) tested infants' association of properties with two objects, but infants were never presented with both objects simultaneously. In a natural setting, infants are tasked with discovering and associating perceptual properties of a clutter of objects all at the same time, and somehow, with time and experience, they are able to learn the necessary associations to navigate their worlds. All of the previous research with single objects was

necessary to establish when, developmentally, different phenomena related to perceptual-motor integration occur. However, the current research built on all of the previous work and tests infants' associations of perceptual information when presented with two objects at a time. The current research consisted of two studies that investigated whether infants could discover an auditory-tactile property of one object that was not visually obvious, associate that property with the visual property of the object, and select that object on subsequent object presentations over an object that did not contain the other perceptually salient property.

**1.3.1 Study 1.** In the first study, 11-month-old infants were presented with two objects initially out of reach, and eye-tracking was used to measure infants' visual exploration of the objects. Within a few seconds, the two objects were moved within the infants' reaching space to allow for manipulation of the objects. Each object was visually plain, painted a solid pastel color, but each object was a different color (comparable in hue to prevent visual salience). Only one object had rice or beans inside, so that certain manipulation would produce auditory and tactile feedback, while the other object was empty. Within each infant the color/auditory-tactile property combination was kept consistent to allow infants to make an association between the color and the auditory-tactile property. However, between infants the combination was counterbalanced to control for a color bias.

Infants were provided with one first trial where the objects were kept out of reach and never moved forward to obtain baseline visual exploration prior to object manipulation. On the second trial, the side of the objects was switched and because the objects were always presented out of reach before being moved forward, this provided a second baseline trial of visual exploration, intending to control for a side bias. From then on, the sides of presentation were randomly counterbalanced, with no more than three presentations on the same side in a row.

Whether the one object presented was filled with rice or beans was also counterbalanced, to avoid habituation to the sound that object would make when manipulated.

Up to nine trials were collected with this procedure, following the first baseline looking trial, after which six additional trials with novel objects with the same color/auditory-tactile combination were presented. These six trials consisted of two consecutive trials each with a novel-shaped object, including a total of three novel object shapes. The purpose of these trials was to see if infants could generalize the learned property association to objects of novel shapes. 11 months was chosen as the target age because based on the previously reviewed literature, infants of this age should be well beyond the transitional period for integrating perceptual properties into their motor plans (Newman et al., 2001; Corbetta & Snapp-Childs, 2009).

Visual and manual exploration were measured and the following predictions were made: First, it was expected that prior to manual exploration of the objects, infants would not have a visual preference for either object, such that there would be no difference in the amount of looking at each object. Given that infants have been shown to discover non-obvious perceptual properties and that such discovery impacts their subsequent behavior (Baldwin, et al., 1993; Mash, 2007, Gottwald & Gredebäck, 2015), it was expected that if infants discovered the auditory-tactile property via manual exploration in this study, they would select that object more on subsequent trials by looking at it more than the other object, contacting it first, and manipulating it more than the other object. Additionally, perhaps the intersensory redundancy of receiving auditory and tactile feedback from manipulating the filled object would make this object more salient to infants (Bahrick and Lickliter, 2000) and encourage exploration and selection of that object; however, this would also require that the visual information be attended to enough to make the association between the object's color and auditory-tactile effect. If this

property was discovered over the discovery phase trials, it was predicted that perhaps this association would be generalized when presented with novel-shaped objects, such that the infants would look more at, contact first, and manipulate the object with the auditory-tactile property more. To my knowledge, there is not any existing literature to suggest that 11-month-old infants can generalize this type of learning, so this aspect of the research design was exploratory. It was also predicted that regardless of discovery, the visual and manual selection of either object would be related to subsequent visual and manual selection of objects across trials.

**1.3.2 Study 2.** In the second study, all procedures were identical, except instead of both stimulus objects being visually plain, the object that did not have the auditory-tactile property was visually detailed. Many studies have shown that infants respond differentially to stimuli with varying complexity or detail (Fantz & Fagan, 1975; Ruff & Turkewitz, 1975, 1979; Kidd et al., 2012; Guan, 2013). Specifically, Guan (2013) showed that when size is controlled for, infants will look first to the more detailed object in a scene. Thus, the expectation was that prior to object manipulation infants would spend more time looking at the visually detailed object. However, the purpose for varying the stimulus details was to see whether after discovery of the auditory-tactile property, infants would override their draw to the visually salient object and select the object with the more salient auditory-tactile property. I predicted that if discovery of the auditory-tactile property was more influential on infants' subsequent perceptual-motor exploration, they would look more at, contact first, and manipulate the object with the auditory-tactile property more. However, if the more interesting visual property was more important for selection, the infants would continue to look more at that object and might even be drawn to contact that object first and manipulate it more, despite the fact that the visually plain object produced a more interesting effect when manipulated.

The predictions for the generalization objects were the same as in study 1, such that infants would show similar looking, reaching, and manipulation behavior for those novel objects as they did for the discovery phase trials. I also predicted that regardless of which object was selected over the course of trials, looking, reaching, and manipulation on a given trial would be related to subsequent looking, reaching, and manipulation behavior.

## CHAPTER 2: METHOD—STUDY 1

### 2.1 Participants

Thirty 11-month-old infants were recruited from the Greater Knoxville, Tennessee area. Infants' caregivers were contacted to participate via phone call. Participant information was obtained from the Child Development Research Group's (CDRG) database. Information was entered into this database after caregivers responded to an interest letter in the mail about the CDRG's research labs at their child's birth, by signing up at one of CDRG's several recruiting events in the Knoxville community, or via the CDRG website. Infants were eligible for recruitment based on the date on which they turned 11 months plus or minus one week. Twelve infants were excluded from the final sample because they did not provide enough data. One infant was excluded due to experimenter error, causing the session to end early. A final sample of 17 infants was used for analysis (8 females,  $M = 47.91$  weeks,  $SD = .46$ ). Fourteen infants were reported by their caregivers as Caucasian. The other three infants were reported as mixed-race. Participants were compensated at each appointment with a photo, a certificate of participation, and a \$10 gift card.

### 2.2 Materials

A Tobii X2-60 remote eye-tracker (Tobii Technology, Inc., Danderyd, Sweden) was used to record eye gaze. It was placed on small, black wooden table placed 60 cm from the infant's eyes and directly below the object presentation area. The table was surrounded by a black tri-fold theater to minimize distractions. In the center of the theater and above the small table was a 15 x 11.5 inch cut-out for the presentation area. A 10 x 13 inch tray with 1-inch edges on both sides and the back sat at the bottom of the presentation window for object presentation. A 10 x 13 x .75 inch foam pad covered in black vinyl was placed within the tray. The tray was affixed to the

front of a 20 x 15 inch platform, which was attached to the small black table via drawer glides to allow the tray to be slid forward during the session. A 17-inch Dell computer monitor was placed in the cut-out for calibration, during which the tray was removed from the platform. Following calibration, the computer monitor was removed and the tray was put into place for subsequent object presentation. Objects were presented on the front edge of the tray, centered and spaced 3 inches apart from each other between the inner edges. The tray slid forward up to 19.25 inches toward the infant and was exactly in line with the presentation window when pulled back (see Figure 2).

Infants were seated in a specially designed infant seat reclined 10 degrees from vertical. The seat was wooden and covered with soft material, and infants were secured with a foam strap around their waist that provided both trunk support and free movement of the arms and legs.

Two digital cameras were placed on either side of the set-up on tripods to record the infant's reaching behavior (side cameras). The side camera views were fed through a video splitter and a digital video capture card (Viewcast by Osprey) and recorded through Debut software (NCH) on a computer, so that both views could be recorded side-by-side in one video file. Another digital camera was placed behind the infant (scene camera) in order to film the stimulus presentations and on which the gaze data from the eye-tracker was superimposed. A webcam was placed above the presentation area, facing the infant, to record the infant's activity to aid in coding reaching and manipulation behaviors.

A motion analysis system called Flock of Birds (by Ascension Technology) was used to record the infant's kinematic wrist activity. Small markers were attached to the dorsal side of the infant's wrists with hypoallergenic tape. Small sleeves made of cut socks were placed on the

infant's arms to distract them from playing with the Bird markers. The Flock of Birds was used for all infants. However, the kinematic recordings were not analyzed for this dissertation.

Stimulus objects included two sets of three fillable wooden eggs (2.75in x 2in; "eggs"), three wooden Russian stacking dolls (3.15in x 2.56in; "dolls"), three round wooden ring boxes (1.97in x 1.378in; "circles"), and three square craft boxes (3in x 3in x 1.75in; "squares"). Of each object type, one in the set of three was filled with rice, one filled with uncooked beans, and one was not filled. Then all objects were glued closed, painted with Craft Smart<sup>®</sup> acrylic, non-toxic paints, and sealed with Folk Art<sup>®</sup> water-base, non-toxic varnish in satin finish (see Figure 3). The final weights of each object are presented in Table 1. Although there were slight differences among the weights of the objects, within each set the differences were almost imperceptible. In each set the filled and unfilled objects were painted either pale blue or pale yellow (Craft Smart<sup>®</sup>), so that in each pair there was one object of each color. All colors were solid, matte, and matched for hue. Two sets of all objects were created so that object-color pairings could be counterbalanced between infants.

### **2.3 Procedure**

When participants arrived to the lab, the experimenter first showed the caregiver the set-up and explained the general procedure. Then they were shown the consent form and given the opportunity to sign and ask any questions. When the paperwork was complete, the infant was securely strapped into the infant seat and the caregiver was seated beside them, to the right of the infant.

Next, the experimenter ran through the calibration with the help of an assistant running the eye-tracking software (Tobii Studio, v.3.4.7) on a computer located behind the presentation theater. To calibrate the infant's eyes to the eye-tracker, a computer monitor was placed in the

presentation window of the theater. The infant needed to look briefly to 5 points on the screen to obtain a signal from their eyes. A cartoon character accompanied by a sound appeared in the four corners of the screen and the center, one point at a time. Individual calibration points could be repeated if the resulting signal was noisy.

Bird markers were attached to the infant's wrists with hypoallergenic tape. Then, the experimenter moved the computer monitor from the presentation window to behind the theater so she could see the live eye-tracking feedback. Then, the tray was affixed to the platform and the curtain was set in place. Each trial began with the curtain of the theater draped over the front of the tray. From behind the theater, the experimenter placed the first pair of stimulus objects on the tray. When the objects were in place, the experimenter audibly said, "We're ready." This signaled one assistant to begin the eye-tracker recording. At the same time, another assistant started recording the video and triggered the kinematic recording on separate computers located behind where the infant was seated. When the experimenter saw that the eye-tracking recording had started, the experimenter pulled the curtain up and over the objects to reveal the stimulus objects to the infant. The experimenter timed 5 seconds of object presentation after the infant's first fixation on the scene, after which the curtain was re-draped in front of the objects and the location of each object on the tray was switched. This trial served as a baseline looking trial to measure scanning behavior before the infants had manual experience with the objects. Then, the same procedure was repeated and the objects were revealed on the opposite sides from trial 1. On this second trial, after 5 seconds of object exposure elapsed following the first scene fixation, the tray was moved forward so that the objects were within the infant's reaching space. This provided two trials of baseline looking behavior prior to manual interaction with the objects. By

switching the sides of the objects between these first two trials, it helped avoid priming the infants with a side bias of looking at the onset of the study.

After the tray was moved into the infant's reaching space, the infant was given the opportunity to touch and manipulate the two objects for 30-40 seconds, which was timed by the experimenter to ensure comparable object exposure on all trials. The amount of object exposure was kept consistent whether the infants interacted with the objects or not. If the infant threw either object, dropped them, or pushed them off of the tray, the object was placed back on the tray within the infant's reach, so that the infant always had access to the objects. If the objects fell within the caregiver's reach, he or she would place them back on the tray. If the objects fell to the other side, away from where the caregiver was seated, an additional experimental assistant was nearby to retrieve the objects and return them to the tray. After the timed object exposure was complete, the experimenter pulled the tray back into the theater. This was the cue for the caregiver to retrieve the objects from the infant if she still had them. The objects were handed back to the experimenter to set up for the next trial. After the two looking baseline trials, up to nine trials were collected with manipulation of the objects during the 'discovery phase.' Only the egg objects were used for the baseline and discovery phase trials. Pairing of the rice-filled or bean-filled object was paired with the unfilled object for each trial was determined by a previously generated, randomized, counterbalanced protocol. Additionally, the color combination of these pairs was previously determined by these protocols and counterbalanced between infants, such that for some infants the filled object was always the blue one and for other infants it was always the yellow one.

Immediately following the discovery phase of this procedure were up to six trials of the 'generalization phase'. The procedure for the generalization phase trials was identical to

discovery phase trials, except the other three object sets were used. Each pair of differently shaped objects was used for only two consecutive trials. The order of the shapes presented was counterbalanced among participants based on the previously generated protocol. The color combinations were consistent with the color combination used for the baseline and discovery phase trials for each infant. Side presentation and rice- or bean-filled object were switched between each two-trial pairing and previously, randomly determined.

## **2.4 Coding**

All coding was done using the eye-tracking videos, which included a superimposed view of the front-facing webcam in the bottom left corner of the video outputs. All eye-tracking was filtered using the Tobii Fixation Filter in Tobii Studio with a pixel radius of 10 pixels. The videos were exported in two formats, one with a sampling rate of 60 frames per second, which aligns with the 60 Hz sampling rate of the eye-tracker. Videos were also exported with a sampling rate of 30 frames per second, which aligned with the 30 Hz sampling rate of the front facing webcam. The 60 frames/sec videos were used to code the fixation data, and the 30 frames/sec videos were used to code the reaching and manipulation of the objects using the view of the infant from the front facing webcam. All coding was done using Datavyu (v.1.3.4).

**2.4.1 Eye-tracking coding.** For all coding certain trial markers were coded for, in addition to coding of the main variables of interest. The trial marker relevant to the fixation coding was the duration of the object presentation while out of reach. Two independent coders identified the first frame when the objects were fully revealed and the frame before the tray began to move out towards the infant. The reliability score on 20% of the total number of trials was 99% agreement for the duration of object presentation. Once this trial marker was identified, coders went back through the videos to identify onsets and offsets of durations of accumulated looking to three

areas of interest, including each object and elsewhere, which included any fixations not on either object. The criteria for determining whether a fixation was located on an object or elsewhere was if the initial fixation that appeared was touching the boundary of the object at all, it was coded as on the object. If there was any gap between the initial fixation and the object, it was coded as elsewhere. Each initial fixation was always the same pixel radius, and as fixations grew in diameter with longer gaze, the initial code that was assigned did not change. Accumulated durations were coded for rather than individual fixations, which means that a code would be started at the first frame a fixation appeared on a given AOI, but as long as fixations subsequently remained on that AOI the code would continue. Codes were stopped on the last frame that a fixation appeared on a given AOI. In addition to coding onsets and offsets of accumulated durations of looking, coders identified whether each object was located on the left or the right. For elsewhere codes, they identified whether the fixation was in between the two objects (“middle) or other, which included any other location. The reliability score on 20% of the trials was 92.8% agreement for the eye-tracking coding. During all coding, coders were blind to which object was filled and which was empty; instead, they coded based on which behaviors occurred on the blue versus the yellow object. Once files were exported for analysis, the information from each color object was aligned with the independent variable for auditory-tactile property.

**2.4.2 Reaching and manipulation coding.** Trial markers were identified in the first sweep of coding for reaching and manipulation behaviors. Trial markers for this batch of coding included the duration of the tray moving forward until manipulation could begin. The onset of this code was the first frame that the tray moved forward. The offset of this code was either the first object contact or when the tray was fully in the infant’s reaching space, whichever occurred first. The

reliability score on 20% of the trials for this variable was 94.0% agreement. Next, the total duration of possible manipulation was coded. The onset of code was the same frame as the offset for the previous variable—either the first object contact or when the tray was fully in the infant’s reaching space, whichever occurred first. The offset for this code could be one of three things: 1) The first frame that the tray moved back if the infants were not in contact with the objects, 2) The last frame of object contact if the tray had already started moving back, or, 3) Sometimes infants were still holding one or both objects when the tray was removed—in this case, the offset would be the last frame before the experimenter or caregiver came into view of the webcam to retrieve the objects. The rationale for this criterion was that once the adult was attempting to retrieve the object, it would skew the manipulation behavior, even though the infant was still in contact with an object. The reliability score on 20% of the trials for this variable was 95.0% agreement. Coders also identified the frame at which the tray began to move back, in order to keep track of how long infants still had the objects between the tray moving back and the end of the trial. The reliability score on 20% of the trials for this variable was 94.0% agreement. Lastly, the frame of first contact of each object was identified, as well as which hand was used to contact each object. The reliability score on 20% of the trials for this variable was 98.0% agreement.

In the next sweep of coding, coders identified when the infants were in contact with each object or not in contact with each object. The blue and yellow objects were coded in separate sweeps. Coders identified frames of onset and offset for ‘contact’ or ‘no contact.’ The start and stop of this coding was determined by the frames of onset and offset for duration of possible manipulation. This means that the first code could either be ‘contact’ or ‘no contact’ depending on whether the infants contacted the object before the tray was all the way out or not. Additionally, the last code for each object could either be ‘contact’ or ‘no contact.’ The

reliability score on 20% of the trials for this variable was 85.7% agreement. Any disagreements were discussed until an agreement was made.

In a last sweep of coding, coders identified when infants either shook each object or banged each object on the tray. Infants performed a wide variety of behaviors on the objects, but both the behaviors of shaking and banging were considered the most revealing in trying to produce the sounding effect from the objects, and thus were considered the most relevant to the research question. Again, the blue and yellow objects were coded for in separate sweeps. Coders identified frames of onset and offset for each instance of shaking the object or banging the object on the tray. The reliability score on 20% of the trials for this variable was 61% agreement. This code was the most difficult for which to identify the onsets and offsets consistently between coders, and to determine if subtle behaviors should be categorized as shaking or banging. Regarding any discrepancy, coders verified that they were coding based on the same objective criteria, and any disagreements were discussed until an agreement was made.

## **2.5 Dependent variables**

Trial marker variables, as described above, were used to track the consistency of object exposure during the looking and manipulation parts of each trial, across trials within participants, as well as between participants. Averages for these variables will be reported in the results.

**2.5.1 Looking variables.** The dependent variables of interest pertaining to the looking behavior were accumulated durations of looking to each AOI within a trial. Once the onsets and offsets of looking codes were exported from Datavyu, individual durations within a trial were calculated and summed. Then, the total duration of looking at the scene for the trial was calculated by summing the total amount of looking to each AOI. Next, proportions of looking to each AOI were calculated by dividing the total sum of looking to each AOI by the total amount of looking

to the scene. From these proportions, I tracked the proportions of looking to the blue object, the yellow object, and elsewhere, the proportions of looking to the filled object versus the unfilled object, and proportions of looking to the object on the left versus the object on the right for all trials across infant participants. This organization allowed me to look for trends based on the independent variables of auditory-tactile property, color, or side. Additionally, which object was fixated first on a given trial was a dependent variable of interest because unpublished analyses from our lab have shown that the first object fixation may be predictive of which object is fixated the most on a given trial. Thus, the first object fixation could serve as an additional measure of object selection. This variable did not have to be coded for separately from the looking durations because it could be extracted from the resulting exported file based on the frames of onset for each code.

**2.5.2 Reaching variables.** The dependent variable of interest for reaching behavior was which object was contacted first for each trial. I calculated the amount of time elapsed between first contacts of each object. I only considered there to be ‘no difference’ in terms of which object was contacted first if the latency between both object contacts was 0ms. Otherwise, for each trial I identified which object was contacted first based on color, auditory-tactile property, side location on the tray, and which hand infants used to contact the object. This allowed me to look for trends based on auditory-tactile property, color, side, or hand preference.

**2.5.3 Manipulation variables.** The first dependent variable of interest for manipulation behavior was the accumulated duration of manipulation of each object, which was operationally defined as the accumulated duration the infant was in contact with each object. Accumulated durations of object contact were calculated from the onsets and offsets that were exported from Datavyu. Then, these durations were summed and normalized by dividing this total by the duration of

possible manipulation. The resulting proportions revealed how much time infants were in contact with each object out of the possible time infants were given to manipulate the objects.

Additionally, the proportions of time infants were not in contact with each object were calculated using the same steps. Furthermore, the proportion of time infants were not in contact with either object was calculated by looking at the overlapping codes of ‘no contact’ with the objects. This calculation allowed me to look at the trends of ‘no contact’ over the course of all trials for each infant.

The second dependent variable of interest for manipulation behavior was the accumulated duration of shaking and banging each object. Durations of shaking and banging were calculated from the onsets and offsets that were exported from Datavyu. Then, these durations were summed, collapsing across shaking and banging codes. These sums were then normalized by dividing this total by the duration of possible manipulation. This proportion was typically a fairly small number because infants exhibited other behaviors over the course of the trial besides shaking and banging; however, these proportions allowed me to establish whether these target behaviors were performed at all during a trial and the patterns of performing these behaviors on each object across trials.

## **2.6 Description of data corpus and inclusion criteria**

For 10 of the 17 infants included in the analysis, the filled object was blue and the unfilled object was yellow. For the other seven infants, the filled object was yellow and the unfilled object was blue. The average number of trials collected from each infant was 14.47 trials ( $SD = 2.53$ ), including both discovery phase ( $M = 9.59$  trials,  $SD = .80$ ) and generalization phase trials ( $M = 5.13$  trials,  $SD = 1.45$ ). Infants had to provide a minimum of seven consecutive trials from the discovery phase to be included for analysis. Fourteen out of 17 infants became fussy at

some point during the experimental session. Of those infants, they became fussy on average starting around trial 10 out of 16. As long as the infants calmed down enough during the trial to look at or manipulate the objects, the data were still used for analysis. If the infants were fussy for the duration of the trial, the data were not used. Even if they did not get fussy during the session, all infants became restless at some point. Restlessness was defined as antsy behavior in the infant seat while objects were out of reach, throwing the objects on the floor, pushing or hitting the objects on the tray, or pushing the tray away. Antsy seat behavior started, on average, around trial 5 ( $n = 16$ ). Infants started throwing the objects around trial 7, on average ( $n = 15$ ), and pushing or hitting the objects around trial 10 ( $n = 11$ ). Lastly, 6 infants pushed the presentation tray away from them and started doing so around trial 6. The trial numbers reported above represent when the first occurrence of a behavior happened, on average, but this does not necessarily mean that the infants continued the behavior for every subsequent trial. As long as infants looked at the objects for a minimum of 750ms or interacted with them at all during manipulation, the data were used for analyses. These minimum criteria were determined by watching the trials on which infants provided the least amount of data to determine a threshold.

Additionally, while caregivers were instructed not to interfere with the session in terms of encouraging their infant to look at the objects or manipulate them in a certain way, this did occasionally occur. Nine of the seventeen caregivers encouraged their infant to look at the objects, either verbally or physically (e.g., pointing). Typically, this occurred when the infant was distracted and not attending to the scene. However, this type of interference only occurred a minimal amount of time, on average only on two to three out of the total number of trials collected for infants whose caregivers did this. Additionally, sometimes caregivers encouraged their infant to shake the objects, either by physically shaking or tapping one of the objects, or

verbally telling the infant to shake it or informing them that one of the objects “shakes.”

Fortunately, this also happened only a minimal amount of the time. Seven out of 17 caregivers interfered during the manipulation part of the trials, either verbally or physically, and this only occurred, on average, for three to five out of the total number of trials (both discovery and generalization phase) collected for the infants whose caregivers did this.

## CHAPTER 3: RESULTS—STUDY 1

### 3.1 Descriptive statistics

**3.1.1 Trial markers.** The average numbers of trials that were usable for analysis of looking data were 6.82 trials ( $SD = 1.29$ ) for the discovery phase and 4.00 trials ( $SD = 1.93$ ) for the generalization phase. The average duration of object presentation while objects were out of reach was 7157.46ms ( $SD = 1654.13$ ) across all usable trials. The average duration of looking at the scene provided by infants per trial was 4867.48ms ( $SD = 1300.78$ ) across all usable trials.

The average numbers of trials that were usable for the analysis of reach and manipulation data were 8.53 trials ( $SD = .87$ ) for the discovery phase and 5.13 trials ( $SD = 1.59$ ) for the generalization phase. The average duration of the tray moving forward until the start of possible manipulation (object's in reaching space) was 2397.46ms ( $SD = 942.62$ ) across all usable trials. The average duration of possible manipulation was 36904.51ms ( $SD = 4419.13$ ) across all usable trials. The average duration from the presentation tray moving back until the end of possible manipulation was 2434.30ms ( $SD = 1984.82$ ) across all usable trials. On average, infants were in contact with at least one object for a total of 29074.04ms ( $SD = 10614.26$ ) across usable trials.

**3.1.2 Baseline looking trials.** Infants provided up to two baseline trials of object looking prior to any manipulation with the objects. Four out of 17 infants provided only one usable baseline trial. Of the 13 infants that provided two baseline trials, six infants showed a bias for looking more to one side than the other, regardless of object ( $n = 2$  left,  $n = 4$  right). For two of these six infants, this side bias was consistent with which object they fixated first during baseline. For the other four infants, the side bias for most look was not consistent with the first fixated object. On the first trial after manipulation, the four infants with the right side bias maintained their preference for looking more at the object presented on the right. The two infants with the left side bias both

shifted to look more at the object on the right after manipulation, but this was not necessarily the object with the auditory-tactile property. The first fixated object after manipulation was not systematically consistent with the most looked object after manipulation.

Of the 13 infants who provided two baseline looking trials, five infants showed a bias for the blue object, and in four cases this object had the auditory-tactile property. One infant showed a bias for the yellow object and in this case it was the object with the auditory-tactile property. Only for the infant who showed the yellow bias was this preference consistent with the first fixated object during baseline. For the infants who preferred the blue object during baseline, they showed a side bias for their first object fixations ( $n = 2$  left,  $n = 3$  right). On the first trial after manipulation, six of these infants continued to look more at the same object for which they showed a bias initially, while one infant shifted; however, this infant shifted to the object without the auditory-tactile property. The first fixated object after manipulation was not systematically consistent with the most looked at object after manipulation.

Although some infants initially showed a looking bias for one color or one side, there was a lot of variability in baseline preferences between infants, which seemed to remain variable after manipulation. This suggests that infants' baseline preferences did not systematically influence their looking preferences after manipulation, although there are some individual differences.

### **3.2 Between object comparisons averaged across trials**

Due to non-normal distributions of variables, Wilcoxon tests were performed to investigate whether there were overall differences between the filled and unfilled objects across infants in terms of mean proportions of first fixation, accumulated looking duration, first contact, accumulated contact duration, and shaking and banging duration (see Figure 5). Any differences would suggest selection of one object over the other. Discovery and generalization phase trials

were averaged across and analyzed separately. For the looking variables, the baseline trials were not included in the averages used in these analyses. Trials could be included in the analyses for manipulation even if there was missing looking data, and vice versa, because the variables were analyzed separately.

For the discovery phase trials, analyses revealed no differences between object for any variable, except for the proportion of shaking and banging ( $Z = 3.10, p = .002, r = .75$ ), such that infants shook and banged the filled object ( $M = 6.93\%, SD = 7.18$ ) proportionately more than the unfilled object ( $M = 4.10\%, SD = 5.14$ ; see Figure 5). Analyses also confirmed there were no effects of color; however, overall, infants looked significantly more to the object on the right ( $M = 34.08\%, SD = 9.04$ ) than the object on the left ( $M = 25.25\%, SD = 9.45; Z = 2.04, p = .041, r = .50$ ). Additionally, Wilcoxon tests comparing between the three variables based on durations (accumulated looking, accumulated contact, shaking and banging) showed that for both objects the proportions of accumulated contact were significantly greater than either the proportions of looking (Filled Object  $Z = 3.53, p < .0001, r = .86$ ; Unfilled Object  $Z = 3.48, p = .001, r = .84$ ) at or shaking or banging the objects (Filled Object  $Z = 3.62, p < .0001, r = .88$ ; Unfilled Object  $Z = 3.62, p < .0001, r = .88$ ), and the overall proportions of looking at either object were significantly greater than the proportions of shaking or banging the objects (Filled Object  $Z = 3.62, p < .0001, r = .88$ ; Unfilled Object  $Z = 3.62, p < .0001, r = .88$ ).

For the generalization phase trials, the analyses revealed significant differences between objects only for the proportions of accumulated contact ( $Z = 2.59, p = .010, r = .63$ ), as well as the proportions of shaking and banging the objects ( $Z = 3.30, p = .001, r = .80$ ; see Figure 6). Infants contacted the filled object ( $M = 60.69\%, SD = 21.20$ ) proportionately more compared to the unfilled object ( $M = 50.81\%, SD = 19.19$ ). They also shook and banged the filled object ( $M =$

5.30%,  $SD = 4.47$ ) proportionately more than the unfilled object ( $M = 1.55\%$ ,  $SD = 1.82$ ).

Analyses also confirmed that there were no effects of color or side for any variable. Additionally, Wilcoxon tests comparing between the three variables based on durations (accumulated looking, accumulated contact, shaking and banging) for each object showed that for both objects the proportions of accumulated contact were significantly greater than either the proportions of looking (Filled Object  $Z = 3.36$ ,  $p = .001$ ,  $r = .84$ ; Unfilled Object  $Z = 2.02$ ,  $p = .044$ ,  $r = .50$ ) at or shaking or banging the objects (Filled Object  $Z = 3.52$ ,  $p < .0001$ ,  $r = .88$ ; Unfilled Object  $Z = 3.52$ ,  $p < .0001$ ,  $r = .88$ ), and the overall proportions of looking at either object were significantly greater than the proportions of shaking or banging the objects (Filled Object  $Z = 3.52$ ,  $p < .0001$ ,  $r = .88$ ; Unfilled Object  $Z = 3.41$ ,  $p = .001$ ,  $r = .85$ ).

Lastly, I used Wilcoxon tests to investigate differences for these averaged variables for each object between the discovery and generalization phases. These analyses showed that infants looked proportionately more at the unfilled object during generalization phase trials ( $M = 38.87\%$ ,  $SD = 18.03$ ) than they did during discovery phase trials ( $M = 29.76\%$ ,  $SD = 6.94$ ;  $Z = 2.12$ ,  $p = .034$ ,  $r = .53$ ). They contacted both objects proportionately less between discovery (Filled Object  $M = 71.32\%$ ,  $SD = 20.92$ , Unfilled Object  $M = 71.48\%$ ,  $SD = 23.96$ ) and generalization phases (Filled Object  $M = 60.69\%$ ,  $SD = 21.20$ , Unfilled Object  $M = 50.81\%$ ,  $SD = 19.19$ ; Filled Object  $Z = 2.25$ ,  $p = .024$ ,  $r = .56$ ; Unfilled Object  $Z = 3.20$ ,  $p = .001$ ,  $r = .80$ ). Infants also shook or banged the unfilled object proportionately less during generalization phase trials ( $M = 1.55\%$ ,  $SD = 1.82$ ) as compared to discovery phase trials ( $M = 4.10\%$ ,  $SD = 5.14$ ;  $Z = 2.22$ ,  $p = .027$ ,  $r = .55$ ).

In sum, infants discovered the auditory-tactile property during the discovery phase by shaking and banging the filled object more than the unfilled object. During the generalization

phase, infants showed selection of the filled object by contacting that object more and by shaking and banging that object more than the unfilled object.

### **3.3 Linear trends across sequence of discovery phase trials**

Hierarchical linear models were performed to assess whether any of the three variables based on durations (accumulated looking, accumulated contact, shaking and banging) changed linearly across the discovery phase trials for the filled object, specifically. These analyses could reveal selection of either object if infants showed increases of behaviors to one object but not the other. Baseline looking trials were not included in the analysis for the looking variable. The only significant linear group effect that was revealed was a decrease in the proportion of accumulated contact of the filled object across the discovery phase trials ( $\beta = -2.48\%$ ,  $SE = 0.94$ ,  $p = .014$ ; Figure 7). One infant in particular showed an even steeper linear decrease than the rest of the group ( $\beta = 32.85\%$ ,  $SE = 12.48$ ,  $p = .017$ ). While the proportions of accumulated looking and proportions of shaking and banging the filled object did not show group linear changes across trials, three infants showed linear increases in the amount of shaking and banging the filled object separate from the rest of the group ( $\beta = 9.15\%$ ,  $SE = 3.56$ ,  $p = .015$ ;  $\beta = 11.12\%$ ,  $SE = 3.63$ ,  $p = .004$ ;  $\beta = 9.95\%$ ,  $SE = 3.56$ ,  $p = .008$ ). In sum, infants decreased their amount of contact with both objects across discovery phase trials.

### **3.4 Relationships between variables in sequence**

Additional non-parametric analyses were conducted to investigate whether each of the five dependent variables were related to each other in sequence across trials. For each trial, the first fixated object, most looked object, first contacted object, most contacted object, and most shaken and banged object was determined (see Figure 4 for sequence). Then, it was determined if each ‘first/most’ object for each variable was the same as the subsequent ‘first/most’ object for

each variable (i.e., first fixation was filled object and most look was filled object on same trial; most contacted object was filled object and next first fixated object was filled on next trial; etc.). If ‘yes,’ there was considered to be a match between variables. The proportion of trials where there was a match between subsequent phases of the perception-action loop (Figure 4) was calculated from the total number of trials and these proportions were used in the analyses. A total of 25 possible match pairings were determined, with each variable as the predictor for the subsequent five variables. To analyze whether any of these variables were more predictive of some variables than others, match pairs were first compared in sequence of the perception-action loop, which allowed me to most directly test the relationships between behaviors in sequence. Then, all behavioral match pairs were compared in groups of five, with each group containing one variable as the predictor of the subsequent five (see Table 2). Thus, Friedman analyses were used to look for differences across the five match pairs in each analysis. If these analyses were significant, Wilcoxon tests were used to test which variable pairs were more related than the others. Matches for discovery phase trials and generalization phase trials were analyzed separately. Four infants were excluded from the generalization phase analyses because they had too much missing data for generalization phase trials. Additionally, matches were identified first focusing only on the filled object. Then, in a separate analysis, matches were computed in consideration of both objects, so that if a match occurred between filled objects or between unfilled objects, all ‘yeses’ were included in the proportions calculated. Baseline looking trials were not included when deriving the match pairs. If there was missing data for any of the variables, then that variable was not eligible as a match pair for that trial and was treated as missing rather than a ‘no match.’

**3.4.1 Match proportions with the filled object.** Match analyses were first conducted only using matches based on the filled object in order to determine the relationships between visual and

manual exploration based on discovery of the auditory-tactile property. For the discovery phase trials, Friedman analyses on the groupings of match pairs revealed a significant difference among the perception-action sequence match pairs ( $\chi^2 = 10.38, p = .034$ ), first fixation match pairs ( $\chi^2 = 10.68, p = .030$ ), but no other match pair groupings showed significant differences (see Figure 8). Across the sequence of behaviors in the perception-action loop, Wilcoxon analyses revealed that the proportion of matching between first fixation of the filled object and most look at that object ( $M = 38.94\%, SD = 24.34$ ) were higher than proportions of matching between most look and first contact of the filled object ( $M = 23.87\%, SD = 18.64, Z = 2.27, p = .023, r = .55$ ), most contact and most shaking and banging the filled object ( $M = 18.95\%, SD = 17.21, Z = 2.12, p = .034, r = .51$ ), and most shaking and banging the filled object and first fixation of that object on the next trial ( $M = 17.40\%, SD = 19.98, Z = 3.31, p = .001, r = .80$ ). Additionally, the proportion of matching between first contact of the filled object and most contact of that object ( $M = 38.94\%, SD = 24.34$ ) was higher than the match proportion between most contact and most shaking and banging the filled object ( $M = 38.94\%, SD = 24.34, Z = 2.35, p = .019, r = .57$ ). Specifically regarding the first fixation, Wilcoxon analyses revealed that the proportion of matching between the first fixation of the filled object and most look at that object ( $M = 38.94\%, SD = 24.34$ ) was higher than proportions of matching with any of the other variables (FF – FC  $M = 20.93\%, SD = 20.24, Z = 2.75, p = .006, r = .67$ ; FF – MC  $M = 21.86\%, SD = 13.27, Z = 3.12, p = .002, r = .76$ ; FF – MS  $M = 20.06\%, SD = 16.24, Z = 2.56, p = .011, r = .62$ ; FF – FF<sub>n</sub>  $M = 27.26\%, SD = 28.76, Z = 2.103, p = .035, r = .51$ ). However, it is worth noting that despite this significant finding, the proportions for all match pairs, including first fixation and most look, were below chance.

For the generalization phase trials, Friedman analyses on the groupings of match pairs revealed a significant difference among the perception-action sequence match pairs ( $\chi^2 = 11.59$ ,  $p = .021$ ), the first contact match pairs ( $\chi^2 = 15.26$ ,  $p = .004$ ), for the proportion of contact match pairs ( $\chi^2 = 9.59$ ,  $p = .048$ ), and for the proportion of shaking and banging match pairs ( $\chi^2 = 9.48$ ,  $p = .05$ ; see Figure 9). No other variable match pairs showed significant differences. Across the sequence of behaviors in the perception-action loop, Wilcoxon analyses revealed that the proportions of matching between first contact of the filled object and most contact of that object ( $M = 33.97\%$ ,  $SD = 21.64$ ,  $Z = 2.50$ ,  $p = .013$ ,  $r = .69$ ), most contact of the filled object and most shaking and banging that object ( $M = 34.62\%$ ,  $SD = 19.79$ ,  $Z = 2.55$ ,  $p = .011$ ,  $r = .71$ ), and most shaking and banging the filled object and first fixation of that object on the next trial ( $M = 35.90\%$ ,  $SD = 25.85$ ,  $Z = 2.81$ ,  $p = .005$ ,  $r = .78$ ) were all higher than the match proportion between most look at the filled object and first contact of that object ( $M = 15.13\%$ ,  $SD = 15.91$ ). Wilcoxon analyses showed that proportion of matching between first contact of the filled object and most contact of that object ( $M = 33.97\%$ ,  $SD = 21.64$ ) was higher than match proportions with any of the other variables (FC – MS  $M = 21.79\%$ ,  $SD = 19.70$ ,  $Z = 2.06$ ,  $p = .040$ ,  $r = .57$ ; FC – ML  $M = 20.64\%$ ,  $SD = 25.29$ ,  $Z = 1.97$ ,  $p = .049$ ,  $r = .55$ ; FC – FC<sub>n</sub>  $M = 10.77\%$ ,  $SD = 13.21$ ,  $Z = 3.08$ ,  $p = .022$ ,  $r = .85$ ), except the match proportion between first contact of the filled object and first fixation of that object on the next trial ( $M = 24.87$ ,  $SD = 30.78$ ). The match proportion between first contact of the filled object and shaking or banging the filled object ( $M = 21.79\%$ ,  $SD = 19.70$ ) was higher than the match proportion between first contact and first contact of the filled object on the next trial ( $M = 10.77\%$ ,  $SD = 13.21$ ,  $Z = 2.03$ ,  $p = .042$ ,  $r = .56$ ). Additionally, the match proportions between most contact and most shaking or banging of the filled object ( $M = 34.62\%$ ,  $SD = 19.79$ ,  $Z = 2.36$ ,  $p = .018$ ,  $r = .65$ ), most contact of the filled

object and first fixation of the filled object on the next trial ( $M = 37.69\%$ ,  $SD = 25.84$ ,  $Z = 2.71$ ,  $p = .007$ ,  $r = .75$ ), and most contact of the filled object and most subsequent contact of that object ( $M = 35.38\%$ ,  $SD = 27.27$ ,  $Z = 2.60$ ,  $p = .009$ ,  $r = .72$ ) were all higher than the match proportion between most contact and subsequent first contact of the filled object ( $M = 18.46\%$ ,  $SD = 19.08$ ). Lastly, match proportions between most shaking and banging the filled object and subsequent first fixation of that object ( $M = 35.90\%$ ,  $SD = 25.85$ ,  $Z = 2.72$ ,  $p = .007$ ,  $r = .76$ ) and between most shaking and banging and most contact of the filled object on the next trial ( $M = 30.77\%$ ,  $SD = 22.53$ ,  $Z = 2.53$ ,  $p = .011$ ,  $r = .70$ ) were higher than the match proportion between most shaking and banging the filled object and first contact of that object on the next trial ( $M = 18.46\%$ ,  $SD = 19.08$ ). However, again, none of these proportions were above chance level. Wilcoxon comparisons for all match pairings between discovery and generalization phase trials for the filled object revealed no differences in the proportion of matches between phases for any pairs.

In sum, based on discovery of the auditory-tactile property, first fixation of the filled object was related to most look at that object more than any other variable during the discovery phase (for summary, see Figure 11). During generalization, first contact of the filled object was most related to most contact of that object. Lastly, most contact and most shaking and banging of the filled object were both least related to first contact of that object on the next trial. Even though these match proportions were lower than chance, the trends found show some relationship between perception and action within visual modalities and within manual modalities.

**3.4.2 Match proportions including both objects.** Next, match analyses were run including matches with either the filled or unfilled objects, in order to determine whether visual and

manual exploration were related regardless of the objects' perceptual properties. For the discovery phase trials, Friedman analyses on the groupings of match pairs revealed significant differences among the perception-action sequence match pairs ( $\chi^2 = 18.26, p < .0001$ ), the first fixation match pairs ( $\chi^2 = 14.01, p = .007$ ), most look match pairs ( $\chi^2 = 11.94, p = .018$ ), first contact match pairs ( $\chi^2 = 26.17, p < .0001$ ), most contact match pairs ( $\chi^2 = 15.01, p = .005$ ), and most shaking and banging match pairs ( $\chi^2 = 10.78, p = .029$ ; see Figure 10). Across the sequence of behaviors in the perception-action loop, Wilcoxon analyses revealed that the proportion of matching between first fixation of either object and most look at the same object ( $M = 68.12\%, SD = 18.99$ ) was higher than the match proportions between most look at either object and first contact of the same object ( $M = 48.04\%, SD = 23.61, Z = 2.69, p = .008, r = .65$ ) and most contact of either object and most shaking and banging the same object ( $M = 31.05\%, SD = 24.20, Z = 3.20, p = .001, r = .78$ ). The match proportion between most look at either object and first contact of the same object ( $M = 48.04\%, SD = 23.61$ ) was higher than the match proportion between most shaking and banging either object and first fixation of the same object on the next trial ( $M = 27.70\%, SD = 24.01, Z = 2.09, p = .037, r = .51$ ). Additionally, the match proportion between first contact of either object and most contact of the same object ( $M = 59.61\%, SD = 20.32$ ) was higher than the match proportions between most contact of either object and most shaking and banging the same object ( $M = 31.05\%, SD = 24.20, Z = 3.21, p = .001, r = .78$ ) and most shaking and banging either object and first fixation of the same object on the next trial ( $M = 27.70\%, SD = 24.01, Z = 3.21, p = .001, r = .78$ ). Specifically regarding the first fixation, Wilcoxon analyses revealed that the proportion of matching between the first fixation of either object and most look at that object ( $M = 68.12\%, SD = 18.99$ ) was higher than match proportions with any of the other variables (FF – FC  $M = 45.39\%, SD = 28.36, Z = 2.33, p$

= .020,  $r = .57$ ; FF – MC  $M = 47.75\%$ ,  $SD = 19.61$ ,  $Z = 2.65$ ,  $p = .008$ ,  $r = .64$ ; FF – MS  $M = 37.50\%$ ,  $SD = 26.95$ ,  $Z = 2.85$ ,  $p = .004$ ,  $r = .69$ ), except the match proportion between the first fixation of either object and subsequent first fixation of that object on the next trial ( $M = 55.41$ ,  $SD = 27.68$ ). For the most look match pairs, Wilcoxon analyses revealed that the match proportions between most look at either object and most contact ( $M = 51.52\%$ ,  $SD = 20.21$ ,  $Z = 2.29$ ,  $p = .022$ ,  $r = .56$ ) or most look at the same object on the next trial ( $M = 62.32\%$ ,  $SD = 32.74$ ,  $Z = 2.77$ ,  $p = .006$ ,  $r = .67$ ) were higher than the match proportion between most look at either object and most shaking or banging the same object ( $M = 36.57\%$ ,  $SD = 22.89$ ). Regarding the first contact, Wilcoxon analyses revealed that the match proportion between first contact of either object and most contact of the same object ( $M = 59.61\%$ ,  $SD = 20.32$ ) was higher than the match proportions with any other variable (FC – MS  $M = 25.49\%$ ,  $SD = 24.29$ ,  $Z = 3.41$ ,  $p = .001$ ,  $r = .83$ ; FC – FF<sub>n</sub>  $M = 45.80$ ,  $SD = 15.07$ ,  $Z = 2.36$ ,  $p = .018$ ,  $r = .57$ ; FC – ML<sub>n</sub>  $M = 43.64$ ,  $SD = 21.10$ ,  $Z = 2.98$ ,  $p = .003$ ,  $r = .72$ ; FC – FC<sub>n</sub>  $M = 40.08\%$ ,  $SD = 20.32$ ,  $Z = 2.68$ ,  $p = .007$ ,  $r = .65$ ). Additionally, the match proportions between first contact of either object and subsequent first fixation ( $M = 45.80\%$ ,  $SD = 15.07$ ,  $Z = 3.08$ ,  $p = .002$ ,  $r = .75$ ), most look ( $M = 43.64\%$ ,  $SD = 21.10$ ,  $Z = 2.76$ ,  $p = .006$ ,  $r = .67$ ), and marginally the first contact of the same object on the next trial ( $M = 40.08\%$ ,  $SD = 20.32$ ,  $Z = 1.91$ ,  $p = .056$ ,  $r = .46$ ) were higher than the match proportion between first contact of either object and most shaking and banging the same object on the same trial ( $M = 25.49\%$ ,  $SD = 24.29$ ). Additional Wilcoxon analyses showed that the match proportion between most contact of either object and subsequent most look ( $M = 58.53\%$ ,  $SD = 29.33$ ,  $Z = 2.54$ ,  $p = .011$ ,  $r = .62$ ), marginally the first contact of the same object on the next trial ( $M = 45.04\%$ ,  $SD = 16.27$ ,  $Z = 1.92$ ,  $p = .055$ ,  $r = .47$ ), and most contact ( $M = 48.69\%$ ,  $SD = 19.81$ ,  $Z = 2.79$ ,  $p = .005$ ,  $r = .68$ ) were higher than the match proportion between most

contact of either object and more subsequent shaking or banging the same object ( $M = 31.05\%$ ,  $SD = 24.20$ ). Lastly, the match proportions between most shaking and banging either object and the subsequent first contact ( $M = 34.31$ ,  $SD = 22.16$ ,  $Z = 2.46$ ,  $p = .014$ ,  $r = .60$ ), and most contact of the same object on the next trial ( $M = 36.82$ ,  $SD = 21.83$ ,  $Z = 3.02$ ,  $p = .003$ ,  $r = .73$ ) were higher than the proportion of matching between most shaking and banging either object and most shaking and banging the same object on the next trial ( $M = 22.18$ ,  $SD = 16.56$ ).

For the generalization phase trials, Friedman analyses on the groupings of match pairs revealed significant differences among the perception-action sequence match pairs ( $\chi^2 = 10.13$ ,  $p = .038$ ), the first contact match pairs ( $\chi^2 = 12.70$ ,  $p = .013$ ; see Figure 11) and a marginal difference among the proportion of shaking and banging match pairs ( $\chi^2 = 9.07$ ,  $p = .059$ ), but no other match pair groupings showed significant differences. Across the sequence of behaviors in the perception-action loop, Wilcoxon analyses revealed that the proportion of matching between first contact of either object and most contact of the same object ( $M = 62.05\%$ ,  $SD = 20.16$ ) was higher than the match proportions between most look at either object and first contact of the same object ( $M = 37.44\%$ ,  $SD = 28.29$ ,  $Z = 2.35$ ,  $p = .019$ ,  $r = .65$ ), marginally most contact of either object and most shaking and banging the same object ( $M = 45.51\%$ ,  $SD = 23.72$ ,  $Z = 1.90$ ,  $p = .057$ ,  $r = .53$ ), and most shaking and banging either object and first fixation of the same object on the next trial ( $M = 42.31\%$ ,  $SD = 28.63$ ,  $Z = 2.05$ ,  $p = .040$ ,  $r = .57$ ). Specifically, Wilcoxon analyses revealed that the match proportion between first contact of either object and most contact of the same object ( $M = 62.05\%$ ,  $SD = 20.16$ ) was higher than the match proportion between first contact of either object and either most shaking and banging ( $M = 31.67\%$ ,  $SD = 23.45$ ,  $Z = 2.94$ ,  $p = .003$ ,  $r = .82$ ) or first contact of the same object on the next trial ( $M = 35.38\%$ ,  $SD = 24.70$ ,  $Z = 2.17$ ,  $p = .030$ ,  $r = .60$ ). The match proportions between most shaking

and banging of either object and the subsequent first fixation ( $M = 42.31\%$ ,  $SD = 28.63$ ,  $Z = 2.68$ ,  $p = .007$ ,  $r = .74$ ) and most contact of the same object on the next trial ( $M = 30.77\%$ ,  $SD = 22.53$ ,  $Z = 2.33$ ,  $p = .020$ ,  $r = .65$ ) were higher than the match proportion between most shaking and banging either object and the first contact of the same object on the next trial ( $M = 20.00\%$ ,  $SD = 20.00$ ). Wilcoxon comparisons for all match pairings between discovery and generalization phase trials for both objects revealed no differences in the proportion of matches between phases for any pairs.

In sum, the match analyses run using matches with both objects provide further evidence of the relationships found between visual and manual exploration with just the filled object (for summary, see Figure 13. First fixation of either object was more related to most look at the same object during the discovery phase, while first contact of either object was more related to most contact of the same object during the discovery phase. First contact of either object was also related to most contact of the same object during generalization. These results confirm that regarding perceptual-motor exploration of two objects, visual exploration is more related to subsequent visual exploration and manual exploration is more related to subsequent manual exploration, than visual and manual exploration are related to each other.

### **3.5 Individual differences**

In order to explore individual differences in how infants visually and manually explored the stimulus objects in study 1, cluster analyses were conducted. A first analysis was conducted on the data averaged across discovery phase trials including all five dependent variables. Then, a second analysis was conducted across each of the discovery phase trials, on each variable separately. For both sets of analyses, dependent variables were only included for the filled object

to investigate whether discovery of the auditory-tactile property was driving any differences between clusters. Baseline looking trials were not included in these analyses.

**3.5.1 Clusters based on variable averages.** A 3K-means cluster analysis run on the five dependent variables for the filled object revealed three significantly different clusters. These differences were driven by the first fixation ( $F(2, 14) = 10.68, p = .002$ ) and the proportion of accumulated contact of the filled object ( $F(2, 14) = 9.21, p = .003$ ; see Figure 14), which were the only variables that showed significant differences between clusters. Cluster 1 showed a moderate proportion of first fixations to the filled object (cluster  $M = 53\%$ ) and a high proportion of contact of the filled object (cluster  $M = 88\%$ ). Cluster 2 showed a low proportion of first fixations to the filled object (cluster  $M = 22\%$ ) and a moderate-to-high proportion of contact of the filled object (cluster  $M = 68\%$ ). Cluster 3 showed a higher proportion of first fixations to the filled object than the other clusters (cluster  $M = 69\%$ ) and a lower, but still moderate proportion of contact of the filled object (cluster  $M = 53\%$ ). In sum, infants across the three clusters varied in terms of how much they fixated the filled object first and how much time they spent contacting the filled object—some infants were more visually selective, while some infants were more manually selective of the filled object.

**3.5.2 Clusters based on sequence of trials.** Next, three separate 3K-means cluster analyses were run across the discovery phase trials for each of the three variables based on durations (accumulated looking, accumulated contact, shaking and banging), individually, using individual values for each trial. These analyses could not be run on the categorical variables (first fixation, first contact) given that the individual data for each trial were not continuous values. These three analyses were conducted to see if there were clusters of individuals who showed changes in each variable across the sequence of trials that were not revealed by looking at the group as a whole.

The analysis on the proportions of looking at the filled object revealed no systematic differences between clusters. The analysis on the proportions of accumulated contact with the filled object revealed three significant clusters for trials 3 through 5 and 7 through 10 ( $ps < .030$ ; Figure 15). Cluster 1 appeared to increase their contact with the filled object across discovery phase trials. Cluster 2 appeared to maintain moderate contact with the filled object and decrease slightly across discovery phase trials. Cluster 3 showed a sharper decrease in accumulated contact with the filled object across discovery phase trials, and showed the lowest proportions of accumulated contact. Lastly, the analysis on the proportion of shaking and banging the filled object revealed three significant clusters for trials 3 through 10 ( $ps < .040$ ; Figure 16). Cluster 1 only contained one infant who showed inconsistent proportions of shaking/banging the filled object, with very high proportions on some trials and zero shaking/banging on other trials. The main trends seemed to be between clusters 2 and 3. Infants in cluster 2 shook and banged the filled object the most overall across all discovery phase trials. Infants in cluster 3 shook and banged the filled object for lower duration proportions than the infants in cluster 2, but still exhibited the behavior across all discovery phase trials. For reference, trajectories for the generalization phase trials are displayed in Figures 15 and 16 as well, but do not necessarily hold the same trends found for each cluster described above.

Because the analysis on the proportions of accumulated contact showed the most robust trends between the three clusters, I graphed the data across trials for the other two variables based on durations [accumulated looking (Figure 17), shaking and banging (Figure 18)], so that each cluster contained the same infants as the clusters derived from the analysis on accumulated contact across trials. Note that these are not the same clusters derived from the separate analyses on accumulated looking and shaking and banging. Each graph contains the trajectory for each

individual infant in the cluster, as well as a bolded line representing the average for the group. This visualization of the data allowed me to further explore differences between the clusters showing significantly different trajectories for accumulated contact. For reference, trajectories for the generalization phase trials are displayed in Figures 15 and 16 as well, but do not necessarily hold the same trends found for each cluster across discovery phase trials. Across discovery phase trials, infants in Accumulated Contact Cluster 1 appeared to show a moderate amount of looking at the filled object and a moderate amount of shaking and banging, in addition to the high proportion and slight increase of contact with the filled object. Accumulated Contact Cluster 2 appeared to show lower overall looking at the filled object and lower amounts of shaking and banging, in addition to the moderate amount and slight decrease in the contact duration with the filled object. Accumulated Contact Cluster 3 was the only group that showed an increase in the amount of looking at the filled object. They also showed the lowest amount of shaking and banging, as well as the most robust decrease in the amount of contact with the filled object. The patterns described here include only the discovery phase trials; although, the patterns per cluster generally seemed to hold for the generalization phase trials for accumulated looking and shaking and banging. These patterns seem to resemble the same patterns found in the clusters derived from the discovery phase averages; however, only five of the 17 infants were sorted into the groups showing the same looking and contact patterns between the two analyses. Interestingly, however, another 10 of the infants, while not sorted into the same clusters, were sorted into neighboring clusters, which suggests that perhaps they were on the borders between clusters, depending on whether their data were averaged or not.

In sum, individual differences were found in terms of how infants behaved with the filled object across discovery phase trials. The primary differences between clusters centered on the

amount of time infants were in contact with the filled object—in particular, some infants increased their accumulated contact, some infants maintained moderate accumulated contact across trials, while other infants decreased contact with the filled object across discovery phase trials. Related to these differences in accumulated contact with the filled object, infants varied in their amounts of looking at and shaking and banging the filled object. It seems that the infants who increased their contact with the filled object showed moderate amounts of looking at and shaking and banging that object. Infants who maintained moderate contact with the filled object across discovery phase trials showed lower looking at and shaking and banging that object. Lastly, the infants who showed a decrease in contact with the filled object across discovery phase trials showed an increase in looking at that object and the lowest amount of shaking and banging that object. These individual differences suggest that infants differed in the way they visually and manually explored the filled object—these differences may not have been reflected by looking at the data across the group as a whole.

## CHAPTER 4: SUMMARY—STUDY 1

Study 1 showed that infants did discover the auditory-tactile property of the filled object, such that they shook or banged that object more than the unfilled object across the discovery phase trials. This trend was also found for the generalization phase trials, which suggests that infants generalized discovery of this property to novel-shaped objects based on color. It is worth noting that although infants showed differential shaking and banging of the filled object, the proportion of this behavior was still fairly low. However, this makes sense given that this variable was normalized out of the total duration of possible manipulation, and even though infants were in contact with the objects for most of this duration, they exhibited other behaviors besides shaking and banging. The fact that shaking and banging the filled object occurred at all shows that infants discovered the auditory-tactile property, and the fact that they did so with the filled object more than with the unfilled object shows selection of the filled object.

Additional evidence supporting that infants generalized the discovery of the auditory-tactile property comes from the finding that infants decreased the amount they shook or banged the unfilled object between discovery and generalization phase trials. While the amount of shaking or banging the filled object was not different between study phases, this decrease in shaking and banging the unfilled object shows that infants became more selective of which object they shook or banged during the generalization phase. Additionally, infants were in contact with the filled object more than the unfilled one, on average, during generalization phase trials, although they decreased their amount of contact with both objects between discovery and generalization phase trials, on average. There were not any major group linear trends found, except a linear decrease in the amount of contact with the filled object across discovery phase trials.

While some variables seemed predictive of other variables regarding the filled object, the proportions of these “matches” were not greater than chance. However, when disregarding the auditory-tactile property and looking at proportion of “matches” for either object, more robust trends were seen. For instance, the first fixation of either object was related to the most look at the same object, first contact of either object was related to the most contact of the same object, most contact of either object was related to most look at the same object on the next trial, and most shaking and banging either object was related to first contact and most contact of the same object on the next trial. These results suggest that there are relationships between different types of perceptual-motor exploration and selection, but this is not necessarily linked to discovery of the auditory-tactile property.

Lastly, cluster analyses revealed that different groupings of infants showed different patterns of perceptual-motor exploration and selection with regards to the filled object. Some infants showed higher proportions of accumulated contact with the filled object and lower proportions of looking, while other infants showed higher looking and lower contact. Other infants both looked and contacted the object a moderate amount. All of these results will be discussed in detail in the general discussion.

Based on the finding that infants could discover an auditory-tactile property of one object, when the two objects presented had similar visual information, a second study was conducted to investigate how discovery of the auditory-tactile property would influence perceptual-motor exploration and selection of the objects when the unfilled object had visual details. Since research shows that visual details are salient to infants (Fantz & Fagan, 1975; Ruff & Turkewitz, 1975, 1979; Guan, 2013), adding this perceptual property to the unfilled object would presumably introduce competition between the visually obvious property and the

auditory-tactile property, which is not visually obvious. The goal of this second study was to see which property would ultimately be more influential on perceptual-motor exploration and selection of the two objects. If discovery of the auditory-tactile property is more influential, it would increase perceptual-motor exploration and selection of the filled object as compared to the unfilled/detailed object; however, if the saliency of the visual details is more influential, this property would encourage more exploration and selection of the unfilled/detailed object. It is also possible that infants may explore and select the unfilled/detailed object more visually, but explore and select the filled object more manually.

## CHAPTER 5: METHOD—STUDY 2

### 5.1 Participants

Twenty-four 11-month-old participants were recruited for study 2. Recruitment was conducted in the same way as in study 1. Six infants were excluded from the final sample because they did not provide enough data. A final sample of 18 infants was used for analysis (11 females,  $M = 47.81$  weeks,  $SD = .61$ ). All infants were reported by their caregivers as Caucasian. Participants were compensated at each appointment with a photo, a certificate of participation, and a \$10 gift card.

### 5.2 Materials

All materials were identical in study 2 as in study 1, except for the stimulus objects. The object shapes used in study 2 were the same, although the weights of the objects varied slightly due to the fact that the construction and filling of the objects were done by hand. The weights of the objects used for study 2 are reported in Table 3. Additionally, while each object pair still contained one blue and one yellow object, the unfilled object in each set was painted with black polka dots on top of the base color ('unfilled/detailed'), while the filled object was painted solid (see Figure 19). The polka dots were painted using Q-tips and were spaced approximately .75 inches apart. Color and filled object combinations were kept consistent within infants, but counterbalanced between infants.

### 5.3 Procedure

The procedure used in study 2 was identical to that used in study 1.

### 5.4 Coding

Coding for study 2 was conducted the same way as in study 1. The only difference was that it was impossible for coders to be blind to which object was filled because the polka dots

made it obvious which object was unfilled/detailed. One coder coded 100% of the data, and a second independent coder coded 20% of the data. Reliability scores for the duration of object presentation and eye-tracking coding were 99.1% and 94.1%, respectively. Reliability scores for frame of tray moving forward, first object contacts, duration of possible manipulation, and frame of tray moving back were 99.1%, 96.8%, 94.4%, and 92.6%, respectively. The reliability score for the coding of object contact and no contact was 86.6%. Lastly, the reliability score for the coding of shaking and banging the objects was 69.4%.

### **5.5 Dependent variables**

All dependent variables in study 2 were the same as in study 1 and were calculated in the same ways.

### **5.6 Description of data corpus**

For seven of the 18 infants included for analysis, the filled object was blue and the unfilled/detailed object was yellow with polka dots. For the other 11 infants, the filled object was yellow and the unfilled/detailed object was blue with polka dots. The average number of trials collected from each infant was 15.06 trials ( $SD = 2.18$ ), including both discovery phase ( $M = 9.67$  trials,  $SD = .59$ ) and generalization phase trials ( $M = 5.33$  trials,  $SD = 1.64$ ). Only three out of 18 infants became fussy at some point during the experimental session. Of those infants, they became fussy on average starting around trial 7. Even if they did not get fussy during the session, all infants became restless at some point. Antsy seat behavior started, on average, around trial 4 ( $n = 15$ ). Infants started throwing the objects around trial 9, on average ( $n = 14$ ), and pushing or hitting the objects around trial 12 ( $n = 12$ ). Lastly, 12 infants pushed the presentation tray away from them and started doing so around trial 9.

Nine of the 18 caregivers encouraged their infant to look at the objects, either verbally or physically (e.g., pointing). This type of interference occurred, on average, on one to two out of

the total number of trials collected for infants whose caregivers did this. Additionally, six out of 18 caregivers interfered during the manipulation part of the trials, either verbally or physically, and this only occurred, on average, for one out of the total number of trials collected for the infants whose caregivers did this.

## CHAPTER 6: RESULTS—STUDY 2

### 6.1 Descriptive statistics

**6.1.1 Trial markers.** The average numbers of trials that were usable for analysis of looking data were 7.17 trials ( $SD = 1.10$ ) for the discovery phase and 5.00 trials ( $SD = 1.61$ ) for the generalization phase. The average duration of object presentation while objects were out of reach was 5622.16ms ( $SD = 1071.81$ ) across all usable trials. The average duration of looking at the scene provided by infants per trial was 4458.73ms ( $SD = 1000.85$ ) across all usable trials.

The average numbers of trials that were usable for the analysis of reach and manipulation data were 8.67 trials ( $SD = .59$ ) for the discovery phase and 5.33 trials ( $SD = 1.64$ ) for the generalization phase. The average duration of the tray moving forward until the start of possible manipulation (object's in reaching space) was 2469.50ms ( $SD = 814.60$ ) across all usable trials. The average duration of possible manipulation was 37719.65ms ( $SD = 4270.69$ ) across all usable trials. The average duration from the presentation tray moving back until the end of possible manipulation was 2574.65ms ( $SD = 1878.28$ ) across all usable trials. On average, infants were in contact with at least one object for a total of 30811.94ms ( $SD = 10598.18$ ) across usable trials.

**6.1.2 Baseline looking trials.** Five out of 18 infants provided either zero or one usable baseline trial. Of the 13 infants that provided two baseline trials, six infants showed a bias for looking more to one side than the other, regardless of object ( $n = 4$  left,  $n = 2$  right). For none of these six infants was this side consistent with which object they fixated first during baseline. However, a different six infants had a side bias for their first fixation ( $n = 2$  left,  $n = 4$  right), which was not consistent with which object they fixated first during baseline. On the first trial after manipulation, the two infants with the right side bias maintained their preference for looking more at the object presented on the right. The four infants with the left side bias two shifted to look more at the object on the right after manipulation and two maintained their left side bias, but

it was not consistent whether the shift was to the filled or unfilled/detailed object. Five out of the six infants with a side bias for their first fixation maintained this side bias for their first fixated object after manipulation.

Of the 13 infants who provided two baseline looking trials, eight infants showed a preference for looking more at the unfilled/detailed object. In six of these cases the object was blue, and in two cases the object was yellow. Only one infant showed a preference for looking more at the filled object during baseline. Six of the 13 infants showed a first fixation preference for the unfilled/detailed object during baseline. Only three of these infants were the same as those who had a looking duration preference for the unfilled/detailed object. On the first trial after manipulation, all of the infants who preferred to look more at the unfilled/detailed object continued this bias. The one infant who preferred to look more at the filled object also maintained this preference. All except one infant who preferred to look first at the unfilled/detailed object maintained this preference on the first trial after manipulation. Two of the four infants who fixated the filled object during baseline switched to looking at the unfilled/detailed object first after one trial of manipulation, while the other two infants maintained their preference for looking first at the filled object.

In this study, many infants had a preference of looking toward the unfilled/detailed object either first or most, although there was still some variability between infants. Most infants who had a preference for looking at the unfilled/detailed object during baseline maintained this preference after manipulation. Infants who either did not have a preference during baseline or preferred to look at the filled object, showed more variability in which object they looked at first or most across trials. This suggests that the visual detail of the unfilled/detailed object influenced

infants' looking behavior in study 2, and in particular, if the detail drew their visual attention right away, it was more likely to hold their visual attention.

## **6.2 Between object comparisons averaged across trials**

Again, due to non-normal distributions of variables, Wilcoxon tests were performed to investigate whether there were overall differences between the filled and unfilled/detailed objects across infants in terms of mean proportions of first fixation, accumulated looking duration, first contact, accumulated contact duration, and shaking and banging duration. Any differences would suggest selection of one object over the other. Discovery and generalization phase trials were averaged and analyzed separately. For the looking variables, the baseline trials were not included in the averages used in these analyses. Trials could be included in the analyses for manipulation even if there was missing looking data, and vice versa, because the variables were analyzed separately.

For the discovery phase trials, the looking variables were the only variables that showed significant differences. Infants fixated the unfilled/detailed object first ( $M = 64.51\%$ ,  $SD = 24.94$ ) more often than the filled object ( $M = 34.79\%$ ,  $SD = 25.42$ ;  $Z = 2.19$ ,  $p = .028$ ,  $r = .52$ ; see Figure 20). Infants also looked at the unfilled/detailed object for longer accumulated durations ( $M = 51.79\%$ ,  $SD = 14.21$ ) than they looked at the filled object ( $M = 20.49\%$ ,  $SD = 11.10$ ;  $Z = 3.55$ ,  $p < .0001$ ,  $r = .84$ ). For both variables there was an effect of side, such that infants fixated the object on the right first more often ( $M = 61.17\%$ ,  $SD = 18.63$ ;  $Z = 2.27$ ,  $p = .023$ ,  $r = .54$ ) and looked more at the object on the right ( $M = 40.27\%$ ,  $SD = 10.66$ ;  $Z = 2.24$ ,  $p = .025$ ,  $r = .53$ ), compared to the object on the left (First Fixation  $M = 38.83\%$ ,  $SD = 18.63$ ; Accumulated Looking  $M = 32.06\%$ ,  $SD = 10.33$ ). There were no effects of color. Additionally, as in the first study, the proportions of accumulated contact of both objects (Filled Object  $M = 78.05\%$ ,  $SD =$

19.48; Unfilled/Detailed Object  $M = 71.77\%$ ,  $SD = 24.56$ ) were higher than the proportions of accumulated looking (Filled Object  $M = 20.49\%$ ,  $SD = 11.10$ ,  $Z = 3.72$ ,  $p < .0001$ ,  $r = .88$ ; Unfilled/Detailed Object  $M = 51.79\%$ ,  $SD = 14.21$ ,  $Z = 2.94$ ,  $p = .003$ ,  $r = .69$ ) or shaking or banging of both objects (Filled Object  $M = 11.11\%$ ,  $SD = 9.35$ ,  $Z = 3.72$ ,  $p < .0001$ ,  $r = .88$ ; Unfilled/Detailed Object  $M = 8.81\%$ ,  $SD = 8.68$ ,  $Z = 3.72$ ,  $p < .0001$ ,  $r = .88$ ), and the proportions of accumulated looking at both objects were higher than the proportions of accumulated shaking or banging both objects (Filled Object  $Z = 2.896$ ,  $p = .004$ ,  $r = .68$ ;  $Z = 3.724$ ,  $p < .0001$ ,  $r = .88$ ).

For the generalization phase trials, the same trends were found as for the discovery phase trials. Infants fixated the unfilled/detailed object first ( $M = 60.69\%$ ,  $SD = 28.22$ ) marginally more often than the filled object ( $M = 39.31\%$ ,  $SD = 20.22$ ;  $Z = 1.93$ ,  $p = .053$ ,  $r = .47$ ; see Figure 21). Infants also looked at the unfilled/detailed object for longer accumulated durations ( $M = 55.18\%$ ,  $SD = 10.61$ ) than they looked at the filled object ( $M = 23.86\%$ ,  $SD = 9.25$ ;  $Z = 3.62$ ,  $p < .0001$ ,  $r = .88$ ). There were no effects of side or color. Additionally, there were no differences found for the other three variables. The average proportion of accumulated contact of the filled object ( $M = 52.78\%$ ,  $SD = 20.56$ ) was higher than the average proportion of accumulated looking of the filled object ( $M = 23.86\%$ ,  $SD = 9.25$ ,  $Z = 3.36$ ,  $p = .001$ ,  $r = .82$ ). The average proportions of accumulated contact with both objects (Filled Object  $M = 23.86\%$ ,  $SD = 9.25$ ; Unfilled/Detailed Object  $M = 55.66\%$ ,  $SD = 23.42$ ) were higher than the average proportions of shaking or banging both objects (Filled Object  $M = 6.95\%$ ,  $SD = 7.55$ ,  $Z = 3.62$ ,  $p < .0001$ ,  $r = .88$ ; Unfilled/Detailed Object  $M = 4.65\%$ ,  $SD = 4.85$ ,  $Z = 3.62$ ,  $p < .0001$ ,  $r = .88$ ), and the proportions of accumulated looking at both objects were higher than the proportions of accumulated shaking or banging both

objects (Filled Object  $Z = 3.27$ ,  $p = .001$ ,  $r = .79$ ; Unfilled/Detailed Object  $Z = 3.62$ ,  $p < .0001$ ,  $r = .88$ ).

Wilcoxon analyses performed to compare all variables between the generalization and discovery phase trials revealed that infants were in contact with both objects less during generalization phase trials (Filled Object  $M = 52.78\%$ ,  $SD = 20.56$ ; Unfilled/Detailed Object  $M = 55.66\%$ ,  $SD = 23.42$ ) than they were during discovery phase trials (Filled Object  $M = 78.05\%$ ,  $SD = 19.48$ ,  $Z = 3.53$ ,  $p < .0001$ ,  $r = .86$ ; Unfilled/Detailed Object  $M = 71.77\%$ ,  $SD = 24.56$ ,  $Z = 2.63$ ,  $p = .009$ ,  $r = .64$ ) Infants also shook or banged both objects less during generalization phase trials (Filled Object  $M = 6.95\%$ ,  $SD = 7.55$ ; Unfilled/Detailed Object  $M = 4.65\%$ ,  $SD = 4.85$ ) than they did during discovery phase trials (Filled Object  $M = 11.11\%$ ,  $SD = 9.35$ ,  $Z = 2.20$ ,  $p = .028$ ,  $r = .53$ ; Unfilled/Detailed Object  $M = 8.81\%$ ,  $SD = 8.68$ ,  $Z = 2.91$ ,  $p = .004$ ,  $r = .71$ ).

In sum, infants showed differences in visual, but not manual, exploration and selection of both objects, such that they fixated first and looked more at the unfilled/detailed object than they did the filled object. No differences were found between first contact, accumulated contact, or shaking and banging either object.

### **6.3 Linear trends across sequence of discovery phase trials**

Hierarchical linear models were performed to assess whether any of the three variables based on durations (accumulated looking, accumulated contact, shaking and banging) changed linearly across the discovery phase trials. These analyses could reveal selection of either object if infants showed increases of behaviors to one object but not the other. Analyses were performed on each object separately. Baseline looking trials were not included in the analyses on looking. Analyses revealed a linear decrease in the proportion of accumulated looking to the filled object ( $\beta =$

1.27%,  $SE = 0.55$ ,  $p = .025$ ; see Figure 22), but no change to the proportion of accumulated looking to the unfilled/detailed object. Both objects showed a linear decrease in the proportion of accumulated contact across the discovery phase trials (Filled  $\beta = -2.61\%$ ,  $SE = 0.83$ ,  $p = .004$ ; Unfilled/Detailed  $\beta = -2.56\%$ ,  $SE = 0.80$ ,  $p = .004$ ; Figure 23). There were no linear changes for the proportion of shaking or banging either object during discovery phase trials. In sum, infants decreased the amount of time they spent looking at the filled object across discovery phase trials, in addition to decreasing their amount of contact with both objects across discovery phase trials.

#### **6.4 Relationships between variables in sequence**

In order to investigate the relationships between perceptual and action across trials in study 2, the same five variables as in study 1 were used to derive match pairs, and non-parametric tests were used to analyze the relationships between the five variables across trials. Discovery and generalization phase trials were analyzed separately. Baseline looking trials were not included in these analyses. If there was missing data for any of the variables, then that variable was not eligible as a match pair for that trial and was treated as missing rather than a ‘no match.’ Matches were calculated in three different ways, based on the filled object only, the unfilled/detailed object only, and then matches with either object combined. For each of the three, proportions of matches between behavioral variables were calculated out of the total number of viable trials, and match pairs were compared in groups of five, in sequence of the perception-action loop, as well as with each variable as the predictor of the subsequent others. One infant was excluded from the analyses on generalization phase trials because he did not complete any generalization phase trials.

**6.4.1 Match proportions with the filled object.** Match analyses were first conducted only using matches based on the filled object in order to determine the relationships between visual and

manual exploration based on discovery of the auditory-tactile property. For the discovery phase trials, Friedman analyses on the groupings of match pairs revealed a significant difference among the perception-action sequence match pairs ( $\chi^2 = 33.26, p < .0001$ ), the first fixation match pairs ( $\chi^2 = 17.45, p = .002$ ), first contact match pairs ( $\chi^2 = 24.62, p < .0001$ ), most contact match pairs ( $\chi^2 = 25.98, p < .0001$ ), and most shaking and banging match pairs ( $\chi^2 = 21.12, p < .0001$ ; see Figure 24). Across the sequence of behaviors in the perception-action loop, Wilcoxon analyses revealed that the proportion of matching between first contact of the filled object and most contact of that object ( $M = 34.09\%$ ,  $SD = 19.56$ ) was higher than the match proportions between first fixation of the filled object and most look at that object ( $M = 8.37\%$ ,  $SD = 12.75$ ,  $Z = 3.34$ ,  $p = .001$ ,  $r = .79$ ), most look at the filled object and first contact of that object ( $M = 6.75\%$ ,  $SD = 12.03$ ,  $Z = 3.58$ ,  $p < .0001$ ,  $r = .84$ ), marginally most contact of the filled object and most shaking and banging that object ( $M = 26.57\%$ ,  $SD = 19.34$ ,  $Z = 1.93$ ,  $p = .054$ ,  $r = .45$ ), and most shaking and banging the filled object and first fixation of that object on the next trial ( $M = 15.96\%$ ,  $SD = 21.24$ ,  $Z = 2.87$ ,  $p = .004$ ,  $r = .68$ ). The match proportion between most contact of the filled object and most shaking and banging that object ( $M = 26.57\%$ ,  $SD = 19.34$ ) was also higher than the match proportions between first fixation of the filled object and most look at that object ( $M = 8.37\%$ ,  $SD = 12.75$ ,  $Z = 3.15$ ,  $p = .002$ ,  $r = .74$ ), most look at the filled object and first contact of that object ( $M = 6.75\%$ ,  $SD = 12.03$ ,  $Z = 3.44$ ,  $p = .001$ ,  $r = .81$ ), and most shaking and banging the filled object and first fixation of that object on the next trial ( $M = 15.96\%$ ,  $SD = 21.24$ ,  $Z = 3.11$ ,  $p = .002$ ,  $r = .73$ ). Specifically regarding the first fixation, Wilcoxon analyses revealed that the match proportion between first fixation of the filled object and first contact of that object ( $M = 24.28\%$ ,  $SD = 19.72$ ) was higher than the match proportions between first fixation and most look at the filled object ( $M = 8.37\%$ ,  $SD = 12.75$ ,  $Z = 2.71$ ,  $p = .007$ ,  $r = .64$ ), or between first

fixation and shaking and banging the filled object ( $M = 13.49\%$ ,  $SD = 19.75$ ,  $Z = 2.22$ ,  $p = .027$ ,  $r = .52$ ). The match proportion between first fixation of the filled object and most contact of that object ( $M = 21.49\%$ ,  $SD = 22.10$ ) was higher than the match proportions between first fixation and most look at the filled object ( $M = 8.37\%$ ,  $SD = 12.75$ ,  $Z = 2.68$ ,  $p = .007$ ,  $r = .63$ ), first fixation and most shaking and banging the filled object ( $M = 13.49$ ,  $SD = 19.75$ ,  $Z = 2.25$ ,  $p = .024$ ,  $r = .53$ ), or first fixation of the filled object and subsequent first fixation of that object on the next trial ( $M = 16.69\%$ ,  $SD = 23.98$ ,  $Z = 2.01$ ,  $p = .040$ ,  $r = .59$ ). Wilcoxon analyses on the first contact match pairs revealed that the match proportions between first contact of the filled object and all other variables (FC – MC  $M = 34.09\%$ ,  $SD = 19.56$ ,  $Z = 3.24$ ,  $p = .001$ ,  $r = .77$ ; FC – MS  $M = 21.78\%$ ,  $SD = 16.35$ ;  $Z = 2.75$ ,  $p = .006$ ,  $r = .65$ ; FC – FF<sub>n</sub>  $M = 20.61\%$ ,  $SD = 21.81$ ,  $Z = 2.65$ ,  $p = .008$ ,  $r = .63$ ; FC – FC<sub>n</sub>  $M = 29.17\%$ ,  $SD = 27.89$ ,  $Z = 2.85$ ,  $p = .004$ ,  $r = .67$ ) was higher than the match proportion between first contact and most look at the filled object ( $M = 7.44\%$ ,  $SD = 14.09$ ). The match proportion between first contact and most contact of the filled object ( $M = 34.09\%$ ,  $SD = 19.56$ ) was also higher than the match proportion between first contact and most shaking and banging the filled object ( $M = 21.78\%$ ,  $SD = 16.35$ ,  $Z = 2.89$ ,  $p = .004$ ,  $r = .68$ ) or first contact of the filled object and subsequent first fixation of that object on the next trial ( $M = 20.61\%$ ,  $SD = 21.81$ ,  $Z = 2.91$ ,  $p = .004$ ,  $r = .69$ ). The match proportions between most contact and most shaking and banging the filled object ( $M = 26.57\%$ ,  $SD = 19.34$ ,  $Z = 3.29$ ,  $p = .001$ ,  $r = .78$ ), most contact of the filled object and first contact of that object on the next trial ( $M = 24.54\%$ ,  $SD = 25.78$ ,  $Z = 2.94$ ,  $p = .003$ ,  $r = .69$ ), and most contact and most contact of the filled object on the next trial ( $M = 28.24$ ,  $SD = 22.19$ ,  $Z = 3.42$ ,  $p = .001$ ,  $r = .81$ ) were all higher than the match proportion between most contact of the filled object and most look at that object on the next trial ( $M = 5.95\%$ ,  $SD = 10.66$ ). The match proportions between most contact

of the filled object and marginally most shaking and banging that object ( $M = 26.57\%$ ,  $SD = 19.34$ ,  $Z = 1.89$ ,  $p = .059$ ,  $r = .45$ ) and between most contact of the filled object and most contact of that object on the next trial ( $M = 28.24\%$ ,  $SD = 22.19$ ,  $Z = 2.76$ ,  $p = .006$ ,  $r = .65$ ) were both higher than the match proportion between most contact and first fixation of the filled object on the next trial ( $M = 19.63\%$ ,  $SD = 22.01$ ). Lastly, the match proportions between most shaking and banging the filled object and all other variables on the next trial (MS – FF<sub>n</sub>  $M = 15.96\%$ ,  $SD = 21.24$ ,  $Z = 2.52$ ,  $p = .012$ ,  $r = .60$ ; MS – FC<sub>n</sub>  $M = 19.48\%$ ,  $SD = 20.88$ ,  $Z = 2.61$ ,  $p = .009$ ,  $r = .62$ ; MS – MC<sub>n</sub>  $M = 21.43\%$ ,  $SD = 18.03$ ,  $Z = 3.05$ ,  $p = .002$ ,  $r = .72$ ; MS – MS<sub>n</sub>  $M = 23.15$ ,  $SD = 20.45$ ,  $Z = 3.33$ ,  $p = .001$ ,  $r = .79$ ) were higher than the match proportion between most shaking and banging the filled object and most look at that object on the next trial ( $M = 2.88\%$ ,  $SD = 7.01$ ). However, it is worth noting that despite these significant findings, the proportions for all match pairs regarding the filled object were below chance.

For the generalization phase trials, Friedman analyses on the groupings of match pairs revealed a significant difference among the perception-action sequence match pairs ( $\chi^2 = 11.19$ ,  $p = .025$ ), the first contact match pairs ( $\chi^2 = 23.74$ ,  $p < .0001$ ) and, marginally, the proportion of contact duration match pairs ( $\chi^2 = 9.40$ ,  $p = .052$ ; see Figure 25). No other variable match pairs showed significant differences. Across the sequence of behaviors in the perception-action loop, Wilcoxon analyses revealed that the proportion of matching between first contact of the filled object and most contact of that object ( $M = 23.53\%$ ,  $SD = 19.60$ ) was higher than the match proportions between either first fixation of the filled object and most look at that object ( $M = 11.18\%$ ,  $SD = 14.58$ ,  $Z = 2.26$ ,  $p = .024$ ,  $r = .55$ ) and most look at the filled object and first contact of that object ( $M = 10.00\%$ ,  $SD = 14.63$ ,  $Z = 2.38$ ,  $p = .018$ ,  $r = .58$ ). Wilcoxon analyses showed that the match proportion between first contact of the filled object and most shaking and

banging that object ( $M = 22.55\%$ ,  $SD = 19.49$ ) was higher than the match proportions between first contact and first fixation of the filled object on the next trial ( $M = 14.12$ ,  $SD = 17.25$ ,  $Z = 2.05$ ,  $p = .040$ ,  $r = .50$ ) or first contact and first contact of the filled object on the next trial ( $M = 10.59\%$ ,  $SD = 17.49$ ,  $Z = 2.50$ ,  $p = .012$ ,  $r = .61$ ). The match proportion between first contact and most shaking and banging the filled object ( $M = 22.55\%$ ,  $SD = 19.49$ ,  $Z = 3.24$ ,  $p = .001$ ,  $r = .79$ ), first contact of the filled object and subsequent first contact of that object on the next trial ( $M = 10.59\%$ ,  $SD = 17.49$ ,  $Z = 2.33$ ,  $p = .020$ ,  $r = .57$ ), and first contact of the filled object and most contact of that object on the next trial ( $M = 23.53\%$ ,  $SD = 19.60$ ,  $Z = 3.38$ ,  $p = .001$ ,  $r = .82$ ) were all higher than the match proportion between first contact and most look at the filled object on the next trial ( $M = 2.35\%$ ,  $SD = 9.70$ ). Additionally, the match proportions between most contact and most shaking and banging the filled object ( $M = 19.61$ ,  $SD = 17.91$ ,  $Z = 2.29$ ,  $p = .022$ ,  $r = .56$ ) and most contact of the filled object and first fixation of that object on the next trial ( $M = 18.53\%$ ,  $SD = 17.03$ ,  $Z = 2.20$ ,  $p = .028$ ,  $r = .53$ ) were both higher than the match proportion between most contact and most look at the filled object on the next trial ( $M = 6.47\%$ ,  $SD = 10.42$ ). The match proportions between most contact of the filled object and most shaking and banging that object ( $M = 19.61\%$ ,  $SD = 17.91$ ,  $Z = 2.60$ ,  $p = .009$ ,  $r = .63$ ) and marginally between most contact and first fixation of that object on the next trial ( $M = 18.53\%$ ,  $SD = 17.03$ ,  $Z = 1.90$ ,  $p = .057$ ,  $r = .46$ ) and most contact and first contact of the filled object on the next trial ( $M = 15.29\%$ ,  $SD = 19.40$ ,  $Z = 1.93$ ,  $p = .053$ ,  $r = .47$ ) were higher than the match proportion between most contact of the filled object and subsequent most contact of that object on the next trial ( $M = 7.06\%$ ,  $SD = 12.13$ ). However, again, none of these proportions were above chance level. Wilcoxon comparisons for all match pairings between discovery and generalization phase trials for the filled object revealed only one difference—the proportion of matching between

most contact of the filled object and subsequent most contact of the filled object on the next trial was higher during discovery phase trials ( $M = 28.24\%$ ,  $SD = 22.19$ ) than during generalization phase trials ( $M = 7.06\%$ ,  $SD = 12.13$ ,  $Z = 2.73$ ,  $p = .006$ ,  $r = .66$ ).

In sum, regarding discovery of the auditory-tactile property, all types of visual and manual exploration measured in this study were more related to subsequent manual exploration than they were to subsequent visual exploration (for summary, see Figure 26). These findings suggest that discovery of the auditory-tactile property influenced more manual exploration and selection of the filled object.

**6.4.2 Match proportions with the unfilled/detailed object.** Next, match analyses were conducted only using matches based on the unfilled/detailed object in order to determine the relationships between visual and manual exploration driven by the visual detail property. For the discovery phase trials, Friedman analyses on the groupings of match pairs revealed a significant difference among the perception-action sequence match pairs ( $\chi^2 = 21.70$ ,  $p < .0001$ ), the first fixation match pairs ( $\chi^2 = 29.98$ ,  $p < .0001$ ), most look match pairs ( $\chi^2 = 39.84$ ,  $p < .0001$ ), first contact match pairs ( $\chi^2 = 19.83$ ,  $p = .001$ ), most contact match pairs ( $\chi^2 = 22.03$ ,  $p < .0001$ ), and most shaking and banging match pairs ( $\chi^2 = 26.60$ ,  $p < .0001$ ; see Figure 27). Across the sequence of behaviors in the perception-action loop, Wilcoxon analyses revealed that the proportion of matching between first fixation and most look at the unfilled/detailed object ( $M = 59.32\%$ ,  $SD = 23.20$ ) were higher than the match proportions most look at the unfilled/detailed object and first contact of that object ( $M = 33.13\%$ ,  $SD = 26.82$ ,  $Z = 2.95$ ,  $p = .003$ ,  $r = .70$ ), first contact of the unfilled/detailed object and most contact of that object ( $M = 28.42\%$ ,  $SD = 21.76$ ,  $Z = 2.82$ ,  $p = .005$ ,  $r = .66$ ), most contact of the unfilled/detailed object and most shaking and banging that object ( $M = 20.76\%$ ,  $SD = 17.17$ ,  $Z = 3.11$ ,  $p = .002$ ,  $r = .73$ ), and most shaking and

banging the unfilled/detailed object and first fixation of that object on the next trial ( $M = 23.99\%$ ,  $SD = 18.79$ ,  $Z = 3.02$ ,  $p = .003$ ,  $r = .71$ ). Specifically regarding the first fixation, Wilcoxon analyses revealed that the match proportion between first fixation of the unfilled/detailed object and subsequent first fixation of that object on the next trial ( $M = 44.79\%$ ,  $SD = 34.19$ ) was higher than the match proportion between first fixation of the unfilled/detailed object and first contact of that object ( $M = 29.23\%$ ,  $SD = 24.67$ ,  $Z = 2.62$ ,  $p = .009$ ,  $r = .62$ ). Additionally, the match proportion between first fixation of the unfilled/detailed object and most look at that object ( $M = 59.32\%$ ,  $SD = 33.20$ ) was higher than the match proportion between first fixation of the unfilled/detailed object and any of the other variables (FF – FC  $M = 29.23\%$ ,  $SD = 24.67$ ,  $Z = 2.87$ ,  $p = .004$ ,  $r = .68$ ; FF – MC  $M = 35.89\%$ ,  $SD = 25.06$ ,  $Z = 2.95$ ,  $p = .003$ ,  $r = .70$ ; FF – MS  $M = 23.76\%$ ,  $SD = 21.82$ ,  $Z = 3.44$ ,  $p = .001$ ,  $r = .81$ ; FF – FF<sub>n</sub>  $M = 44.79\%$ ,  $SD = 34.19$ ,  $Z = 2.61$ ,  $p = .009$ ,  $r = .62$ ). The match proportion between first fixation of the unfilled/detailed object and most contact of that object ( $M = 35.89\%$ ,  $SD = 25.06$ ) was marginally higher than the match proportion between first fixation and most shaking and banging the unfilled/detailed object ( $M = 23.76\%$ ,  $SD = 21.82$ ,  $Z = 1.95$ ,  $p = .051$ ,  $r = .46$ ). Wilcoxon analyses on the most look match pairs revealed that the match proportion between most look at the unfilled/detailed object and subsequent first fixation of that object on the next trial ( $M = 55.00\%$ ,  $SD = 33.48$ ) was higher than the match proportion between most look at the unfilled/detailed object and any other variable (ML – FC  $M = 33.13\%$ ,  $SD = 26.82$ ,  $Z = 2.77$ ,  $p = .006$ ,  $r = .65$ ; ML – MC  $M = 39.98\%$ ,  $SD = 25.38$ ,  $Z = 2.58$ ,  $p = .010$ ,  $r = .61$ ; ML – MS  $M = 29.87\%$ ,  $SD = 23.72$ ,  $Z = 2.84$ ,  $p = .004$ ,  $r = .67$ ), except the match proportion between most look and the subsequent most look at the unfilled/detailed object on the next trial ( $M = 77.78\%$ ,  $SD = 31.18$ ). Also, the match proportion between most look at the unfilled/detailed object and most look at that object on the next trial ( $M$

= 77.78%,  $SD = 31.18$ ) was higher than the match proportions between most look at the unfilled/detailed object and any other variable (ML – FC  $M = 33.13\%$ ,  $SD = 26.82$ ,  $Z = 3.62$ ,  $p < .0001$ ,  $r = .85$ ; ML – MC  $M = 39.98$ ,  $SD = 25.38$ ,  $Z = 3.62$ ,  $p < .0001$ ,  $r = .85$ ; ML – MS  $M = 29.87\%$ ,  $SD = 23.72$ ,  $Z = 3.58$ ,  $p < .0001$ ,  $r = .84$ ; ML – FF<sub>n</sub>  $M = 55.00\%$ ,  $SD = 33.48$ ,  $Z = 3.19$ ,  $p = .001$ ,  $r = .75$ ). The match proportions between first contact of the unfilled/detailed object and first fixation of that object on the next trial ( $M = 27.14\%$ ,  $SD = 22.57$ ,  $Z = 1.99$ ,  $p = .046$ ,  $r = .47$ ), first contact and most look at the unfilled/detailed object on the next trial ( $M = 31.74\%$ ,  $SD = 23.60$ ,  $Z = 2.57$ ,  $p = .010$ ,  $r = .61$ ), and first contact and most contact with the filled object on the next trial ( $M = 28.41$ ,  $SD = 21.76$ ,  $Z = 2.26$ ,  $p = .024$ ,  $r = .53$ ) were all higher than the match proportion between first contact with the unfilled/detailed object and subsequent first contact of that object on the next trial ( $M = 20.54$ ,  $SD = 20.76$ ). The match proportion between first contact of the unfilled/detailed object and first fixation of that object on the next trial ( $M = 27.14$ ,  $SD = 22.57$ ,  $Z = 2.02$ ,  $p = .044$ ,  $r = .48$ ), first contact and most look at that object on the next trial ( $M = 31.74\%$ ,  $SD = 23.60$ ,  $Z = 2.74$ ,  $p = .006$ ,  $r = .65$ ), and first contact and most contact with the unfilled/detailed object on the next trial ( $M = 28.42$ ,  $SD = 21.76$ ) were also higher than the match proportion between first contact of the unfilled/detailed object and most shaking and banging that object ( $M = 15.05\%$ ,  $SD = 15.67$ ,  $Z = 2.45$ ,  $p = .014$ ,  $r = .58$ ). The match proportion between most contact of the unfilled/detailed object and first fixation of that object on the next trial ( $M = 33.21\%$ ,  $SD = 21.54$ ) was higher than the match proportion between most contact and first contact of the unfilled/detailed object on the next trial ( $M = 20.63\%$ ,  $SD = 17.34$ ,  $Z = 2.59$ ,  $p = .010$ ,  $r = .61$ ). The match proportion between most contact of the unfilled/detailed object and most look at that object on the next trial ( $M = 39.57\%$ ,  $SD = 24.96$ ) was also higher than the match proportions between most contact and shaking and banging the unfilled/detailed object ( $M$

= 20.76%,  $SD = 17.17$ ,  $Z = 2.64$ ,  $p = .008$ ,  $r = .62$ ), most contact and first contact of the unfilled/detailed object on the next trial ( $M = 20.63\%$ ,  $SD = 17.34$ ,  $Z = 2.73$ ,  $p = .006$ ,  $r = .64$ ), and most contact and most contact of the unfilled/detailed object on the next trial ( $M = 27.02\%$ ,  $SD = 22.10$ ,  $Z = 2.65$ ,  $p = .008$ ,  $r = .63$ ). Lastly, the match proportion between most shaking and banging the unfilled/detailed object and first fixation of that object on the next trial ( $M = 23.99\%$ ,  $SD = 18.79$ ) was higher than the match proportions between most shaking and banging the unfilled/detailed object and first contact of that object on the next trial ( $M = 12.70\%$ ,  $SD = 13.57$ ,  $Z = 2.54$ ,  $p = .011$ ,  $r = .60$ ) or most shaking and banging and most shaking and banging the unfilled/detailed object on the next trial ( $M = 13.19\%$ ,  $SD = 16.31$ ,  $Z = 3.24$ ,  $p = .001$ ,  $r = .76$ ). The match proportion between most shaking and banging the unfilled/detailed object and most at that object on the next trial ( $M = 29.74\%$ ,  $SD = 23.36$ ) was higher than the match proportions between most shaking and banging and first contact of the unfilled/detailed object on the next trial ( $M = 12.70\%$ ,  $SD = 13.57$ ,  $Z = 2.97$ ,  $p = .003$ ,  $r = .70$ ), most shaking and banging the unfilled/detailed object and most contact of that object on the next trial ( $M = 17.46$ ,  $SD = 17.20$ ,  $Z = 2.53$ ,  $p = .011$ ,  $r = .60$ ), or most shaking and banging and most shaking and banging the unfilled/detailed object on the next trial ( $M = 13.19$ ,  $SD = 16.21$ ,  $Z = 3.07$ ,  $p = .002$ ,  $r = .72$ ). For all of these significant findings, some of the proportions for the match pairs regarding the unfilled/detailed object were below chance, while others were not (see Figure 23).

For the generalization phase trials, Friedman analyses on the groupings of match pairs revealed a significant difference among the perception-action sequence match pairs ( $\chi^2 = 36.87$ ,  $p < .0001$ ), the first fixation match pairs ( $\chi^2 = 33.94$ ,  $p < .0001$ ), most look match pairs ( $\chi^2 = 28.38$ ,  $p < .0001$ ), first contact match pairs ( $\chi^2 = 19.11$ ,  $p = .001$ ), most contact match pairs ( $\chi^2 = 27.68$ ,  $p < .0001$ ), and most shaking and banging match pairs ( $\chi^2 = 23.40$ ,  $p < .0001$ ; see Figure

28). Across the sequence of behaviors in the perception-action loop, Wilcoxon analyses revealed that the proportion of matching between first fixation of the unfilled/detailed object and most look at that object ( $M = 55.78\%$ ,  $SD = 22.64$ ) was higher than the match proportions between first contact of the unfilled/detailed object and most contact of that object ( $M = 37.25\%$ ,  $SD = 23.22$ ,  $Z = 2.34$ ,  $p = .019$ ,  $r = .57$ ), most contact of the unfilled/detailed object and most shaking and banging that object ( $M = 18.63\%$ ,  $SD = 18.52$ ,  $Z = 3.41$ ,  $p = .001$ ,  $r = .83$ ), and most shaking and banging the unfilled/detailed object and first fixation of that object on the next trial ( $M = 15.00\%$ ,  $SD = 14.25$ ,  $Z = 3.52$ ,  $p < .0001$ ,  $r = .85$ ). The match proportion between most look at the unfilled/detailed object and first contact of that object ( $M = 49.02\%$ ,  $SD = 18.29$ ) was higher than the match proportions between first contact of the unfilled/detailed object and most contact of that object ( $M = 37.25\%$ ,  $SD = 23.22$ ,  $Z = 2.71$ ,  $p = .007$ ,  $r = .66$ ), most contact of the unfilled/detailed object and most shaking and banging that object ( $M = 18.63\%$ ,  $SD = 18.52$ ,  $Z = 3.37$ ,  $p = .001$ ,  $r = .82$ ), and most shaking and banging the unfilled/detailed object and first fixation of that object on the next trial ( $M = 15.00\%$ ,  $SD = 14.25$ ,  $Z = 3.58$ ,  $p < .0001$ ,  $r = .87$ ). Additionally, the match proportion between first contact of the unfilled/detailed object and most contact of that object ( $M = 37.25\%$ ,  $SD = 23.22$ ) was higher than the match proportions between most contact of the unfilled/detailed object and most shaking and banging that object ( $M = 18.63\%$ ,  $SD = 18.52$ ,  $Z = 2.46$ ,  $p = .014$ ,  $r = .60$ ) and most shaking and banging the unfilled/detailed object and first fixation of that object on the next trial ( $M = 15.00\%$ ,  $SD = 14.25$ ,  $Z = 2.78$ ,  $p = .005$ ,  $r = .67$ ). Specifically regarding the first fixation, Wilcoxon analyses revealed that the match proportion between first fixation of the unfilled/detailed object and most look at that object ( $M = 55.78\%$ ,  $SD = 22.64$ ) was higher than the match proportions between first fixation of the unfilled/detailed object and any of the other variables (FF – FC  $M = 34.90\%$ ,

$SD = 20.89$ ,  $Z = 3.19$ ,  $p = .001$ ,  $r = .77$ ;  $FF - MC$   $M = 33.92\%$ ,  $SD = 19.76$ ,  $Z = 3.19$ ,  $p = .001$ ,  $r = .78$ ;  $FF - MS$   $M = 14.90\%$ ,  $SD = 17.60$ ,  $Z = 3.64$ ,  $p < .0001$ ,  $r = .88$ ;  $FF - FF_n$   $M = 30.88\%$ ,  $SD = 30.73$ ,  $Z = 3.63$ ,  $p = .001$ ,  $r = .82$ ). The match proportions between first fixation of the unfilled/detailed object and first contact of that object ( $FC$   $M = 34.90\%$ ,  $SD = 20.89$ ,  $Z = 3.12$ ,  $p = .002$ ,  $r = .76$ ), first fixation and most contact of the unfilled/detailed object ( $M = 33.92\%$ ,  $SD = 19.76$ ,  $Z = 3.00$ ,  $p = .003$ ,  $r = .73$ ), and first fixation and subsequent first fixation of the unfilled/detailed object on the next trial ( $M = 30.88\%$ ,  $SD = 30.73$ ,  $Z = 2.40$ ,  $p = .016$ ,  $r = .58$ ) were all higher than the match proportion between first fixation of the unfilled/detailed object and most shaking and banging that object ( $M = 14.90\%$ ,  $SD = 17.60$ ). Wilcoxon analyses on the most look match pairs revealed that the match proportion between most look at the unfilled/detailed object and subsequent most look at that object on the next trial ( $M = 70.59\%$ ,  $SD = 27.67$ ) was higher than the match proportions between most look at the unfilled/detailed object and any other variable ( $ML - FC$   $M = 49.02$ ,  $SD = 18.29$ ,  $Z = 3.34$ ,  $p = .001$ ,  $r = .81$ ;  $ML - MC$   $M = 49.02$ ,  $SD = 18.29$ ,  $Z = 3.04$ ,  $p = .002$ ,  $r = .74$ ;  $ML - MS$   $M = 18.04$ ,  $SD = 19.08$ ,  $Z = 3.48$ ,  $p < .0001$ ,  $r = .85$ ;  $ML - FF_n$   $M = 43.63\%$ ,  $SD = 33.25$ ,  $Z = 2.94$ ,  $p = .003$ ,  $r = .71$ ). The match proportions between most look at the unfilled/detailed object and any other variable ( $FC$   $M = 49.02$ ,  $SD = 18.29$ ,  $Z = 3.34$ ,  $p = .001$ ,  $r = .81$ ;  $MC$   $M = 49.02\%$ ,  $SD = 18.29$ ,  $Z = 3.19$ ,  $p = .001$ ,  $r = .77$ ,  $FF$   $M = 43.63\%$ ,  $SD = 33.25$ ,  $Z = 2.69$ ,  $p = .007$ ,  $r = .65$ ;  $ML$   $M = 70.59\%$ ,  $SD = 27.67$ ,  $Z = 3.48$ ,  $p < .0001$ ,  $r = .85$ ) were also higher than the match proportion between most look and most shaking and banging the unfilled/detailed object ( $M = 18.04\%$ ,  $SD = 19.08$ ). The match proportion between first contact of the unfilled/detailed object and most look at that object on the next trial ( $M = 42.65\%$ ,  $SD = 33.13$ ) was higher than the match proportions between first contact of the unfilled/detailed object and any other variable ( $FC - MS$   $M = 15.69\%$ ,  $SD = 14.99$ ,

$Z = 2.73, p = .006, r = .66$ ;  $FC - FF_n M = 27.35\%, SD = 26.11, Z = 2.12, p = .034, r = .52$ ;  $FC - FC_n M = 26.47\%, SD = 25.73, Z = 2.37, p = .018, r = .57$ ), except the match proportion between first contact of the unfilled/detailed object and most contact of that object on the next trial ( $M = 37.25\%, SD = 23.22$ ). The match proportion between first contact of the unfilled/detailed object and most contact of that object ( $M = 37.25\%, SD = 23.22$ ) was higher than the match proportions between first contact of the unfilled/detailed object and any other variable ( $FC - MS M = 15.69\%, SD = 14.99, Z = 2.92, p = .004, r = .71$ ;  $FC - FF_n M = 27.35\%, SD = 26.11, Z = 2.03, p = .042, r = .49$ ;  $FC - FC_n M = 26.47\%, SD = 25.73, Z = 2.28, p = .022, r = .55$ ), except the match proportion between first contact and most look at the unfilled/detailed object on the next trial ( $M = 42.65\%, SD = 33.13$ ). The match proportion between most contact of the unfilled/detailed object and first fixation of that object on the next trial ( $M = 33.82\%, SD = 28.15$ ) was higher than the match proportion between most contact and most shaking and banging the unfilled/detailed object ( $M = 18.63\%, SD = 18.52, Z = 2.07, p = .038, r = .50$ ). The match proportion between most contact of the unfilled/detailed object and most look at that object on the next trial ( $M = 51.18\%, SD = 30.95$ ) was also higher than the match proportions between most contact of the unfilled/detailed object and any other variable ( $MC - MS M = 18.63\%, SD = 18.52, Z = 3.04, p = .002, r = .74$ ;  $MC - FF_n M = 33.82\%, SD = 28.15, Z = 2.31, p = .021, r = .56$ ;  $MC - FC_n M = 37.06\%, SD = 21.73, Z = 2.30, p = .022, r = .56$ ;  $MC - MC_n M = 27.06\%, SD = 23.39, Z = 3.21, p = .001, r = .78$ ). Additionally, the match proportion between most contact of the unfilled/detailed object and first contact of that object on the next trial ( $M = 37.06\%, SD = 21.73$ ) was higher than the match proportion between most contact and most shaking and banging the unfilled/detailed object ( $M = 18.63\%, SD = 18.52, Z = 2.64, p = .008, r = .64$ ) and most contact and subsequent most contact of the unfilled/detailed object on the next trial ( $M = 27.06\%, SD = 23.39, Z = 2.31,$

$p = .021, r = .56$ ). Lastly, the match proportions between most shaking and banging the unfilled/detailed object and first fixation of that object on the next trial ( $M = 15.00\%$ ,  $SD = 14.25$ ,  $Z = 2.75$ ,  $p = .006$ ,  $r = .67$ ) and most shaking and banging and most contact of the unfilled/detailed object on the next trial ( $M = 11.76\%$ ,  $SD = 12.37$ ,  $Z = 2.45$ ,  $p = .014$ ,  $r = .59$ ) were both higher than the match proportion between most shaking and banging and subsequent most shaking and banging the unfilled/detailed object on the next trial ( $M = 4.71\%$ ,  $SD = 11.25$ ). The match proportion between most shaking and banging the unfilled/detailed object and most look at that object on the next trial ( $M = 18.53\%$ ,  $SD = 15.89$ ) was higher than the match proportion between most shaking and banging the unfilled/detailed object and first contact of that object on the next trial ( $M = 9.41\%$ ,  $SD = 12.49$ ,  $Z = 2.59$ ,  $p = .010$ ,  $r = .63$ ), most shaking and banging and most contact with the unfilled/detailed object on the next trial (MC  $M = 11.76\%$ ,  $SD = 12.37$ ,  $Z = 2.23$ ,  $p = .026$ ,  $r = .54$ ), or most shaking and banging and subsequent most shaking and banging the unfilled/detailed object on the next trial ( $M = 4.71\%$ ,  $SD = 11.25$ ,  $Z = 3.02$ ,  $p = .003$ ,  $r = .73$ ). For all of these significant findings, some of the proportions for the match pairs regarding the unfilled/detailed object were below chance, while others were not (see Figure 23). Wilcoxon comparisons for all match pairings between discovery and generalization phase trials for the filled object revealed only one difference—the proportion of matching between most contact of the unfilled/detailed object and subsequent first contact of the unfilled/detailed object on the next trial was higher during generalization phase trials ( $M = 37.06\%$ ,  $SD = 21.73$ ) than during discovery phase trials ( $M = 20.63\%$ ,  $SD = 17.34$ ,  $Z = 2.41$ ,  $p = .016$ ,  $r = .58$ ).

In sum, regarding the visual detail property, all types of visual and manual exploration measured in this study were more related to subsequent visual exploration than they were to

subsequent manual exploration (for summary, see Figure 29). These findings suggest that the visual detail property influenced more visual exploration and selection of the unfilled/detailed object.

**6.4.3 Match proportions including both objects.** Lastly, match analyses were run including matches with either the filled or unfilled objects, in order to determine whether visual and manual exploration were related regardless of the objects' perceptual properties. For the discovery phase trials, Friedman analyses on the groupings of match pairs revealed significant differences among the perception-action sequence match pairs ( $\chi^2 = 14.08, p = .007$ ), the first fixation match pairs ( $\chi^2 = 12.14, p = .016$ ), most look match pairs ( $\chi^2 = 30.93, p < .0001$ ), and first contact match pairs ( $\chi^2 = 14.55, p = .006$ ; see Figure 30). Across the sequence of behaviors in the perception-action loop, Wilcoxon analyses revealed that the proportion of matching between first fixation of either object and most look at the same object ( $M = 66.99\%$ ,  $SD = 29.47$ ) was higher than the match proportions between most look at either object and first contact of that object ( $M = 39.87\%$ ,  $SD = 23.59$ ,  $Z = 3.06, p = .002, r = .72$ ) and most shaking and banging either object and first fixation of the same object on the next trial ( $M = 41.08\%$ ,  $SD = 22.72$ ,  $Z = 2.11, p = .035, r = .50$ ). The match proportions between first contact of either object and most contact of the same object ( $M = 63.82\%$ ,  $SD = 18.39$ ) was higher than the match proportions between most look at either object and first contact of the same object ( $M = 39.87\%$ ,  $SD = 23.59$ ,  $Z = 3.03, p = .002, r = .71$ ), most contact of either object and most shaking and banging the same object ( $M = 47.55\%$ ,  $SD = 25.61$ ,  $Z = 2.01, p = .044, r = .48$ ), and most shaking and banging either object and first fixation of the same object on the next trial ( $M = 41.08\%$ ,  $SD = 22.72$ ,  $Z = 2.64, p = .008, r = .62$ ). Specifically regarding the first fixation, Wilcoxon analyses revealed that the match proportions between first fixation of either object and

most look at the same object ( $M = 66.99\%$ ,  $SD = 29.47$ ,  $Z = 2.45$ ,  $p = .014$ ,  $r = .58$ ), first fixation of either object and most contact with the same object ( $M = 59.14$ ,  $SD = 19.17$ ,  $Z = 2.62$ ,  $p = .009$ ,  $r = .62$ ), and first fixation of either object and subsequent first fixation of the same object on the next trial ( $M = 61.37\%$ ,  $SD = 25.27$ ,  $Z = 2.55$ ,  $p = .011$ ,  $r = .60$ ) were all higher than the match proportion between first fixation of either object and most shaking and banging the same object ( $M = 40.23\%$ ,  $SD = 22.68$ ). For the most look match pairs, Wilcoxon analyses revealed that the match proportion between most look at either object and first fixation of the same object on the next trial ( $M = 58.56\%$ ,  $SD = 26.57$ ) was higher than the match proportions between most look at either object and first contact of the same object ( $M = 39.87\%$ ,  $SD = 23.59$ ,  $Z = 2.49$ ,  $p = .013$ ,  $r = .59$ ) or most look at either object and most shaking and banging the same object ( $M = 35.77\%$ ,  $SD = 21.80$ ,  $Z = 2.58$ ,  $p = .010$ ,  $r = .61$ ). The match proportion between most look at either object and subsequent most look at the same object on the next trial ( $M = 82.99\%$ ,  $SD = 20.72$ ) was higher than the match proportion between most look at either object and any other variable (ML – FC  $M = 39.87\%$ ,  $SD = 23.59$ ,  $Z = 3.68$ ,  $p < .0001$ ,  $r = .87$ ; ML – MC  $M = 50.53\%$ ,  $SD = 23.20$ ,  $Z = 3.34$ ,  $p = .001$ ,  $r = .79$ ; ML – MS  $M = 35.77\%$ ,  $SD = 21.80$ ,  $Z = 3.68$ ,  $p < .0001$ ,  $r = .87$ ; ML – FF<sub>n</sub>  $M = 58.56\%$ ,  $SD = 26.57$ ,  $Z = 3.13$ ,  $p = .002$ ,  $r = .74$ ). Lastly, the match proportion between most look at either object and most contact of the same object ( $M = 50.53\%$ ,  $SD = 23.20$ ) was higher than the match proportion between most look at either object and most shaking and banging the same object ( $M = 35.77$ ,  $SD = 21.80$ ,  $Z = 1.98$ ,  $p = .048$ ,  $r = .47$ ). Regarding the first contact, Wilcoxon analyses revealed that the match proportions between first contact of either object and most contacted of the same object ( $M = 63.82\%$ ,  $SD = 18.39$ ) was higher than the match proportions between first contact of either object and any other variable (FC – MS  $M = 37.52\%$ ,  $SD = 18.79$ ,  $Z = 3.24$ ,  $p = .001$ ,  $r = .76$ ; FC – FF<sub>n</sub>  $M = 46.16$ ,  $SD$

= 21.54,  $Z = 2.53$ ,  $p = .012$ ,  $r = .60$ ; FC – ML<sub>n</sub>  $M = 40.04$ ,  $SD = 18.99$ ,  $Z = 3.29$ ,  $p = .001$ ,  $r = .78$ ; FC – FC<sub>n</sub>  $M = 49.72$ ,  $SD = 21.78$ ,  $Z = 2.08$ ,  $p = .037$ ,  $r = .49$ ).

For the generalization phase trials, Friedman analyses on the groupings of match pairs revealed a significant difference among the perception-action sequence match pairs ( $\chi^2 = 20.40$ ,  $p < .0001$ ), the first fixation match pairs ( $\chi^2 = 21.26$ ,  $p < .0001$ ), most look match pairs ( $\chi^2 = 24.64$ ,  $p < .0001$ ), most contact match pairs ( $\chi^2 = 17.13$ ,  $p = .002$ ), and most shaking and banging match pairs ( $\chi^2 = 11.17$ ,  $p = .025$ ; see Figure 31). Across the sequence of behaviors in the perception-action loop, Wilcoxon analyses revealed that the proportions of matching between first fixation of either object and most look at the same object ( $M = 67.94\%$ ,  $SD = 22.34$ ), most look at either object and first contact of either object ( $M = 58.04\%$ ,  $SD = 16.33$ ), and first contact of either object and most contact of the same object ( $M = 59.80\%$ ,  $SD = 30.08$ ) were all higher than the match proportions between most contact of either object and most shaking and banging the same object ( $M = 37.25\%$ ,  $SD = 28.58$ ; FF – ML  $Z = 3.10$ ,  $p = .002$ ,  $r = .75$ ; ML – FC  $Z = 2.37$ ,  $p = .018$ ,  $r = .57$ ; FC – MC  $Z = 2.14$ ,  $p = .032$ ,  $r = .52$ ) and most shaking and banging either object and first fixation of the same object on the next trial ( $M = 29.71\%$ ,  $SD = 17.63$ ; FF – ML  $Z = 3.31$ ,  $p = .001$ ,  $r = .80$ ; ML – FC  $Z = 3.083$ ,  $p = .002$ ,  $r = .75$ ; FC – MC  $Z = 2.30$ ,  $p = .021$ ,  $r = .56$ ). Specifically regarding the first fixation, Wilcoxon analyses revealed that the match proportion between first fixation of either object and most look at the same object ( $M = 67.94\%$ ,  $SD = 22.34$ ) was higher than the match proportions between first fixation of either object and most contact of the same object ( $M = 51.86\%$ ,  $SD = 22.58$ ,  $Z = 2.20$ ,  $p = .028$ ,  $r = .53$ ), first fixation of either object and most shaking and banging the same object ( $M = 30.20\%$ ,  $SD = 26.26$ ,  $Z = 3.46$ ,  $p = .001$ ,  $r = .84$ ), and marginally first fixation of either object and subsequent first fixation of the same object on the next trial ( $M = 50.10$ ,  $SD = 28.37$ ,  $Z = 1.92$ ,  $p = .011$ ,  $r =$

.47). The match proportions between first fixation of either object and subsequent first fixation of the same object ( $M = 50.10\%$ ,  $SD = 28.37$ ,  $Z = 2.25$ ,  $p = .025$ ,  $r = .55$ ), first fixation of either object and first contact of the same object ( $M = 53.82$ ,  $SD = 25.07$ ,  $Z = 2.99$ ,  $p = .003$ ,  $r = .73$ ), and first fixation of either object and most contact of the same object ( $M = 51.86\%$ ,  $SD = 22.58$ ,  $Z = 2.53$ ,  $p = .011$ ,  $r = .62$ ) were all higher than the match proportion between first fixation of either object and most shaking and banging the same object ( $M = 30.20\%$ ,  $SD = 26.26$ ).

Wilcoxon analyses on the most look match pairs revealed that the match proportion between most look at either object and subsequent most look at the same object ( $M = 71.76\%$ ,  $SD = 25.74$ ) was higher than the match proportions between most look at either object and most shaking and banging the same object ( $M = 24.12\%$ ,  $SD = 26.91$ ,  $Z = 3.24$ ,  $p = .001$ ,  $r = .79$ ) and most look at either object and first fixation of the same object on the next trial ( $M = 47.45\%$ ,  $SD = 31.77$ ,  $Z = 2.81$ ,  $p = .005$ ,  $r = .68$ ). The match proportions between most look at either object and first fixation of the same object ( $M = 47.45\%$ ,  $SD = 31.77$ ,  $Z = 2.42$ ,  $p = .016$ ,  $r = .66$ ), most look at either object and first contact of the same object ( $M = 58.04\%$ ,  $SD = 16.33$ ,  $Z = 3.21$ ,  $p = .001$ ,  $r = .78$ ), and most look at either object and most contact of the same object ( $M = 59.61\%$ ,  $SD = 17.63$ ,  $Z = 3.36$ ,  $p = .001$ ,  $r = .81$ ) were all higher than the match proportion between most look at either object and most shaking and banging the same object ( $M = 24.12$ ,  $SD = 26.91$ ). The match proportion between most contact of either object and most look at the same object ( $M = 57.35\%$ ,  $SD = 33.45$ ) was higher than the match proportions between most contact of either object and most shaking and banging the same object ( $M = 37.25\%$ ,  $SD = 28.58$ ,  $Z = 2.16$ ,  $p = .031$ ,  $r = .52$ ) and most contact of either object and subsequent most contact of the same object on the next trial ( $M = 34.12\%$ ,  $SD = 22.10$ ,  $Z = 2.84$ ,  $p = .005$ ,  $r = .69$ ). The match proportion between most contact of either object and first contact of the same object on the next trial ( $M =$

54.71%,  $SD = 22.10$ ) was also higher than the match proportion between most contact of either object and most shaking and banging the same object ( $M = 37.25\%$ ,  $SD = 28.59$ ,  $Z = 1.96$ ,  $p = .046$ ,  $r = .48$ ). Additionally, the match proportion between most contact of either object and first fixation of the same object on the next trial ( $M = 50.88\%$ ,  $SD = 31.24$ ) was marginally higher than the match proportion between most contact of either object and subsequent most contact of the same object on the next trial ( $M = 34.12$ ,  $SD = 22.10$ ,  $Z = 1.92$ ,  $p = .055$ ,  $r = .47$ ). Lastly, the match proportion between most shaking and banging either object and first fixation of the same object on the next trial ( $M = 29.71\%$ ,  $SD = 17.63$ ) was higher than the match proportion between most shaking and banging either object and most shaking or banging the same object on the next trial ( $M = 16.47\%$ ,  $SD = 16.18$ ,  $Z = 2.84$ ,  $p = .004$ ,  $r = .69$ ).

Wilcoxon comparisons for all match pairings between discovery and generalization phase trials for either object revealed several differences. First, proportions of match pairs between first fixation and most shaking and banging either object (Discovery  $M = 41.62\%$ ,  $SD = 22.58$ ; Generalization  $M = 30.20\%$ ,  $SD = 26.26$ ), first contact and subsequent first contact of either object on the next trial (Discovery  $M = 49.71\%$ ,  $SD = 22.45$ ; Generalization  $M = 37.06\%$ ,  $SD = 20.54$ ), most contact and subsequent most contact of either object on the next trial (Discovery  $M = 54.65\%$ ,  $SD = 14.35$ ; Generalization  $M = 34.12\%$ ,  $SD = 22.10$ ), most shaking and banging and first contact of either object on the next trial (Discovery  $M = 37.97\%$ ,  $SD = 20.64$ ; Generalization  $M = 21.18\%$ ,  $SD = 16.54$ ), most shaking and banging and most contact of either object on the next trial (Discovery  $M = 39.93\%$ ,  $SD = 21.10$ ; Generalization  $M = 24.71\%$ ,  $SD = 22.95$ ), and most shaking and banging and subsequent most shaking and banging either object on the next trial (Discovery  $M = 38.01\%$ ,  $SD = 18.16$ ; Generalization  $M = 16.47\%$ ,  $SD = 16.18$ ) were all higher during discovery phase trials than during generalization phase trials. Second, proportions

of match pairs between most look and first contact were higher during generalization phase trials ( $M = 58.04\%$ ,  $SD = 16.33$ ) than during the discovery phase ( $M = 41.24\%$ ,  $SD = 23.57$ ).

In sum, when regarding match pairs with either object, as in study 1, visual types of object exploration were more related to subsequent visual exploration and manual types of object exploration were more related to subsequent manual exploration (for summary, see Figure 32).

## 6.5 Individual differences

In order to explore individual differences in how infants visually and manually explored the stimulus objects in study 2, cluster analyses were conducted on the data averaged across discovery phase trials including all five dependent variables for both objects, resulting in 10 total variables. Baseline looking trials were not included in this analysis. A 3K-means cluster analysis run on the five dependent variables for the both objects revealed 3 significantly different clusters. These clusters varied by the first fixation ( $F(2, 15) = 14.43$ ,  $p < .0001$ ), accumulated looking ( $F(2, 15) = 11.73$ ,  $p = .001$ ), first contact ( $F(2, 15) = 3.70$ ,  $p = .050$ ), and the accumulated contact of the filled object ( $F(2, 15) = 11.03$ ,  $p = .001$ ), and the first fixation ( $F(2, 15) = 13.86$ ,  $p < .0001$ ), accumulated looking ( $F(2, 15) = 8.66$ ,  $p = .003$ ), and the accumulated contact of the unfilled/detailed object ( $F(2, 15) = 11.49$ ,  $p = .001$ ), which were the variables that showed significance (see Figure 33). Cluster 1 showed a high proportion of first fixation (cluster  $M = 77\%$ ) and accumulated looking at the unfilled/detailed object (cluster  $M = 50\%$ ), and a moderate proportion of first contact (cluster  $M = 64\%$ ) and accumulated contact of the filled object (cluster  $M = 47\%$ ). Cluster 2 showed high proportions of first fixation (cluster  $M = 79\%$ ), accumulated looking (cluster  $M = 61\%$ ), first contact (cluster  $M = 50\%$ ), and accumulated contact (cluster  $M = 90\%$ ) of the unfilled/detailed object. However, this cluster still showed a high proportion of accumulated contact of the filled object (cluster  $M = 88\%$ ), even though proportions were lower

for this object for all other variables (First Fixation cluster  $M = 20\%$ , Accumulated Looking cluster  $M = 18\%$ , First Contact cluster  $M = 35\%$ ). Lastly, cluster 3 showed higher proportions of first fixation (cluster  $M = 63\%$ ), first contact (cluster  $M = 62\%$ ), and accumulated contact of the filled object (cluster  $M = 78\%$ ) than the other clusters, and lower proportions of these variables for the unfilled/detailed object (First Fixation cluster  $M = 37\%$ , Accumulated Looking cluster  $M = 39\%$ , Accumulated Contact cluster  $M = 57\%$ ). This cluster also showed the highest proportion of the three clusters for accumulated looking at the filled object (cluster  $M = 31\%$ ), although this was still a low value.

In sum, infants differed in how they explored and selected the two stimulus objects visually and manually. Some infants were more selective of the unfilled/detailed object both visually and manually, while some infants were more selective of the filled object both visually and manually. Other infants were visually selective of the unfilled/detailed object, but manually selective of the filled object.

## CHAPTER 7: SUMMARY—STUDY 2

Analyses from study 2 showed that infants fixated the unfilled/detailed object first proportionately more often and looked at the unfilled/detailed object proportionately more than the filled object when averaging across discovery phase trials. No differences were found between the proportions of first contact, accumulated contact, or shaking and banging either object. These results suggest that the visual property of the unfilled/detailed object drove infants' looking behavior, but neither the visual nor the auditory-tactile properties influenced infants to differentially manipulate the objects. The same trends were found for these variables for the generalization phase trials. Linear trends were found for looking behavior and manipulation behavior, such that infants decreased both their proportions of looking to the filled object and their proportions of accumulated contact with both objects across discovery phase trials.

The results of the match analyses for study 2 showed that for matches based on the filled object, proportions of matching for any variable pair were never above chance; however, the directions of the trends suggest that looking and manipulation of the filled object were more related to subsequent manipulation of the filled object (first contact, most contact, most shaking/banging) than they were to subsequent looking at the filled object (first fixation, most look). Infants in study 2 had higher proportions of perceptual-motor matching with the unfilled/detailed object, but even still, only some proportions of matching were above chance. The directions of the trends suggest that looking and manipulation of the unfilled/detailed object lead to more looking at the unfilled/detailed object on subsequent trials (first fixation, most look) than they were to subsequent manipulation of the unfilled/detailed object (first contact, most contact, most shaking/banging). These results suggest that the auditory-tactile property influenced higher perceptual-motor integration and object selection during manipulation, and the

visual property influenced higher perceptual-motor integration and object selection during of looking.

When looking at the proportion of perceptual-motor matching for either object, regardless of the auditory-tactile property, proportions of matching were much higher. First fixation of either object was more related to the most look or subsequent first fixation at the same object than it was to most shaking or banging the same object. Most look at either object was more related to subsequent most look at the same object than any other variable. Lastly, first contact of either object was more related to most contact of the same object than any other variable. These results are similar to what was found in study 1, showing that looking behavior is very related to subsequent looking behavior in this task, and first contact and subsequent manipulation behaviors are very related. These findings will be discussed more in detail in the general discussion.

Lastly, cluster analyses revealed three significantly different clusters based on first fixation, accumulated looking, first contact, and proportion of accumulated contact of both objects. Cluster 1 showed high selection of the unfilled/detailed object via looking behaviors, but low looking to the other object, and moderate selection of the filled object via manipulation behaviors, but low manipulation of the other object. Cluster 2 showed high selection of the unfilled/detailed object via both looking and manipulation, but still maintained contact with the filled object a high amount. Cluster 3 showed highest selection of the filled object via looking and manipulation, and low amounts of all behaviors for the other object.

## CHAPTER 8: GENERAL DISCUSSION

Research has shown that infants use feedback produced by perceptual-motor exploration of objects to inform future interactions with those objects and their environments (Gibson, 1988). Studies have also shown that infants can discover a non-obvious property of a single object via manipulation (Baldwin et al., 1993) and that infants manipulate objects differently depending on their perceptual properties (Ruff, 1984; Palmer, 1989; Rochat, 1989; Morgante & Keen 2008). One goal of the current research (study 1) was to investigate how discovery of an auditory-tactile property of one object would influence perceptual-motor exploration between two objects presented at the same time. A second goal of the current research (study 2) was to investigate how this motor discovery would impact perceptual-motor exploration of both objects when the object without the auditory-tactile property had a competing visual property. These research questions were tested in two separate studies where infants were presented with the set of objects both out of reach and within reach over several trials in order to give them opportunities to explore the objects both visually and manually. In the first study both objects were visually similar except for color, but one object had an auditory-tactile property that could only be discovered via manipulation. In the second study, the object without the auditory-tactile property had visual details.

### **8.1 Role of competing perceptual properties on exploration and selection of objects**

Results showed that in both studies infants explored the objects differently, but this depended on the object properties. In study 1, infants discovered the auditory-tactile property by shaking and banging the filled object more than the unfilled object, but did not explore the objects differently in terms of looking behavior, reaching, or the amount of time they spent contacting the objects. In study 2, infants' visual attention was drawn to the unfilled/detailed

object as shown by more first fixations and accumulated looking to that object, but infants did not explore the objects differently based on reaching or manipulation behaviors. These findings are somewhat consistent with results from prior studies. It seems that infants were able to discover the auditory-tactile property even when presented with two objects, but only when there was not competing visual information. This extends Baldwin et al.'s (1993) finding that infants could discover a non-obvious object property via manipulation when the object was presented in isolation. This also confirms the initial prediction that infants would discover the auditory-tactile property of one object when presented with two objects. However, the prediction that this discovery would encourage subsequent visual and manual selection of that object was not confirmed. Furthermore, it seems that when the other object presented has a competing visual property, the salience of that property overrides discovery of the auditory-tactile property. Regardless of whether infants discovered the property in study 2, which was not clear from the analyses presented here, they did not reach for or manipulate the objects differently. This finding disconfirms the prediction that discovery of the auditory-tactile property would override the effect of the visual saliency in terms of subsequent object exploration and selection, but it confirms the prediction that the salience of the visual detail would drive selection of that object.

There are several possible explanations for these differences in behavior between the two studies. First consistent with other studies, the salient visual detail drew more visual attention (Fantz & Fagan, 1975; Ruff & Turkewitz, 1975, 1979; Kidd, Piantadosi, Aslin, 2012; Guan, 2013), whereas when the visual information was similar, there were no differences in visual behavior. This pull of the salient visual property may have made distinguishing the two objects based on a non-visual property more difficult for infants in the second study. The main research question of the second study was whether discovery of the auditory-tactile property would

override the salience of the competing visual property; however, it seems that, in the second study, the salience of the visual detail dominated over discovery of the auditory-tactile property.

Additionally, infants in both studies had a tendency to reach for and maintain contact with both objects and in study 2, infants did shake and bang the objects, they just did so with both objects the same amount. Perhaps, if infants shook and banged both objects, they did produce the auditory-tactile effect, but either could not tell which of the two objects produced the effect, or it did not matter to them which object was producing the effect because the fact that it was happening alone encouraged them to continue the behaviors with both objects. In either case, the infants likely received both auditory and tactile feedback but did not associate the feedback with either stimulus in particular. Several researchers have argued that object selection is not just dependent on producing feedback, but to attending to the feedback and actively making the association between the feedback and the stimulus. Gibson (1988) described this in terms of infants observing the consequences of their actions. The Angulo-Kinzler (2001) mobile study was a prime example of infants doing this and incorporating their observations into their behavior by adjusting their leg angle to make the mobile move. Other researchers have described focused attention versus casual attention, where infants in focused attention intently look at and examine an object while they are manipulating it, compared to casually attending to the object but not really focusing on it while manipulating it (Ruff, 1986; Lansink & Richards, 1997). Studies have shown that infants are able to pick up more information about object properties when they manipulate objects in focused attention versus casual attention (Ruff, 1982). Based on the current findings from study 2, infants may have been manipulating both objects but not actually attending to the auditory-tactile feedback as being associated with one object over the other. Additionally, it is possible that the intersensory redundancy provided by producing the

auditory-tactile effect recruited the infants' attention to that property, but reduced attention to the modality-specific property of the object's information. The task required that the infants associate the object's color with the auditory-tactile property in order to select that object on subsequent trials, but the competition between those properties may have inhibited attention to both at the same time (Bahrick et al., 2004; Bahrick & Lickliter, 2002, 2012). Motor constraints may have also played a role in the lack of differential reaching and manipulation of objects in study 2. Studies have shown that infants have trouble inhibiting certain preferred motor responses, particularly between the ages of 7 and 12 months, which is the period when reaching becomes proficient and independent locomotion begins (Smith et al., 1999). Motor constraints were described as inhibiting flexible motor behavior in both the A-not-B-task (Smith et al., 1999) and in a task that required switching between unimanual and bimanual reaching to accommodate object size (Corbetta et al., 2000). Perhaps in the current study, reaching for and manipulating both objects was a reflexive-like behavior for infants, and developmental constraints inhibited motor flexibility to interact with the objects differentially based on their perceptual properties.

In the real world, we know that infants are ultimately able to associate perceptual-motor feedback of their actions with stimulus properties to learn about the world around them, and that the natural environment is cluttered with a plethora of objects with competing perceptual information. The current study does not entirely explain how infants are able to make these associations in a naturalistic setting, but the findings do suggest that non-obvious properties are more easily learned when there is no competing information, while when there is competing information, the visual information predominates.

## **8.2 (Lack of) integration between perception and action during the exploration of objects**

In terms of perception-action matching, results from both studies showed that when exploring two objects, 11-month-old infants were more likely to show matching within sensory modalities rather than between sensory modalities (see Figure 34). Specifically in study 2, perception-action matching occurred more with reaching and manipulation behaviors for the filled object and more with looking behaviors for the unfilled/detailed object (see Figure 35). These findings only partially supported the prediction that looking, reaching, and manipulation behaviors would be related across trials and suggest that at 11 months there is a disconnection between visual and manual modalities of object exploration and selection and that at this age, the two perceptual systems are still coordinating.

These findings are consistent with other studies that have shown that 8- to 9-month-old infants had trouble integrating visual and haptic information to adapt their reaching styles to objects of different sizes across trials (Corbetta et al., 2000; Corbetta & Snapp-Childs, 2009). Specifically, Corbetta and Snapp-Childs (2009) argued that perception and action are in competition when reaching, grasping, and manipulating objects while attempting to simultaneously perceive the object's physical properties. These authors cited other studies that showed that looking at objects while manipulating them inhibited infants' recognition memory (Gottfried, Rose, & Bridger, 1978; Rose, Gottfried, Bridger, 1979). Taking these explanations together, it is possible that in the current studies, when infants engaged in both visual and manual exploration of the objects, competition between the two perceptual modalities inhibited any integration between behaviors. Corbetta and Snapp-Childs (2009) argued that 8 to 9 months of age was a transitional age, where infants were starting to integrate visual and haptic information into their action plans with one object. The findings from the current studies would suggest that

even at 11 months, infants are still not able to integrate visual and haptic exploration very well, at least not when exploring two objects at a time.

Studies investigating cross-modal transfer (also called cross-modal matching) have noted discrepancies between visual and tactile modes of object exploration as well (Rose, Gottfried, & Bridger, 1981; Wagner & Sakovits, 1986; Rose & Orlian, 1991), particularly throughout the first year of infancy. In cross-modal transfer tasks, infants are familiarized with an object in one modality only (usually visual or tactile) and tested for object discrimination/recognition in the other modality. Object recognition is typically determined by seeing if infants have a preference for either the novel or familiar object, presented simultaneously. Typically, a novelty preference is said to be indicative of object recognition; however, some researchers have argued that a preference for the familiar object is also evidence of recognition (Wagner & Sakovits, 1986). Several of these types of studies have found that infants show more object recognition with intra-modal transfer tasks, specifically visual-visual transfer than they do with cross-modal transfer tasks (Rose, et al., 1981; Wagner & Sakovits, 1986; Rose & Orlian, 1991); however, within cross-modal transfer, infants are better able to discriminate between the two objects with tactile-visual transfer than they are with visual-tactile transfer. Familiarization time is said to play a role in this discrepancy, as infants are quicker to encode visual information and need more time to process information tactually. For instance, Wagner and Sakovits (1986) showed that infants were quicker to reach a novelty preference with visual exploration than they were with tactile exploration. Additionally, Rose and Orlian (1991) argued that visual and tactile modes of exploration may attune infants to different characteristics of an object, which, without overlapping exploration in both modalities, as in the transfer tasks, could result in the differences seen in the difficulty with different types of transfer. In relation to the current studies, infants

were able to explore the objects visually during tactile exploration, which would presumably make perceptual integration more efficient; however, the auditory-tactile property was such that it could not be discovered or identified visually, and the visual properties of color and detail could not be identified tactually. These characteristics could have made perceptual integration and subsequent selection more difficult because an additional process of association of the properties needed to take place.

Another factor that seemed to be involved in determining which behaviors of object exploration were related was the perceptual property of the objects. This finding suggests that bottom-up processing may have played a role in the infants' perceptual-motor exploration of the objects. In bottom-up processing, the sensory input from the environment—in this case, the object properties—drives the perception of the stimulus. The fact that there were different proportions of perception-action matching in study 2 depending on which object was being considered suggests that bottom-up processing may have been driving the relationships.

What does this disconnect between visual and manual exploration of objects mean for the development and integration of these systems? One study with adult humans showed that haptic exploration of 3-dimensional objects activated visual areas of the brain, such as the lateral occipitotemporal complex (specifically middle and lateral occipital areas) known to be associated with visual processing of objects in addition to motor areas of the brain, such as the somatosensory cortex (James, Humphrey, Gati, Servos, Menon, & Goodale, 2002). Additionally, when participants only looked at the objects after having previously manipulated them, activation of visual brain areas was enhanced. A different study with primates also showed activation of both motor and visual brain areas (also the somatosensory and lateral occipitotemporal cortices) during perception of objects with properties that can be both visually

and haptically perceived, such as texture (Armedi, Malach, Hendler, Peled, & Zohary, 2001). Taken together, these studies show that by adulthood in humans, as well as primates, there is great synergy between neural pathways relating to visual and motor exploration and selection of 3-dimensional objects. Less is known about the relationship between these neural pathways in human infants due to the limitations regarding brain imaging with that population. However, given that studies with adults show so much synergy between visual and motor brain areas (James et al., 2002), it can be assumed that the neural mechanisms between perceptual modalities of object exploration coordinate sometime between 11 months and adulthood, and presumably, this integration occurs much earlier during development than adulthood. There remain gaps in the research in terms of when this integration takes place and if activity of the neural mechanisms actually relate to the behavioral integration of the systems, as is being assumed here. One way to address this gap would be to conduct the same experiments described in this dissertation with increasingly older ages to see when the disconnection between visual and manual exploration vanishes and those separate behaviors become predictive of each other. Additionally, perhaps safer brain mapping methods such as EEG or fNIRS could be used to measure brain activity during perceptual-motor exploration of objects in infants.

### **8.3 Individual differences in perceptual-motor exploration of objects**

Individual differences found in terms of how infants explored and selected the objects in both studies also provide insight into the development and integration of visual and manual systems of behavior. In study 1, infants largely differed in terms of whether they selected the filled object more visually or manually. In study 2, some infants selected the filled object both visually and manually, some infants selected the unfilled/detailed object both visually and manually, but some infants selected the unfilled/detailed object visually and the filled object

manually. These findings suggest that infants may rely on the two sensory systems in different ways to explore objects and extract information about the objects' properties. If this is true, it would indicate that the development of integration of visual and manual systems may happen uniquely for each infant instead of coordinating in one universal way. Presumably, the history of individual experiences of each infant would play a role in how the systems merge and integrate. Of course, context would also matter—there may be contexts where the systems show better integration, but in the particular tasks of the current studies the integration was not exhibited.

#### **8.4 Generalization of object selection based on object properties**

In both studies, the generalization phase trials were used as an exploratory measure to see whether infants would generalize their object selection from the discovery phase when presented with objects of novel shapes. In both studies, infants seemed to show the same differences in how they explored the objects between discovery and generalization phases, but in study 1 this was particularly based on discovery of the auditory-tactile property. Results from study 1 showed that infants shook and banged the filled object more than the unfilled object both during the discovery phase and the generalization phase. This finding would suggest that infants discovered the auditory-tactile property during the discovery phase and generalized selection of that object by shaking and banging during the generalization phase. Additional analyses also showed that infants shook and banged the unfilled object less between discovery and generalization phases, providing even more evidence that infants were more selective of the filled object during generalization. Furthermore, results showed that infants were in contact with the filled object more than the unfilled object during the generalization phase but not during the discovery phase, which shows that infants were more selective of the filled object based on this variable during generalization than they were during the discovery phase.

In the second study, infants did exhibit the same differential exploration and selection of the objects between the discovery and generalization phases, but this was not based on discovery of the auditory-tactile property. In both phases of the study, infants did not show differences in terms of first contact, accumulated contact, or shaking and banging the objects. They did, however, show higher proportions of first fixations and accumulated looking to the unfilled/detailed object than the filled object in both phases of the study. This finding probably has more to do with the strong effect of the salient visual detail than it does generalization of a learned association. As mentioned, many studies have shown that infants have preferences for looking at visual details (Fantz & Fagan, 1975; Ruff & Turkewitz, 1975, 1979; Kidd, Piantadosi, Aslin, 2012; Guan, 2013), and it seems that this property of the unfilled/detailed object dominated the infants' exploratory behavior regardless of the objects' shapes. These findings partially support the initial prediction that if infants discovered the auditory-tactile property and selected that object across trials, they would generalize that selection with novel shapes, in that generalization of selection was only shown in study 1 where there was evidence of discovery of the auditory-tactile property. It was expected that selection during the discovery phase would be represented in all dependent variables and that in turn generalization would appear in all variables. This part of the prediction was not confirmed because generalization in study 1 was only shown with accumulated contact and shaking and banging behaviors, and not for first contact or either of the looking variables. However, this mirrors the lack of differences found for those behaviors during the discovery phase as well.

There were some limitations to the generalization phases of the studies that constrain the analyses and interpretation of those trials. First, only two trials were collected per object shape, which precluded me from looking for effects specifically based on object shape. Additionally,

some infants did not complete all generalization trials, which resulted in a lot of missing data for analyses of those trials. Lastly, I did not specifically establish whether individual infants had discovered the auditory-tactile property of the filled object during the discovery phase before analyzing the generalization trials. It is possible that some infants may have only discovered the auditory-tactile property during the generalization phase trials, and this may have impacted the group effect. The different object shapes consisted of very different volumes, resulting in slightly different auditory-tactile effects when the objects were manipulated. Thus, for infants who did not discover the auditory-tactile property with the eggs, they may have only discovered the property when manipulating the other-shaped objects. One way to address this in an analysis would be to code when, across all trials, infants began shaking or banging the filled object, and look at the quantity of these behaviors between discovery and generalization phase trials.

### **8.5 Limitations and future directions**

There were some additional limitations to the current studies, which could be addressed with subsequent analyses or additional studies. First, visual attention could not be measured with the eye-tracker while the objects were in reach, but it would be interesting to know whether infants were looking at the objects or not while manipulating them, as a measure of focused attention. Additional coding could be done using the video recordings to assess when infants were looking at the objects while manipulating them versus when infants were looking away from the objects while manipulating them.

Second, while it was noted anecdotally that infants often reached for and manipulated both objects at the same time, this was not systematically measured. Additional coding could be done to assess when infants were in contact with both objects at a time versus only one object at a time. The type of contact could also be coded to determine how the objects were being

manipulated while infants were in contact with them. These measures could reveal individual differences that may have impacted whether infants discovered the auditory-tactile property or not.

A third limitation was that there may have been differences in the infants' grasping abilities, which may have affected whether they discovered the auditory-tactile property or not. Additionally, the egg objects tended to roll away if they were not grasped completely, which may have made the task more difficult. Additional coding could be done to categorize the infants based on the efficiency of their grasps and number of attempts to successfully grasp the objects. One could predict that infants who are efficient at grasping may be more likely to discover and show selection based on the auditory-tactile property because infants who are less efficient at grasping may have had to devote more attention to picking up the objects and less attention to the objects' perceptual properties. Additionally, kinematic data were collected but not analyzed; these data could provide additional information about individual differences in how infants reached for, grasped, and manipulated the objects.

Lastly, the data collected for both studies was limited to only one age. As mentioned, 11 months seems to still be a transitional age for the task presented in the current research. It would be interesting to test increasingly older ages in the same task to see when object selection based on discovery of the auditory-tactile property becomes more robust. Additionally, perhaps manipulating different perceptual properties of the objects than what were manipulated in these studies, or making the auditory-tactile property more salient would provide further insight into how infants parse and select relevant and interesting perceptual information when presented with more than one object.

## **8.6 Concluding remarks**

In sum, the current research shows that at 11 months, integration of perceptual and motor exploration and selection, particularly when exploring two objects, is still developing. Between the two studies presented here, infants were able to discover an auditory-tactile property of one of the objects, but only when there was not a competing visual property. When there was competition of visual details, infants looked more at that object and did not differentially reach for or manipulate the objects. The findings from both studies also show that the systems for visual and manual exploration of objects are still not entirely coordinated at 11 months. The current research adds to the existing literature on the relationship between perceptual and motor behaviors in terms of object exploration and selection, but future research will need to be done to further determine when infants are beyond the transitional age for differentiating perceptual properties between more than one object, and when such differentiation begins to impact object selection.

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## APPENDIX

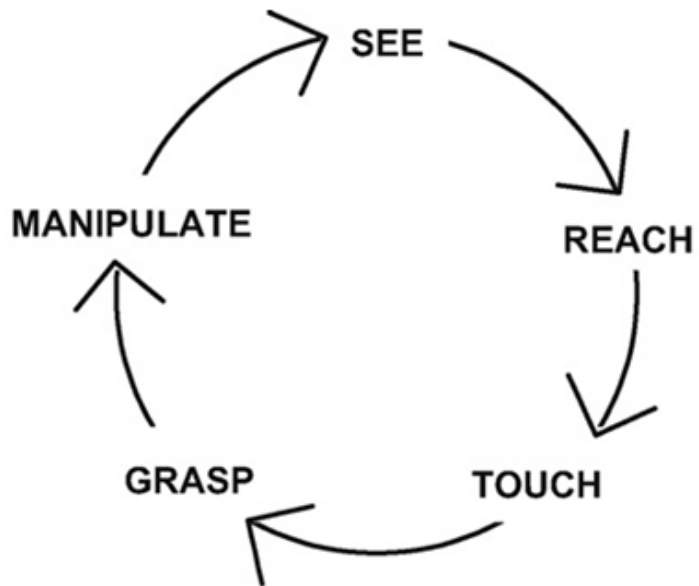


*Figure 1.* Exploration loop, adapted from Corbetta & Snapp-Childs (2009).

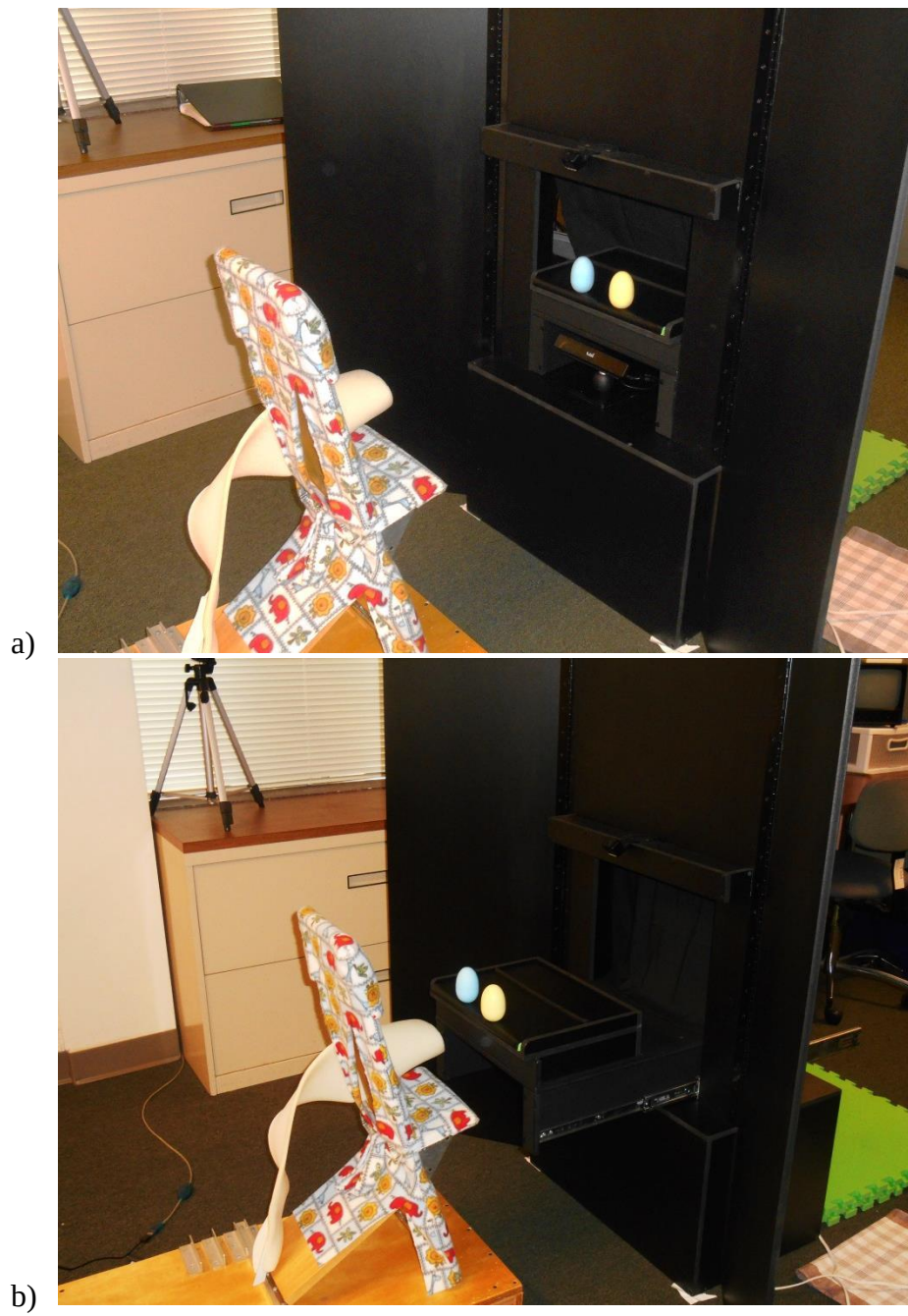


*Figure 2. Experimental set-up: a) tray pulled back, b) tray pushed forward.*



*Figure 3.* Study 1 stimulus objects. From left to right: eggs, dolls, circles, squares.

Table 1.

Study 1 stimulus object weights in grams.

| Study 1 Stimulus Object Weights (g) |               |                 |           |             |            |              |
|-------------------------------------|---------------|-----------------|-----------|-------------|------------|--------------|
| Color/Fill                          |               |                 |           |             |            |              |
| Object Type                         | Blue/Unfilled | Yellow/Unfilled | Blue/Rice | Yellow/Rice | Blue/Beans | Yellow/Beans |
| Eggs                                | 27            | 27              | 36        | 35          | 33         | 34           |
| Dolls                               | 33            | 34              | 48        | 46          | 44         | 42           |
| Circles                             | 33            | 29              | 36        | 35          | 38         | 40           |
| Squares                             | 69            | 70              | 89        | 87          | 111        | 112          |

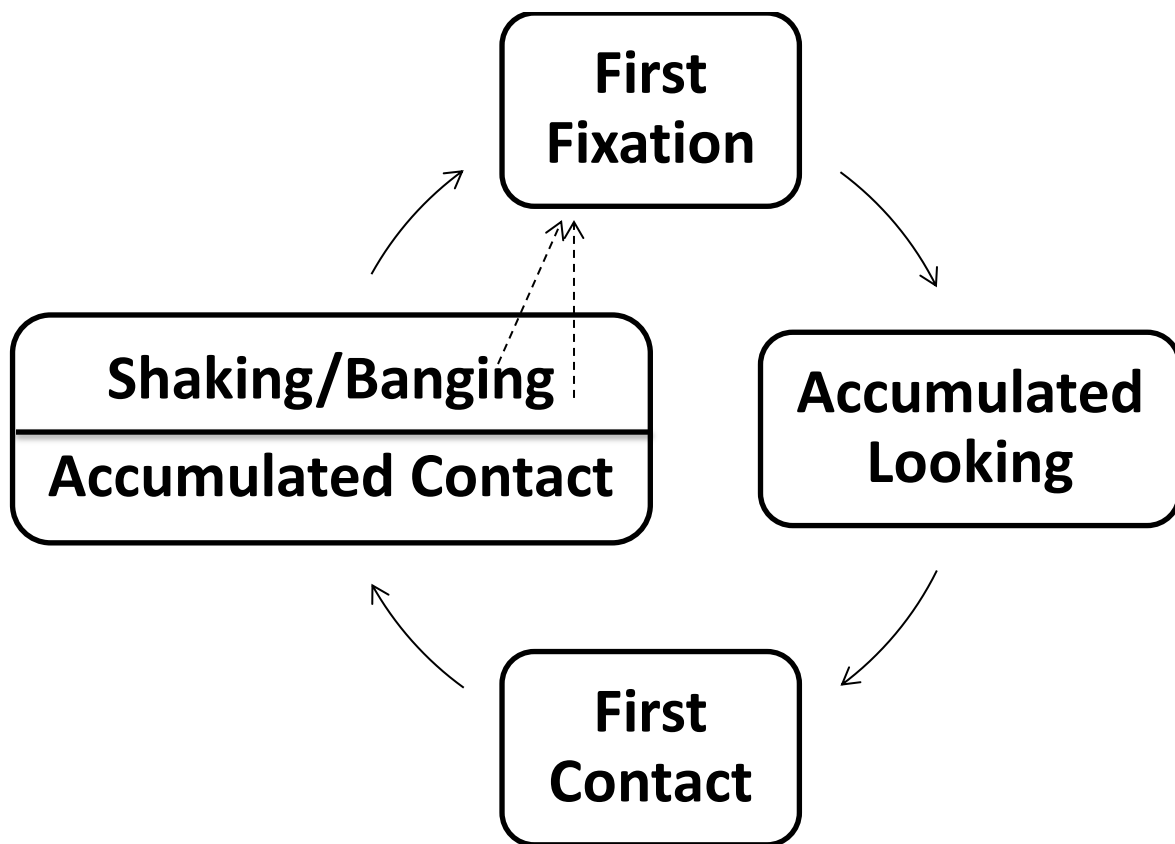


*Figure 4.* Temporal sequence of dependent variables.

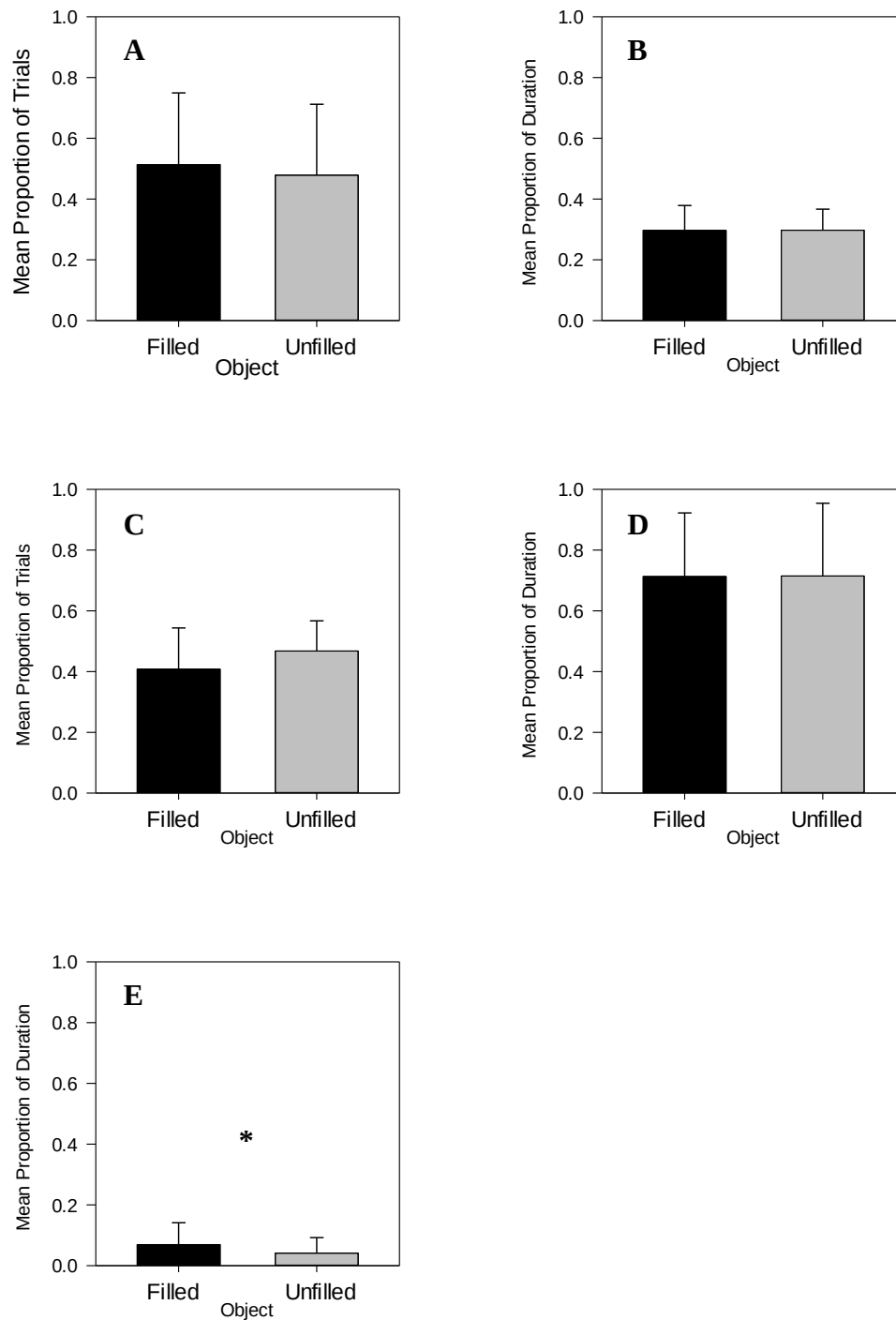


*Figure 5.* Mean proportion of durations and trial number (SD) for the discovery phase trials by object (filled and unfilled): a) first fixation, b) accumulated looking, c) first contact, d) accumulated contact, and e) shaking and banging.

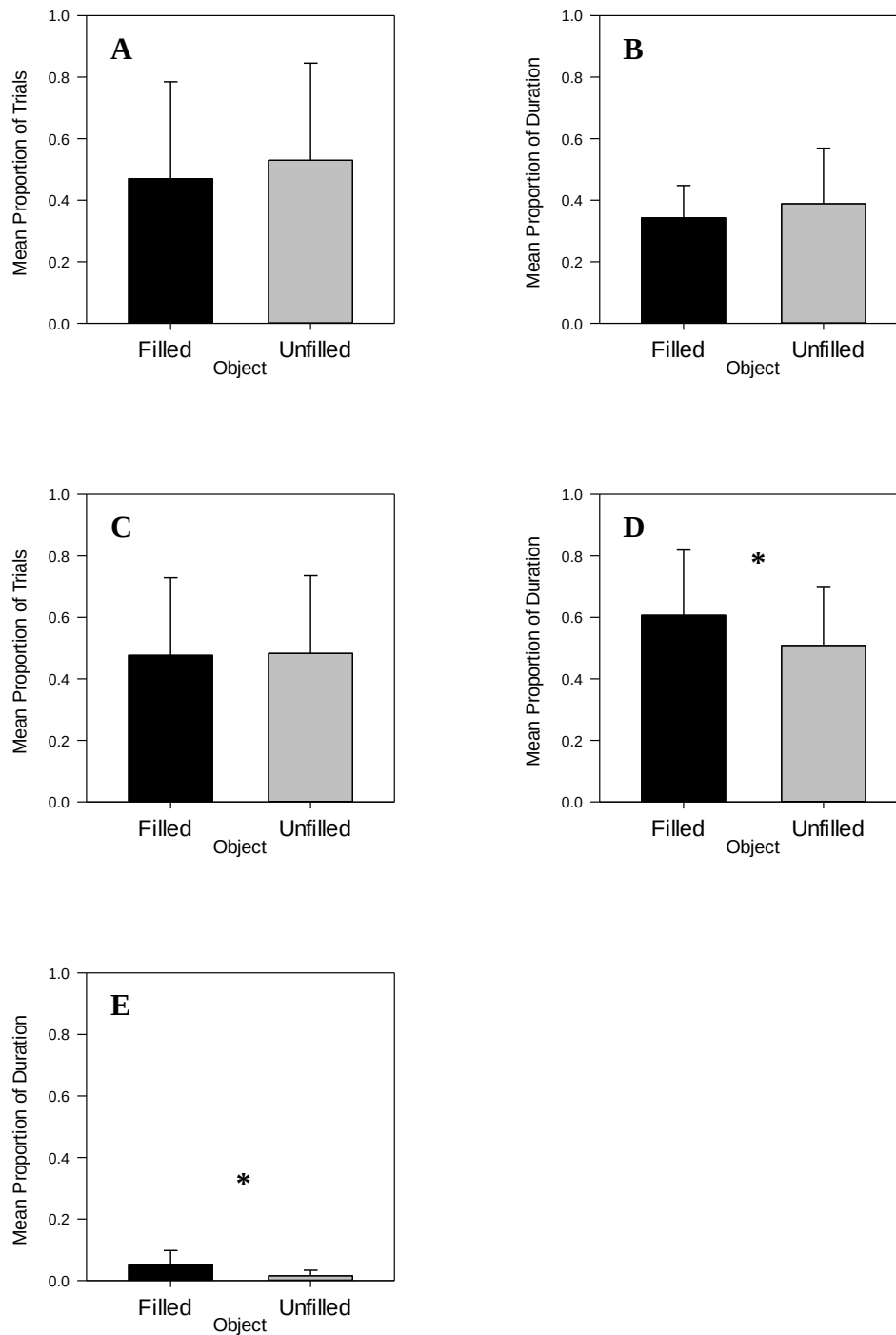


*Figure 6.* Mean proportion of durations and trial number (SD) for the generalization phase trials by object (filled and unfilled): a) first fixation, b) accumulated looking, c) first contact, d) accumulated contact, and e) shaking and banging.

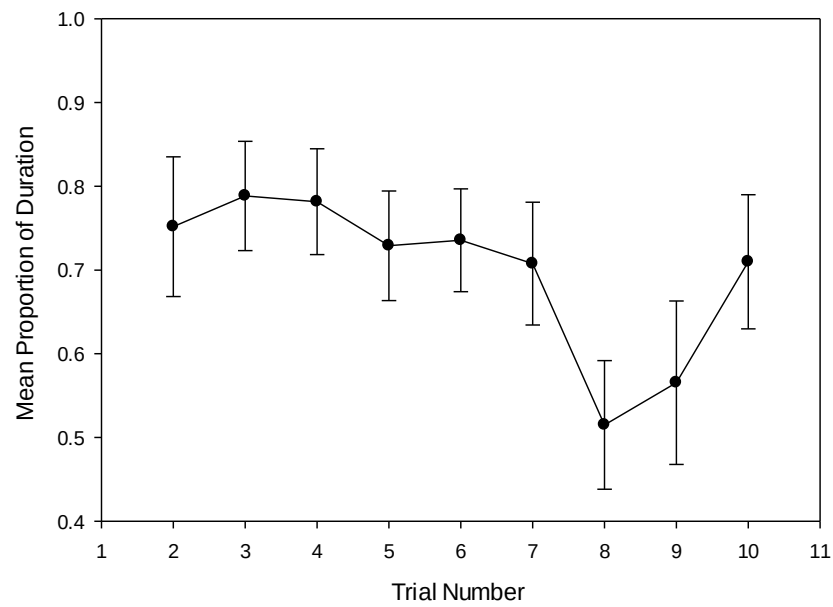


*Figure 7.* Mean proportions of durations (SE) of accumulated contact with the filled object across discovery phase trials.

Table 2.

Variable match pairs and labels.

| <b>First Fixation (FF) Match Pairs</b>           |                      |
|--------------------------------------------------|----------------------|
| First Fixation – Most Look                       | FF – ML              |
| First Fixation – First Contact                   | FF – FC              |
| First Fixation – Most Contact                    | FF – ML              |
| First Fixation – Most Shake/Bang                 | FF – MS              |
| First Fixation – next First Fixation             | FF – FF <sub>n</sub> |
| <b>Most Look (ML) Match Pairs</b>                |                      |
| Most Look – First Contact                        | ML – FC              |
| Most Look – Most Contact                         | ML – MC              |
| Most Look – Most Shake/Bang                      | ML – MS              |
| Most Look – next First Fixation                  | ML – FF <sub>n</sub> |
| Most Look – next Most Look                       | ML – ML <sub>n</sub> |
| <b>First Contact (FC) Match Pairs</b>            |                      |
| First Contact – Most Contact                     | FC – MC              |
| First Contact – Most Shake/Bang                  | FC – MS              |
| First Contact – next First Fixation              | FC – FF <sub>n</sub> |
| First Contact – next Most Look                   | FC – ML <sub>n</sub> |
| First Contact – next First Contact               | FC – FC <sub>n</sub> |
| <b>Most Contact (MC) Match Pairs</b>             |                      |
| Most Contact – Most Shake/Bang                   | MC – MS              |
| Most Contact – next First Fixation               | MC – FF <sub>n</sub> |
| Most Contact – next Most Look                    | MC – ML <sub>n</sub> |
| Most Contact – next First Contact                | MC – FC <sub>n</sub> |
| Most Contact – next Most Contact                 | MC – MC <sub>n</sub> |
| <b>Most Shake/Bang (MS) Match Pairs</b>          |                      |
| Most Shaking/Banging – next First Fixation       | MS – FF <sub>n</sub> |
| Most Shaking/Banging – next Most Look            | MS – ML <sub>n</sub> |
| Most Shaking/Banging – next First Contact        | MS – FC <sub>n</sub> |
| Most Shaking/Banging – next Most Contact         | MS – MC <sub>n</sub> |
| Most Shaking/Banging – next Most Shaking/Banging | MS – MS <sub>n</sub> |

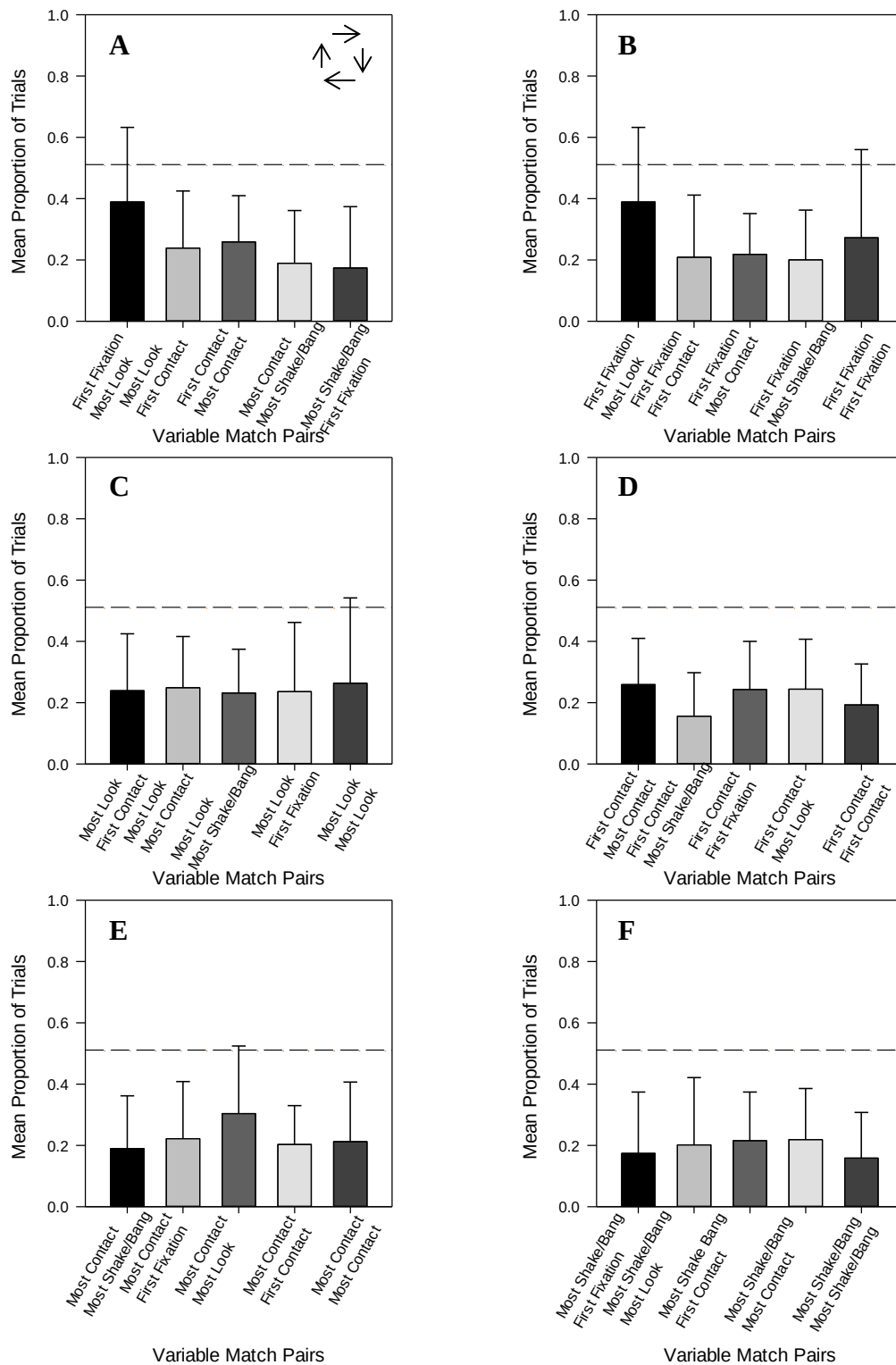


**Figure 8.** Mean proportion of match pairs (SD) on filled object for discovery phase trials: a) perception-action sequence of match pairs, b) first fixation match pairs, c) most look match pairs, d) first contact match pairs, e) most contact match pairs, f) most shake/bang match pairs.

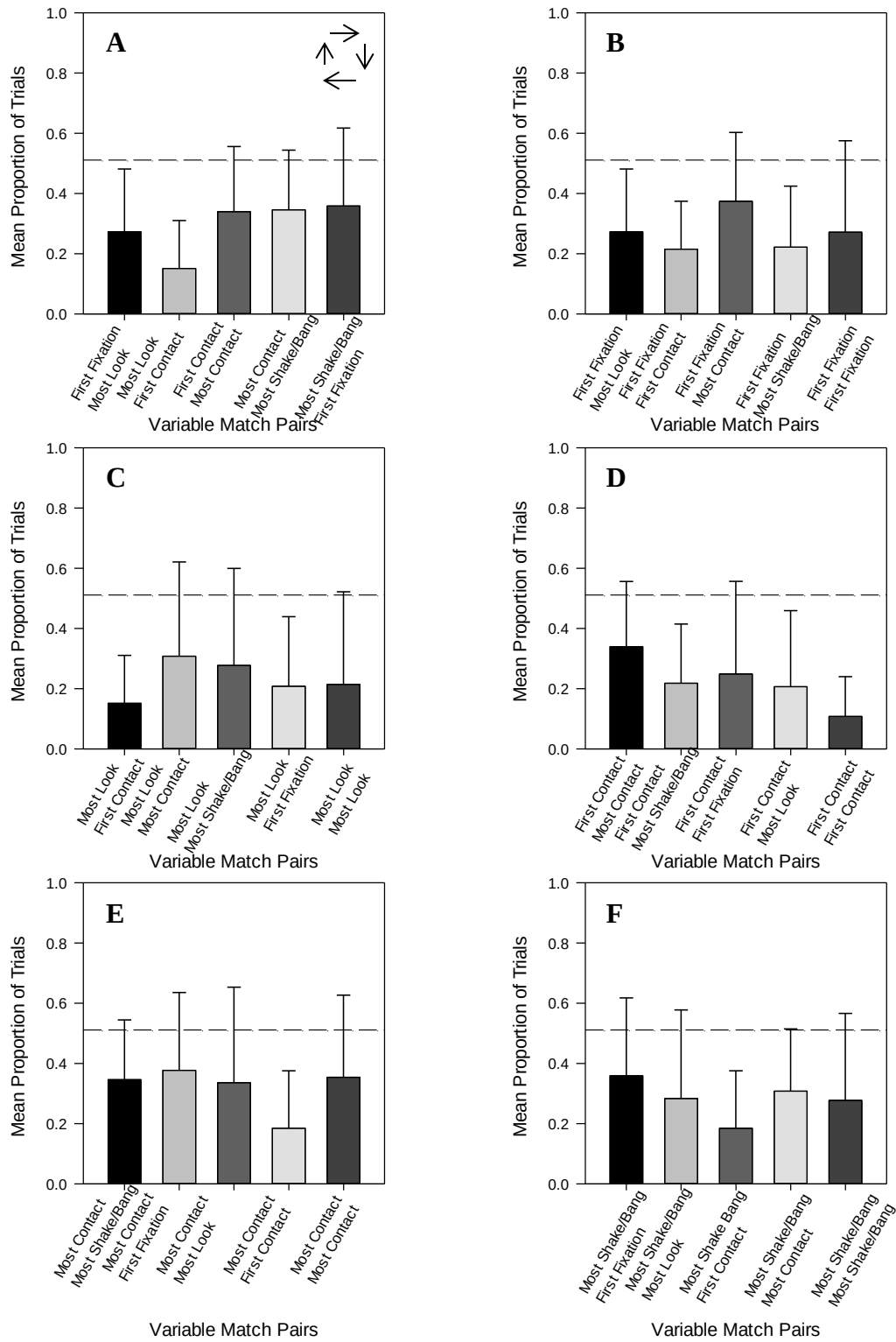


**Figure 9.** Mean proportion of match pairs (SD) on filled object for generalization phase trials: a) perception-action sequence of match pairs, b) first fixation match pairs, c) most look match pairs, d) first contact match pairs, e) most contact match pairs, f) most shake/bang match pairs.

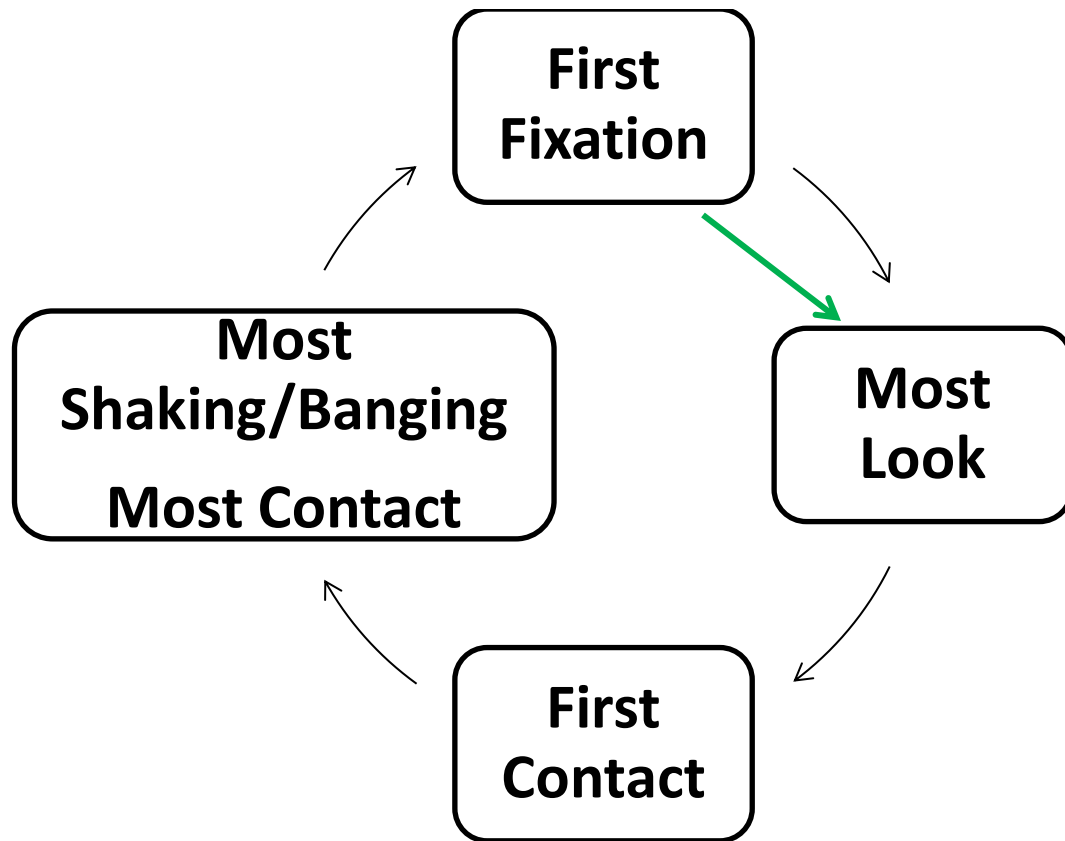


*Figure 10.* Summary of significant match pairs with both objects. Green arrows represent match proportions higher than the other variable pairs.

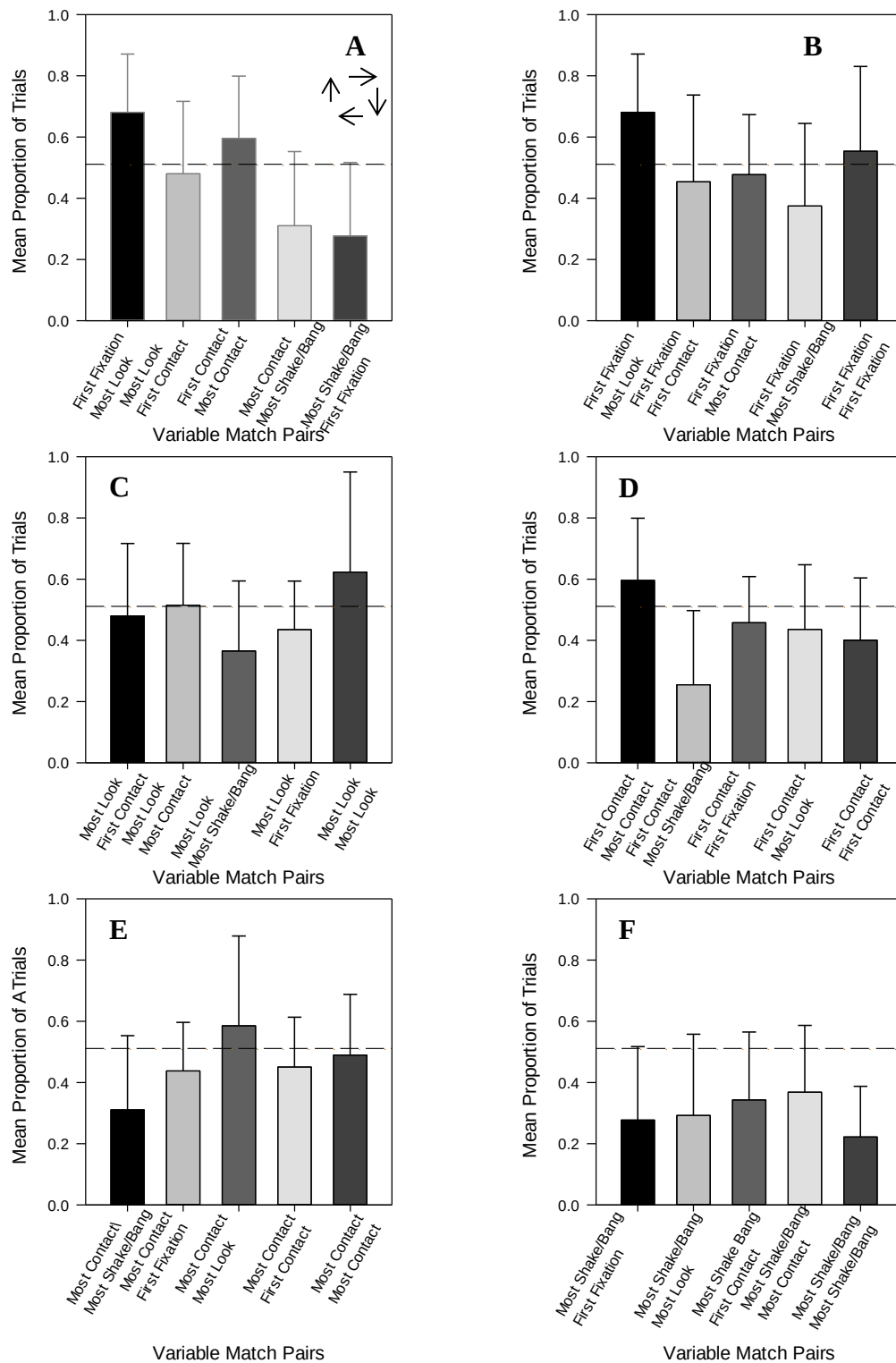


**Figure 11.** Mean proportion of match pairs (SD) on both objects for discovery phase trials: a) perception-action sequence of match pairs, b) first fixation match pairs, c) most look match pairs, d) first contact match pairs, e) most contact match pairs, f) most shake/bang match pairs.

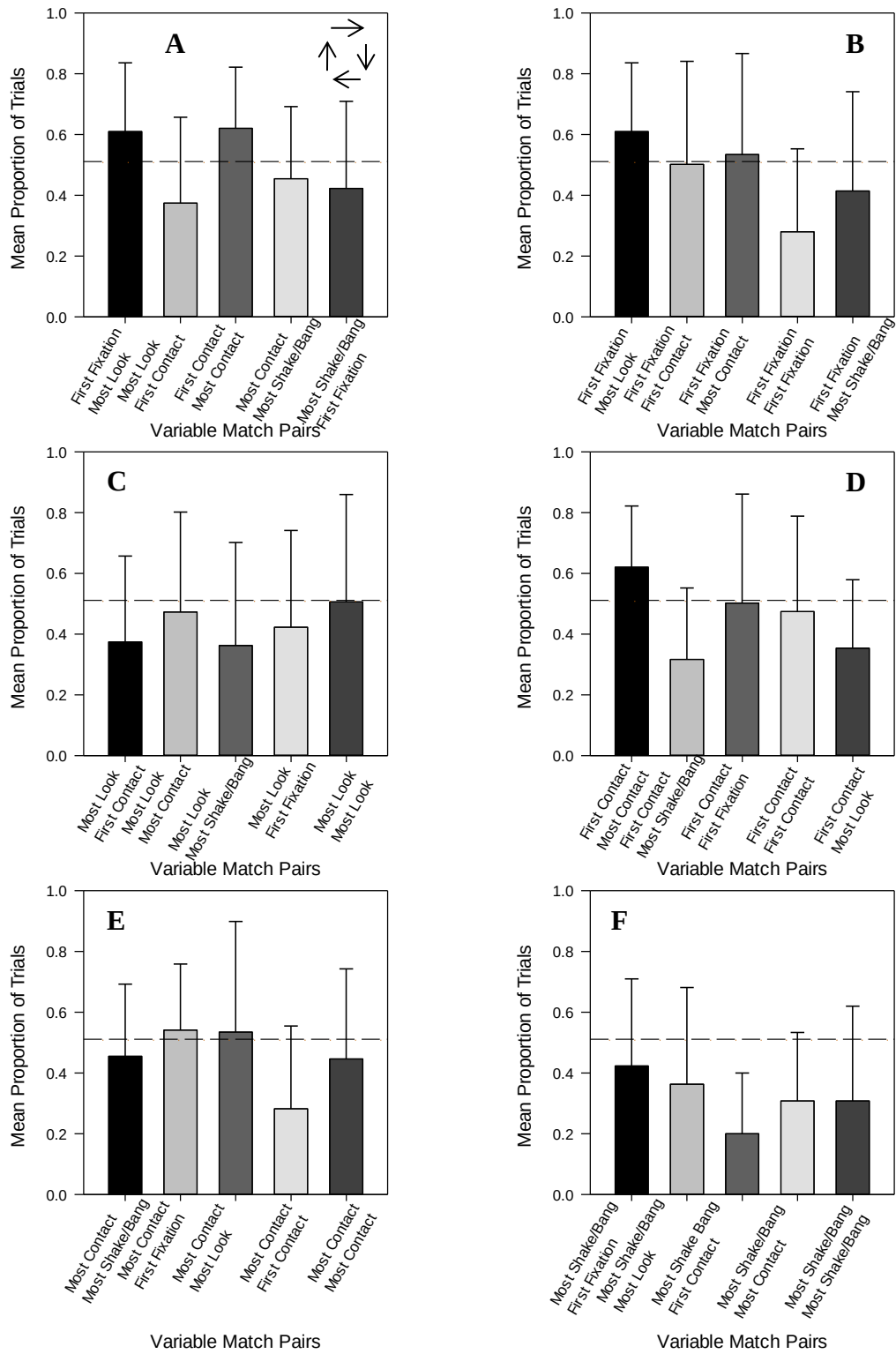


*Figure 12.* Mean proportion of match pairs (SD) on both objects for generalization phase trials: a) perception-action sequence of match pairs, b) first fixation match pairs, c) most look match pairs, d) first contact match pairs, e) most contact match pairs, f) most shake/bang match pairs.

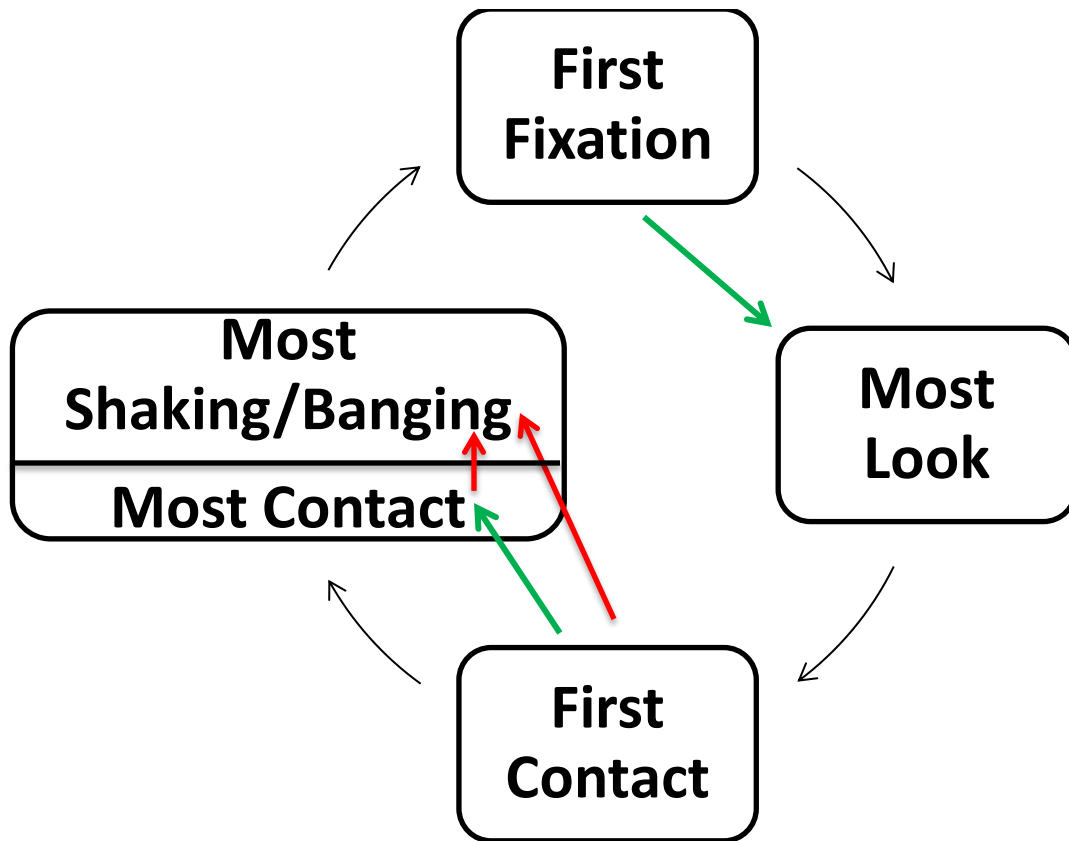


*Figure 13.* Summary of significant match pairs with both objects. Green arrows represent match proportions higher than the other variable pairs; red arrows represent match proportions lower than the other variable pairs.

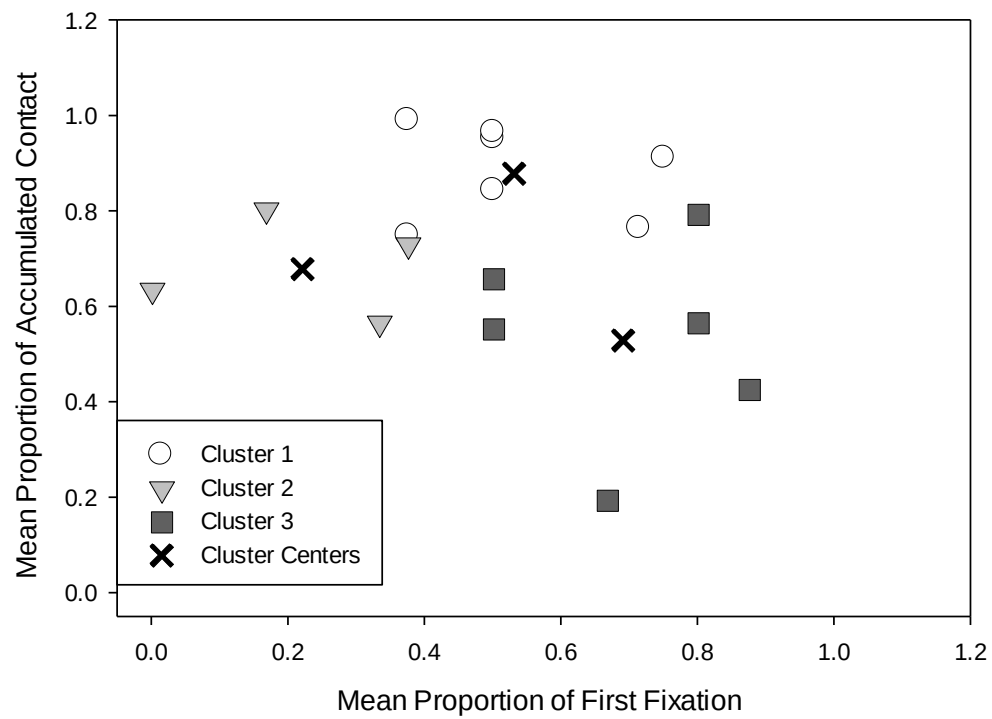


*Figure 14.* Mean proportions of first fixation trials and durations of accumulated contact by cluster for discovery phase trials.

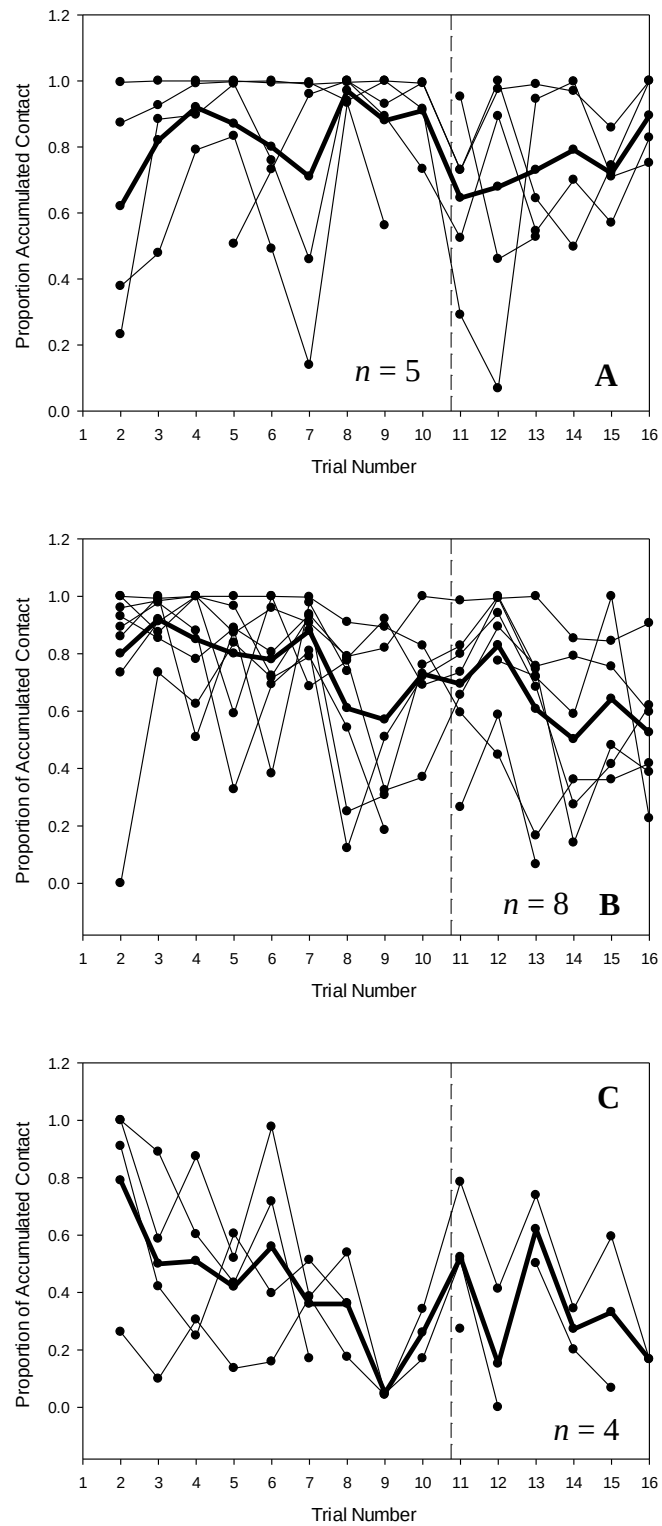


Figure 15. Mean proportions of durations of accumulated contact by cluster: a) cluster 1, b) cluster 2, c) cluster 3.

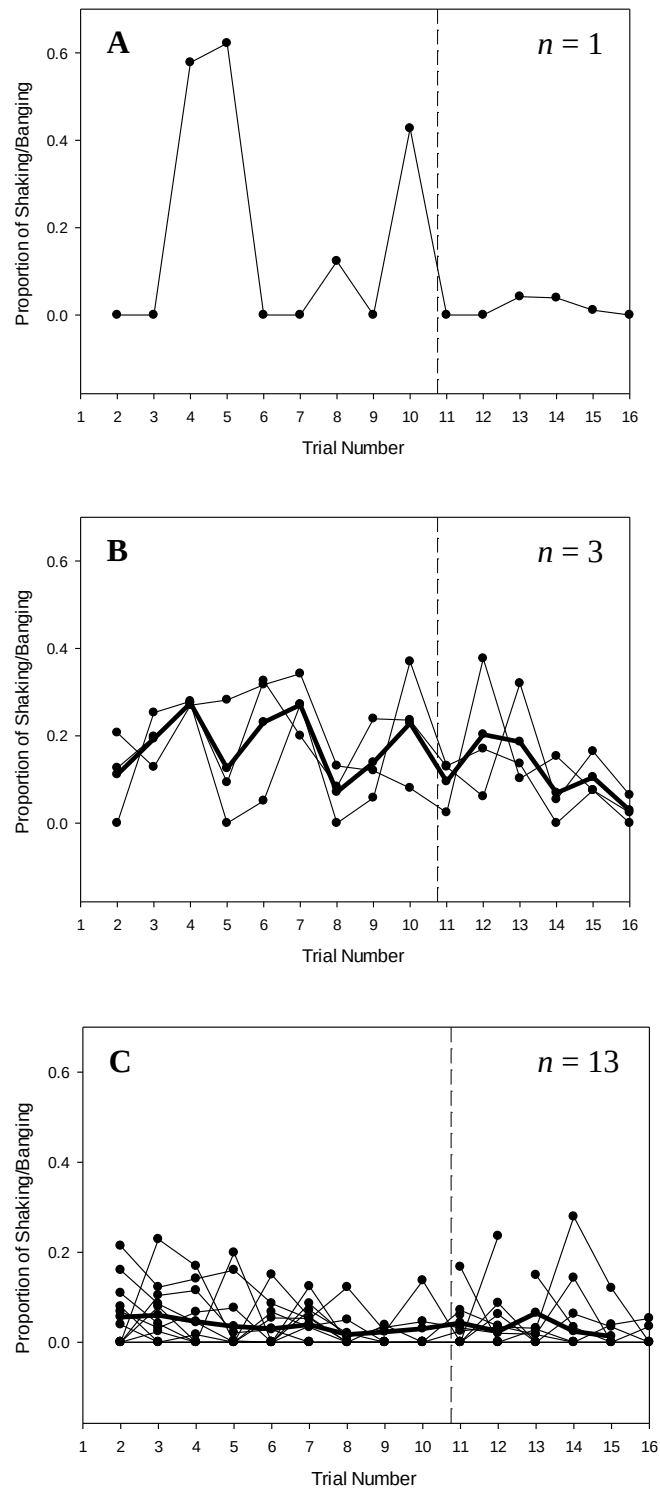


Figure 16. Mean proportions of shaking and banging the filled object across discovery and generalization phase trials: a) cluster 1, b) cluster 2, c) cluster 3.

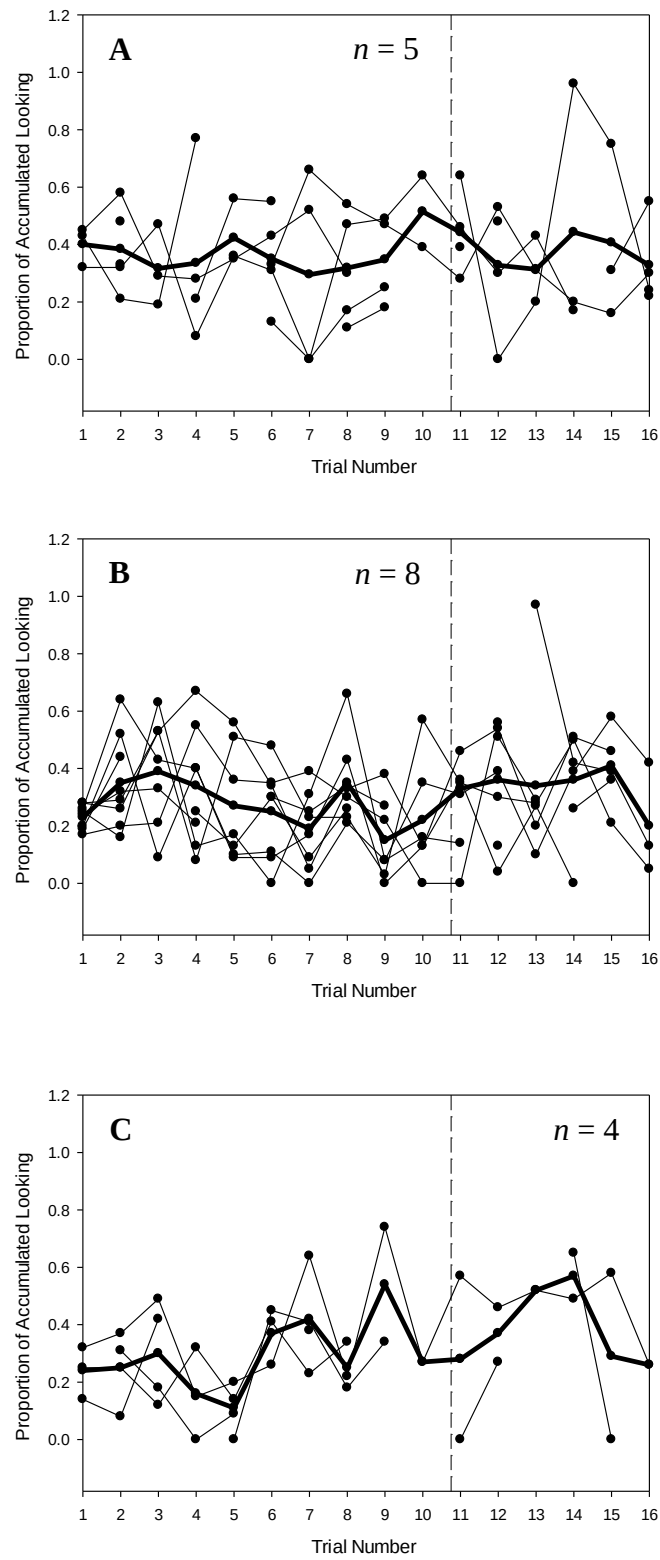


Figure 17. Mean proportions of durations of accumulated looking by cluster based on significant accumulated contact clusters: a) cluster 1, b) cluster 2, c) cluster 3.

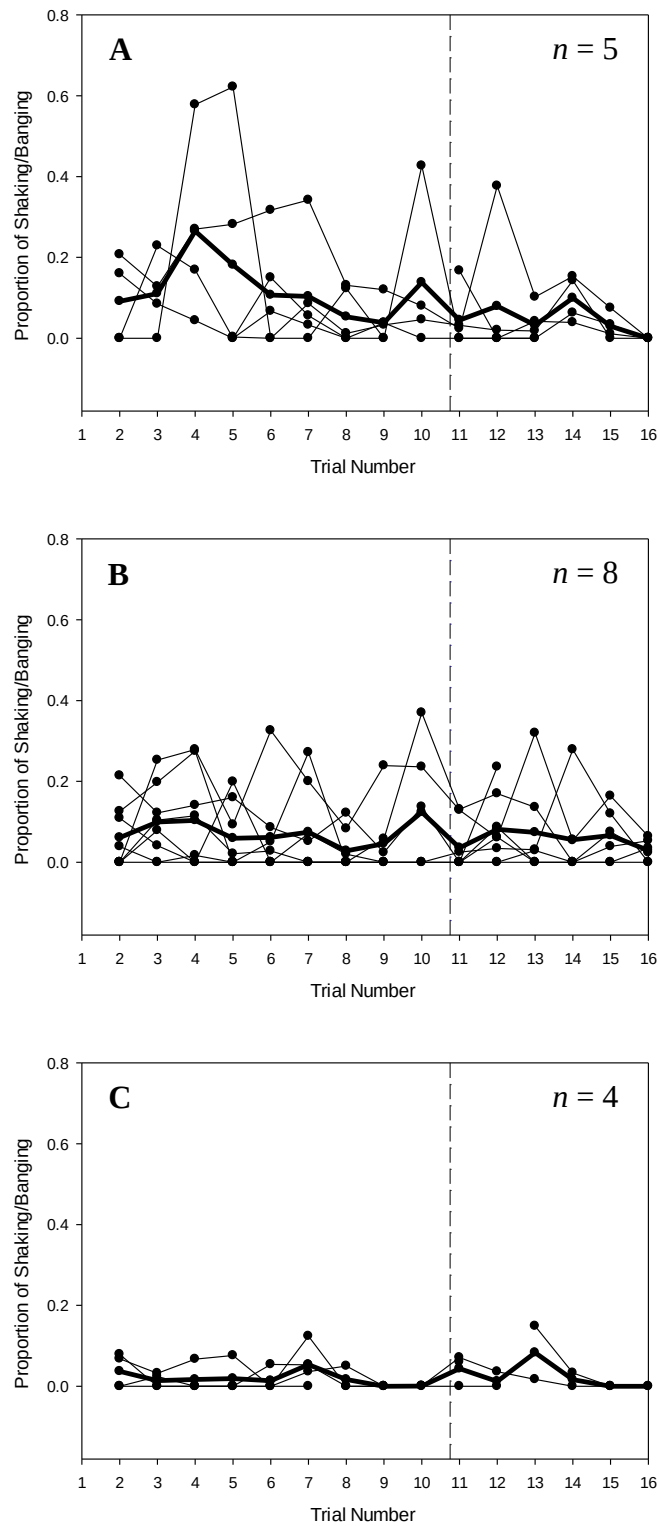


*Figure 18.* Mean proportions of durations of shaking/banging by cluster based on significant accumulated contact clusters: a) cluster 1, b) cluster 2, c) cluster 3.

Table 3.

Study 2 stimulus object weights in grams.

| Study 2 Stimulus Object Weights (g) |                            |                              |           |             |            |              |
|-------------------------------------|----------------------------|------------------------------|-----------|-------------|------------|--------------|
| Color/Fill                          |                            |                              |           |             |            |              |
| Object Type                         | Blue/Unfilled/<br>Detailed | Yellow/Unfilled/<br>Detailed | Blue/Rice | Yellow/Rice | Blue/Beans | Yellow/Beans |
| Eggs                                | 31                         | 28                           | 38        | 37          | 34         | 36           |
| Dolls                               | 22                         | 24                           | 34        | 32          | 39         | 36           |
| Circles                             | 27                         | 26                           | 36        | 35          | 38         | 40           |
| Squares                             | 60                         | 62                           | 84        | 81          | 90         | 88           |

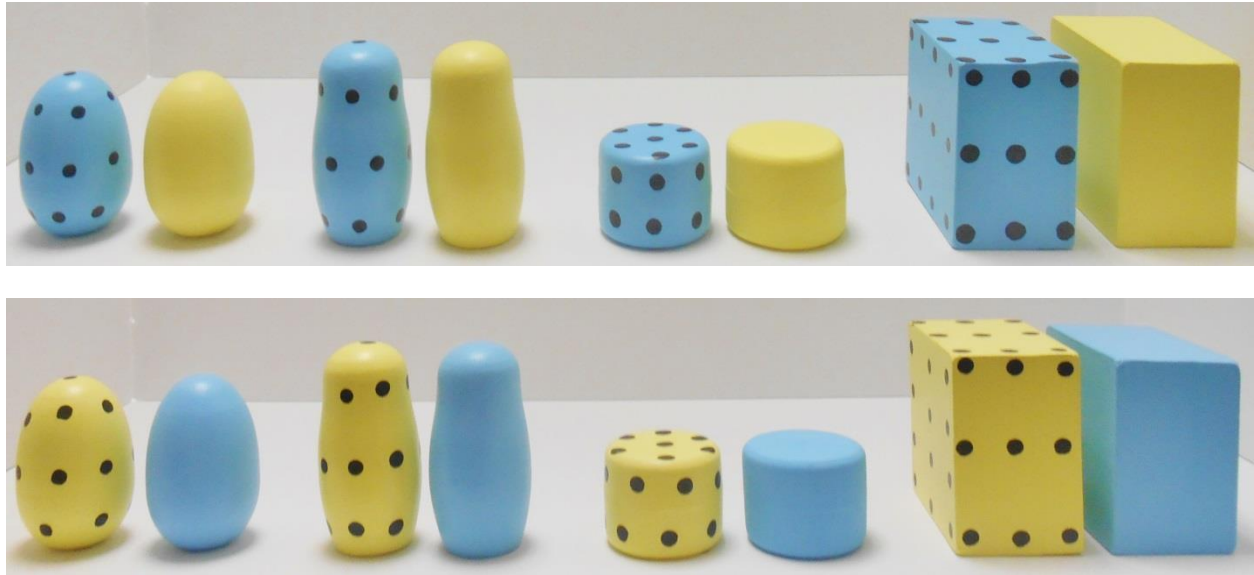


*Figure 19.* Study 2 stimulus objects. Top: blue/dotted – unfilled/detailed, yellow – filled; Bottom: yellow/dotted – unfilled/detailed, blue – filled; Left to right: eggs, dolls, circles, squares.

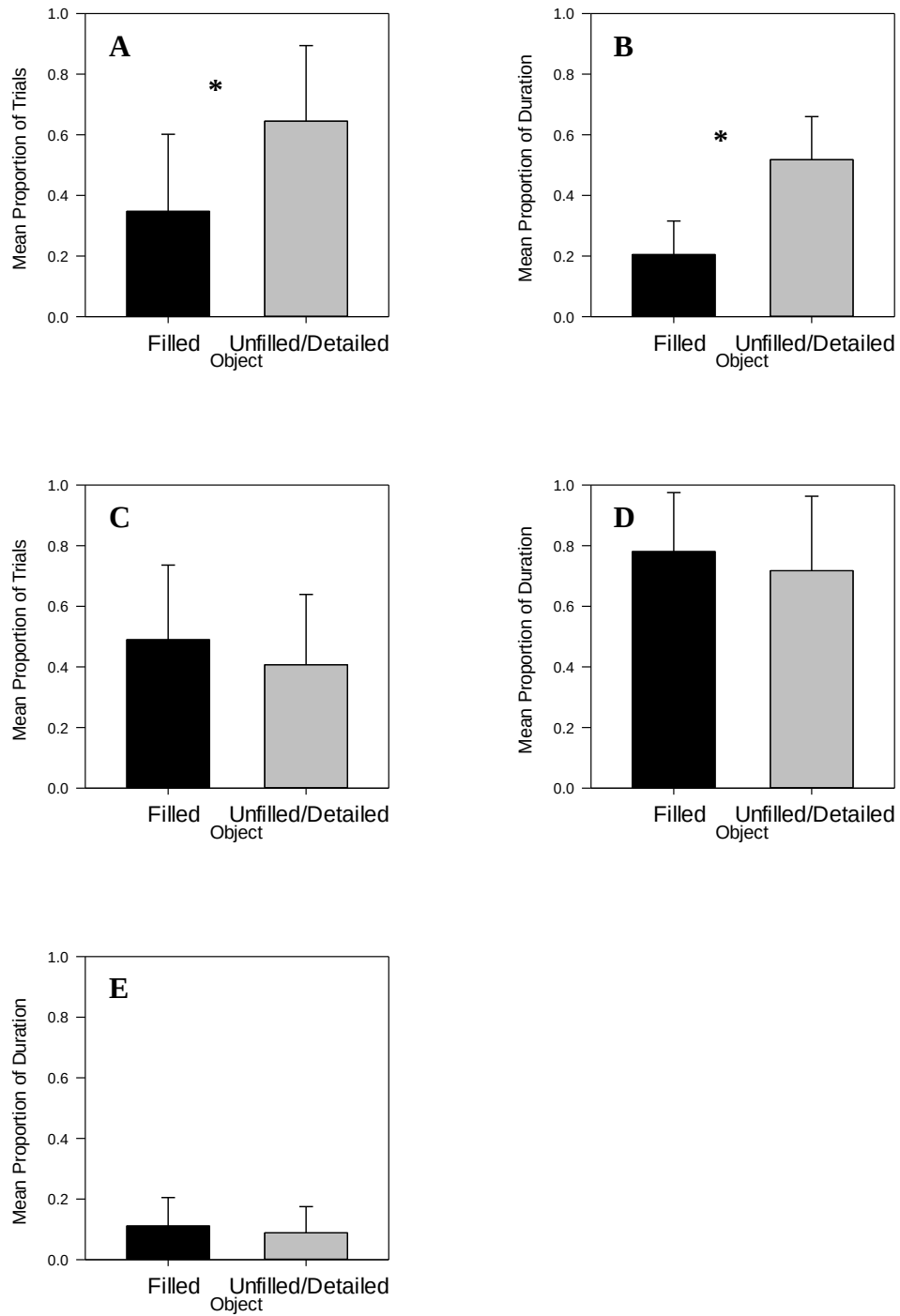


*Figure 20.* Mean proportion of durations and trial number (SD) for the discovery phase trials by object (filled and unfilled; study 2): a) first fixation, b) accumulated looking, c) first contact, d) accumulated contact, and e) shaking and banging.

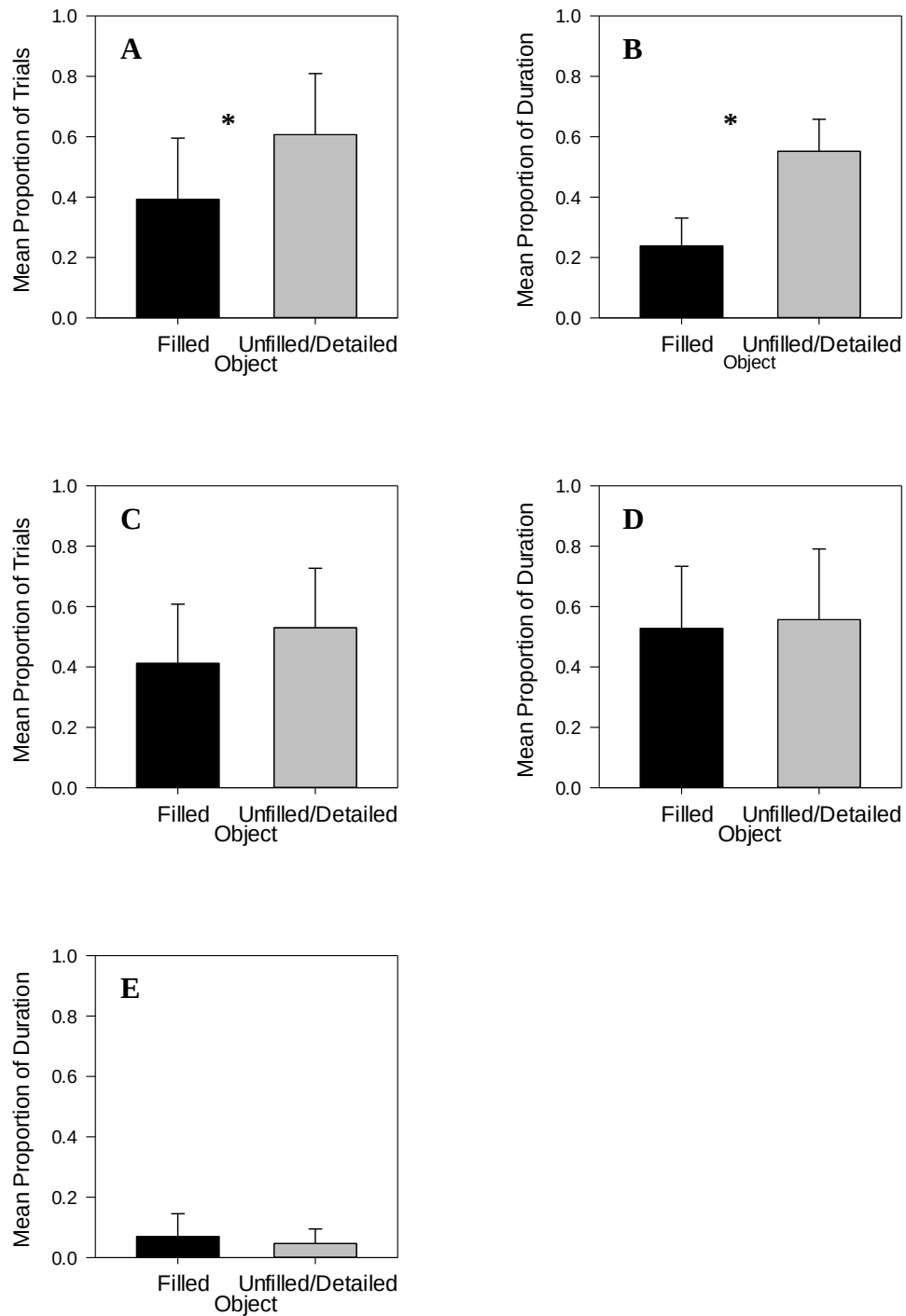


*Figure 21.* Mean proportion of durations and trial number (SD) for the generalization phase trials by object (filled and unfilled/detailed; study 2): a) first fixation, b) accumulated looking, c) first contact, d) accumulated contact, and e) shaking and banging.

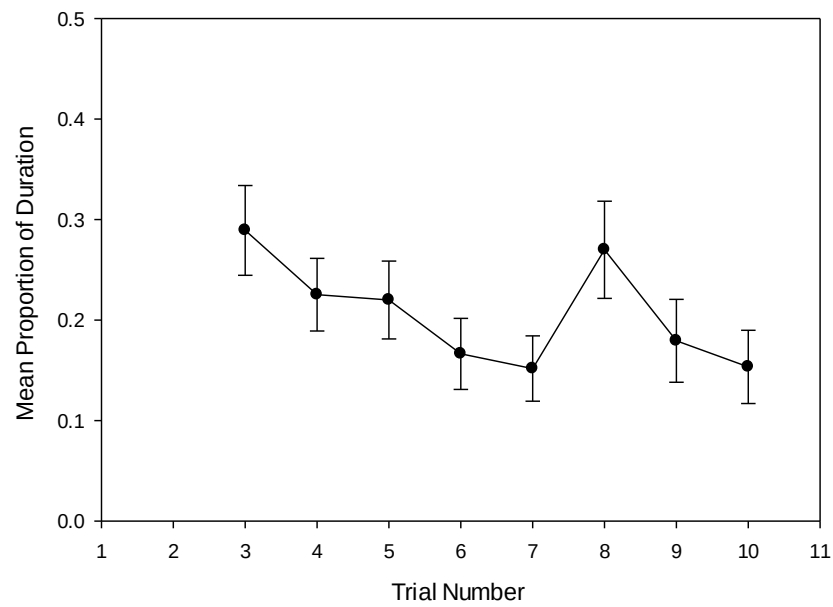


*Figure 22.* Mean proportions of durations (SE) of accumulated looking at the filled object across discovery phase trials.

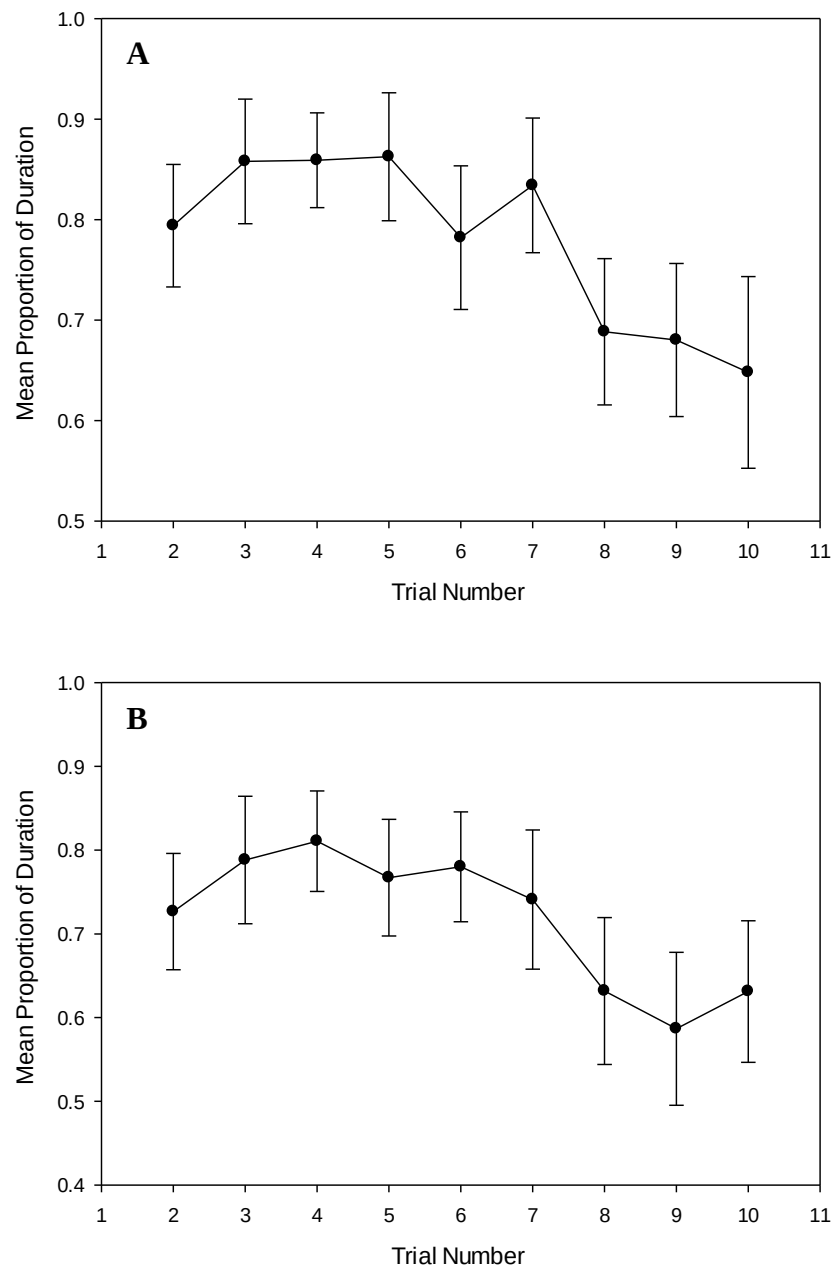


*Figure 23.* Mean proportions of durations (SE) of accumulated contact with the across discovery phase trials: a) filled object and b) unfilled/detailed

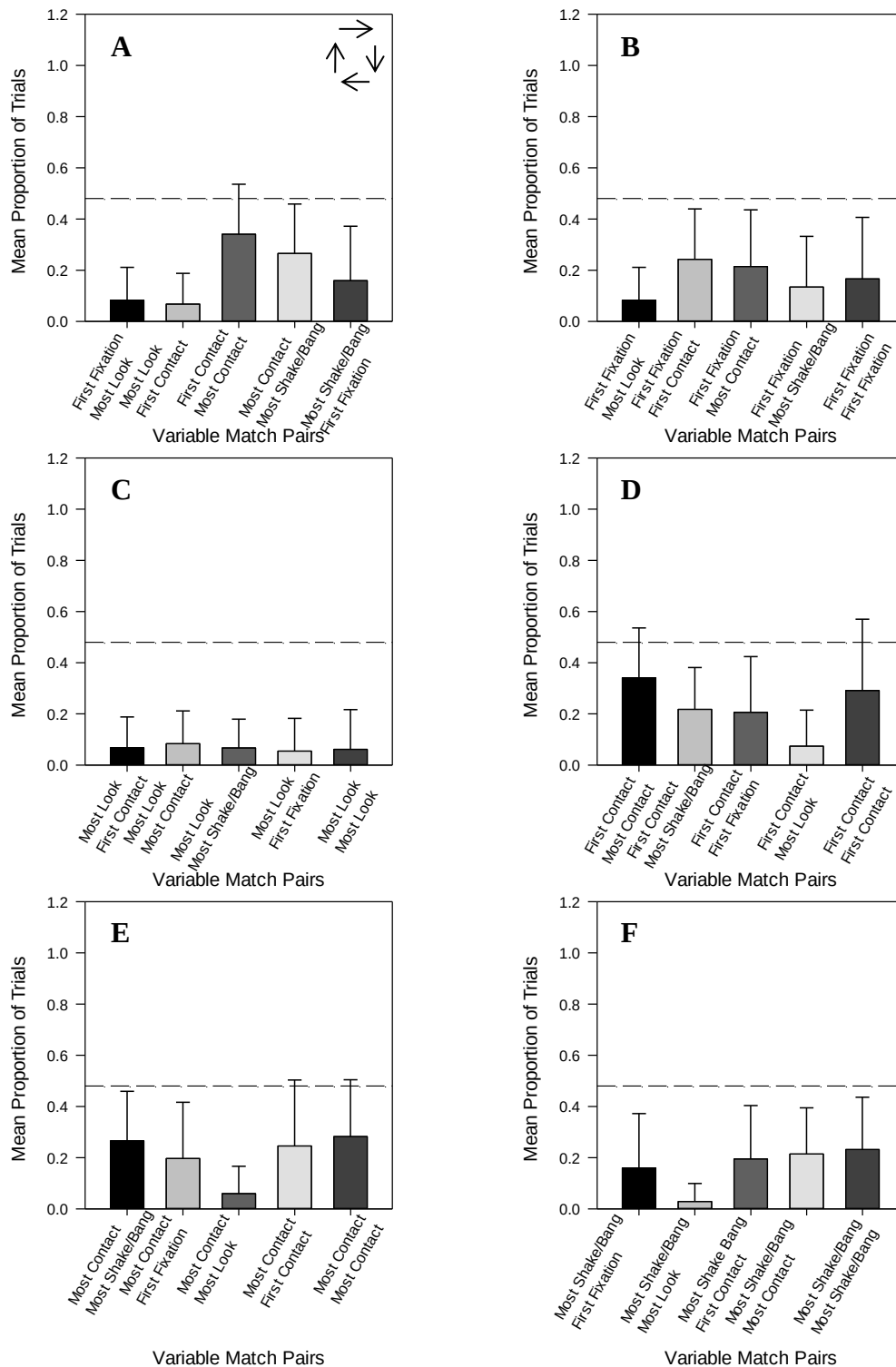


Figure 24. Mean proportion of match pairs (SD) on filled object for discovery phase trials (study 2): a) perception-action sequence of match pairs, b) first fixation match pairs, c) most look match pairs, d) first contact match pairs, e) most contact match pairs, f) most shake/bang match pairs.

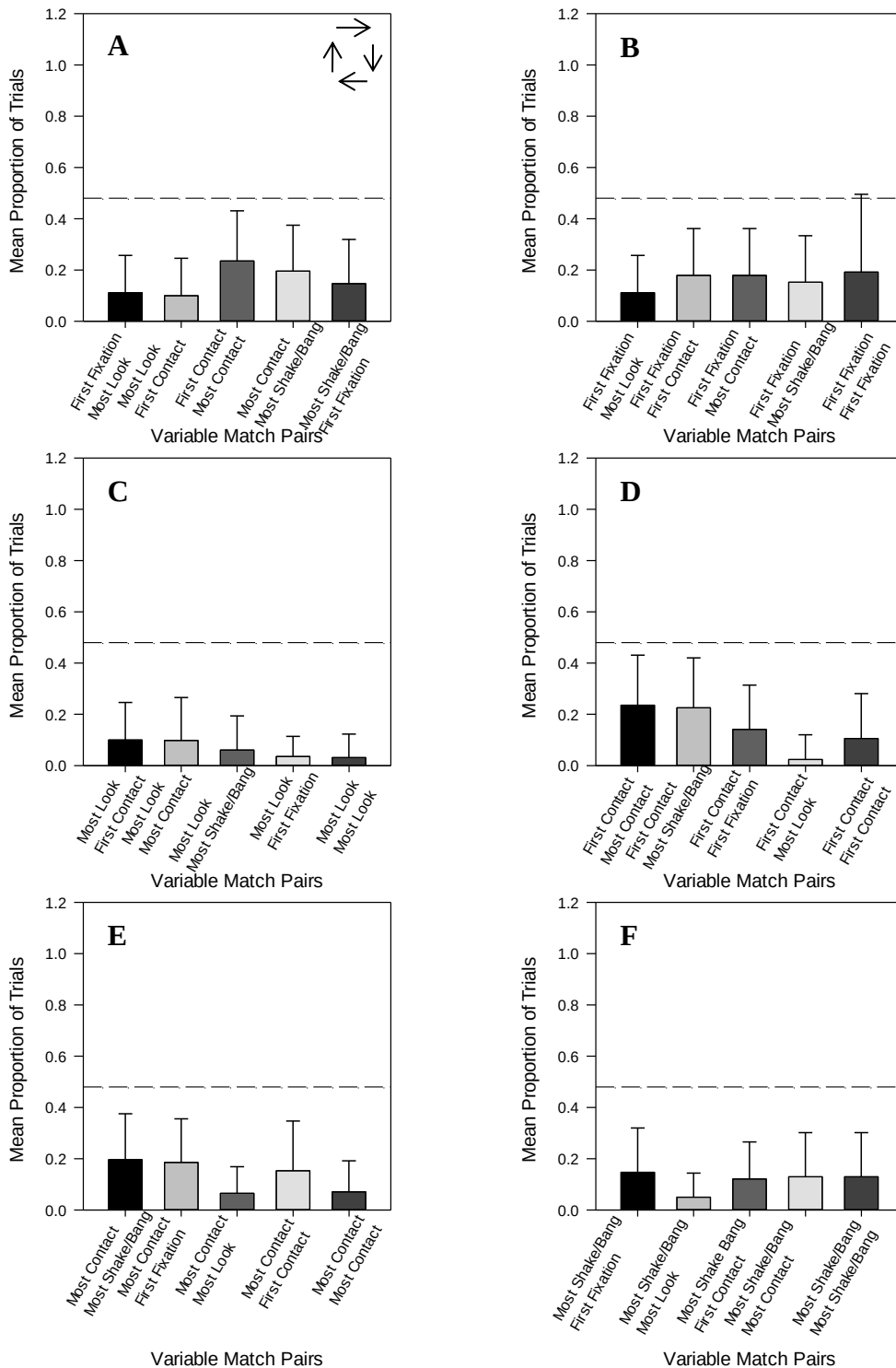


Figure 25. Mean proportion of match pairs (SD) on filled object for generalization phase trials (study 2): a) perception-action sequence of match pairs, b) first fixation match pairs, c) most look match pairs, d) first contact match pairs, e) most contact match pairs, f) most shake/bang match pairs.

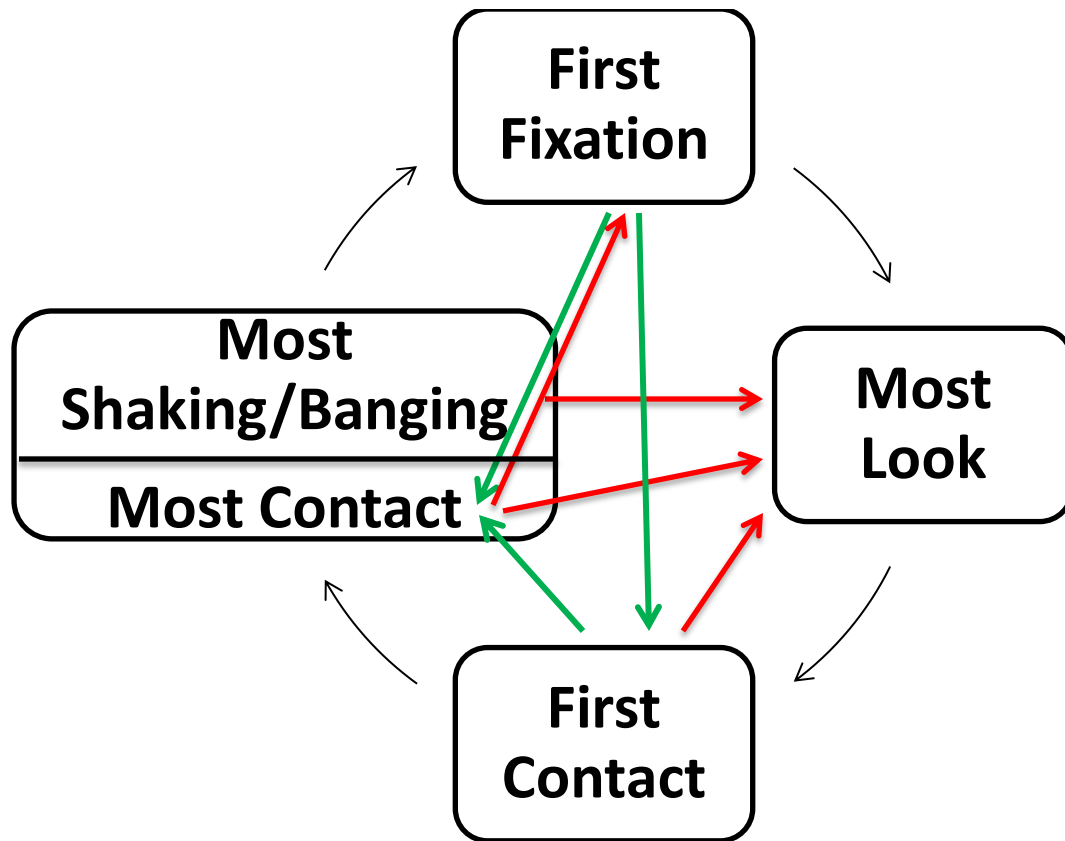


*Figure 26.* Summary of significant match pairs with the filled object (study 2). Green arrows represent match proportions higher than the other variable pairs; red arrows represent match proportions lower than the other variable pairs.

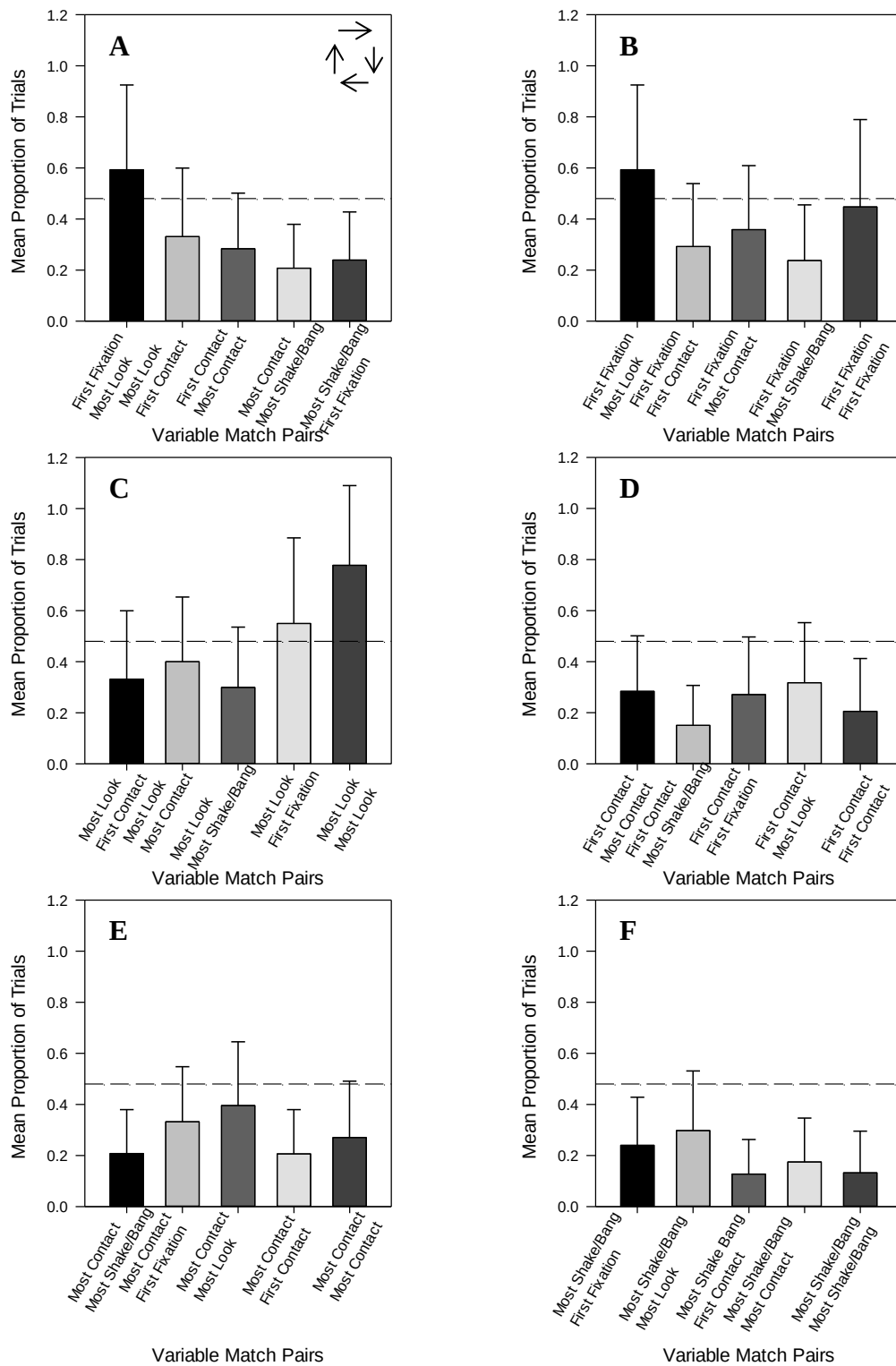


Figure 27. Mean proportion of match pairs (SD) on unfilled/detailed object for discovery phase trials (study 2): a) perception-action sequence of match pairs, b) first fixation match pairs, c) most look match pairs, d) first contact match pairs, e) most contact match pairs, f) most shake/bang match pairs.

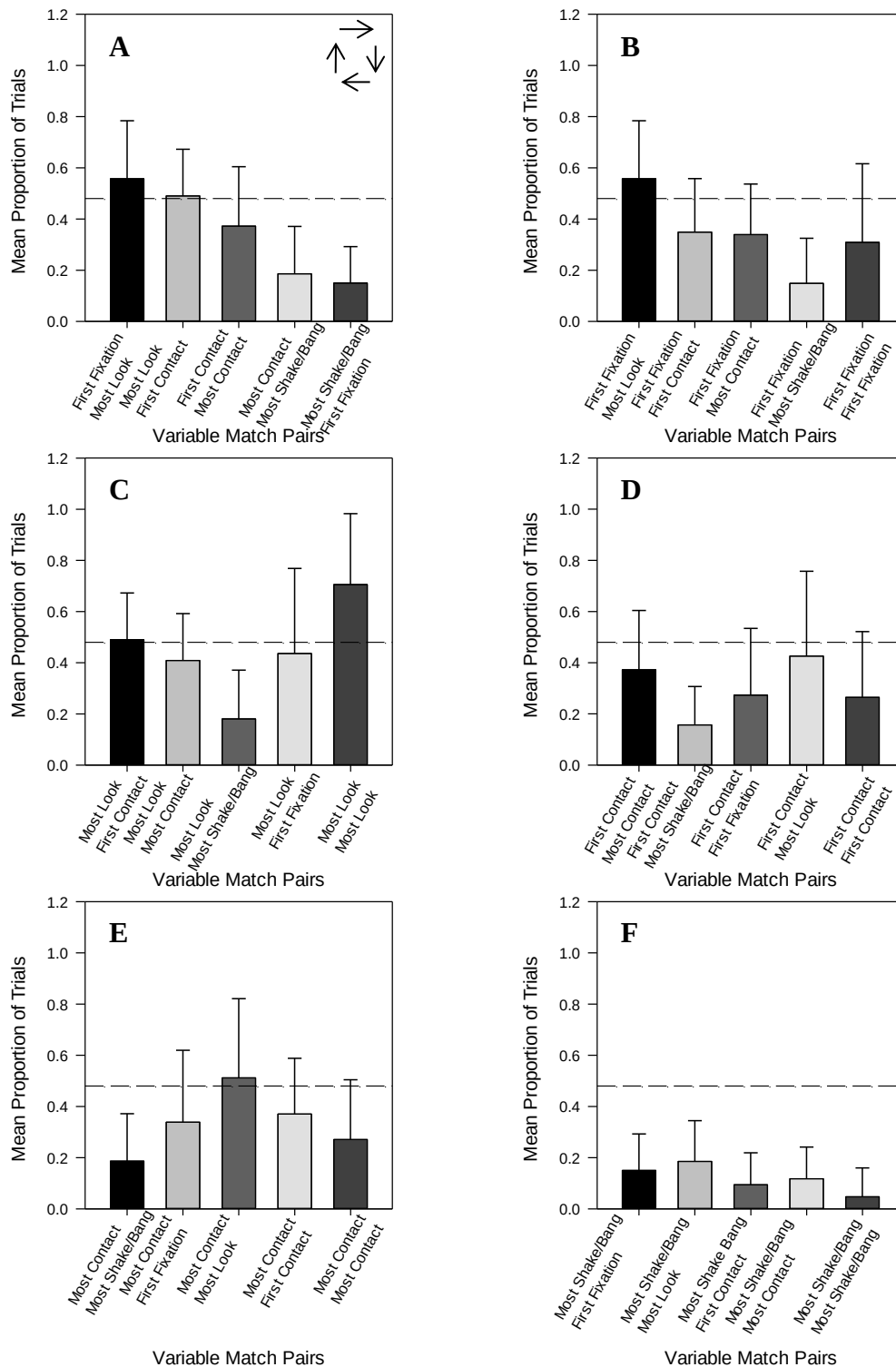


Figure 28. Mean proportion of match pairs (SD) on unfilled/detailed object for generalization phase trials (study 2): a) perception-action sequence of match pairs, b) first fixation match pairs, c) most look match pairs, d) first contact match pairs, e) most contact match pairs, f) most shake/bang match pairs.

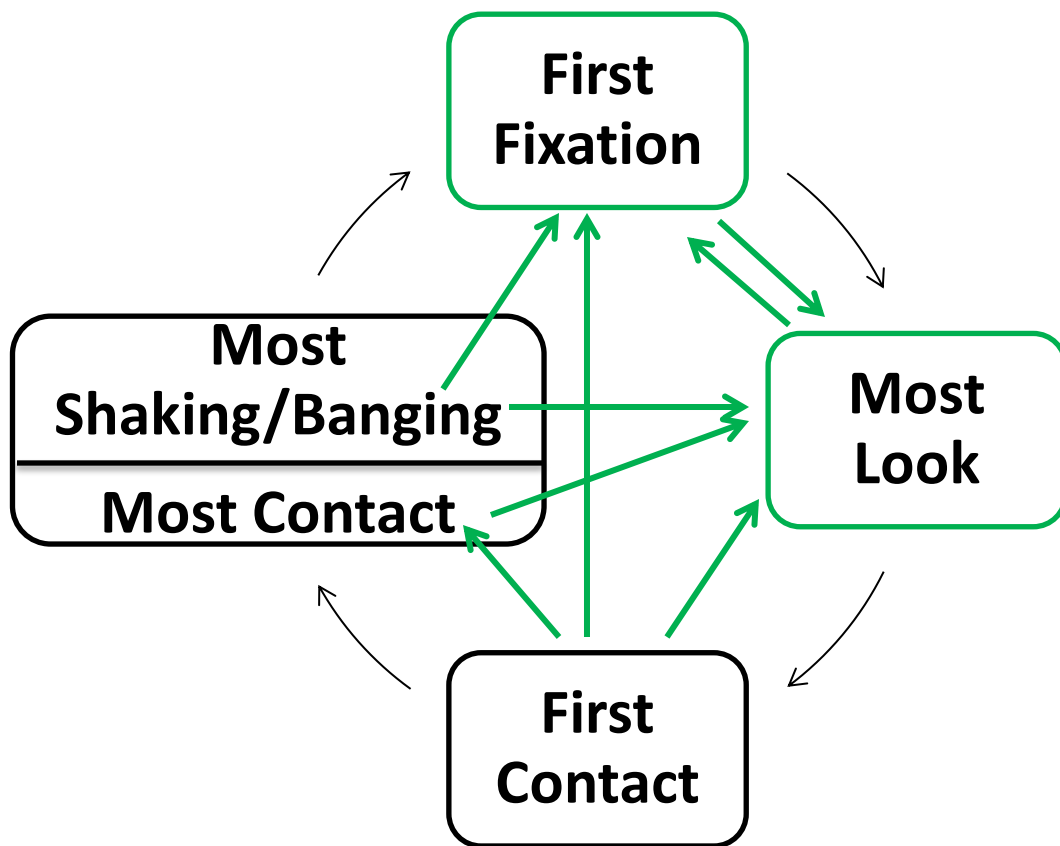


*Figure 29.* Summary of significant match pairs with the unfilled/detailed object (study 2). Green arrows represent match proportions higher than the other variable pairs.

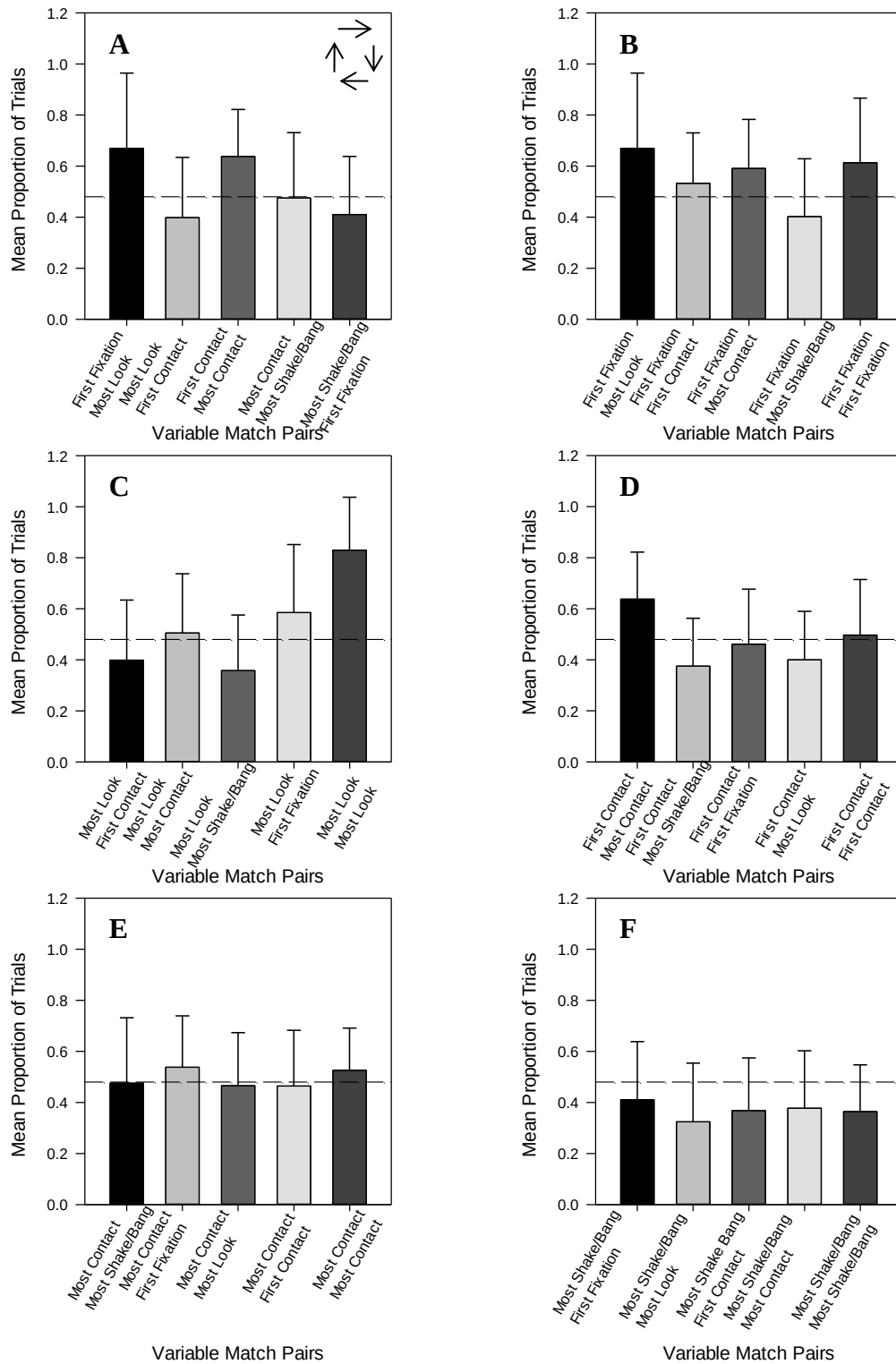


*Figure 30.* Mean proportion of match pairs (SD) on both objects for discovery phase trials (study 2): a) perception-action sequence of match pairs, b) first fixation match pairs, c) most look match pairs, d) first contact match pairs, e) most contact match pairs, f) most shake/bang match pairs.

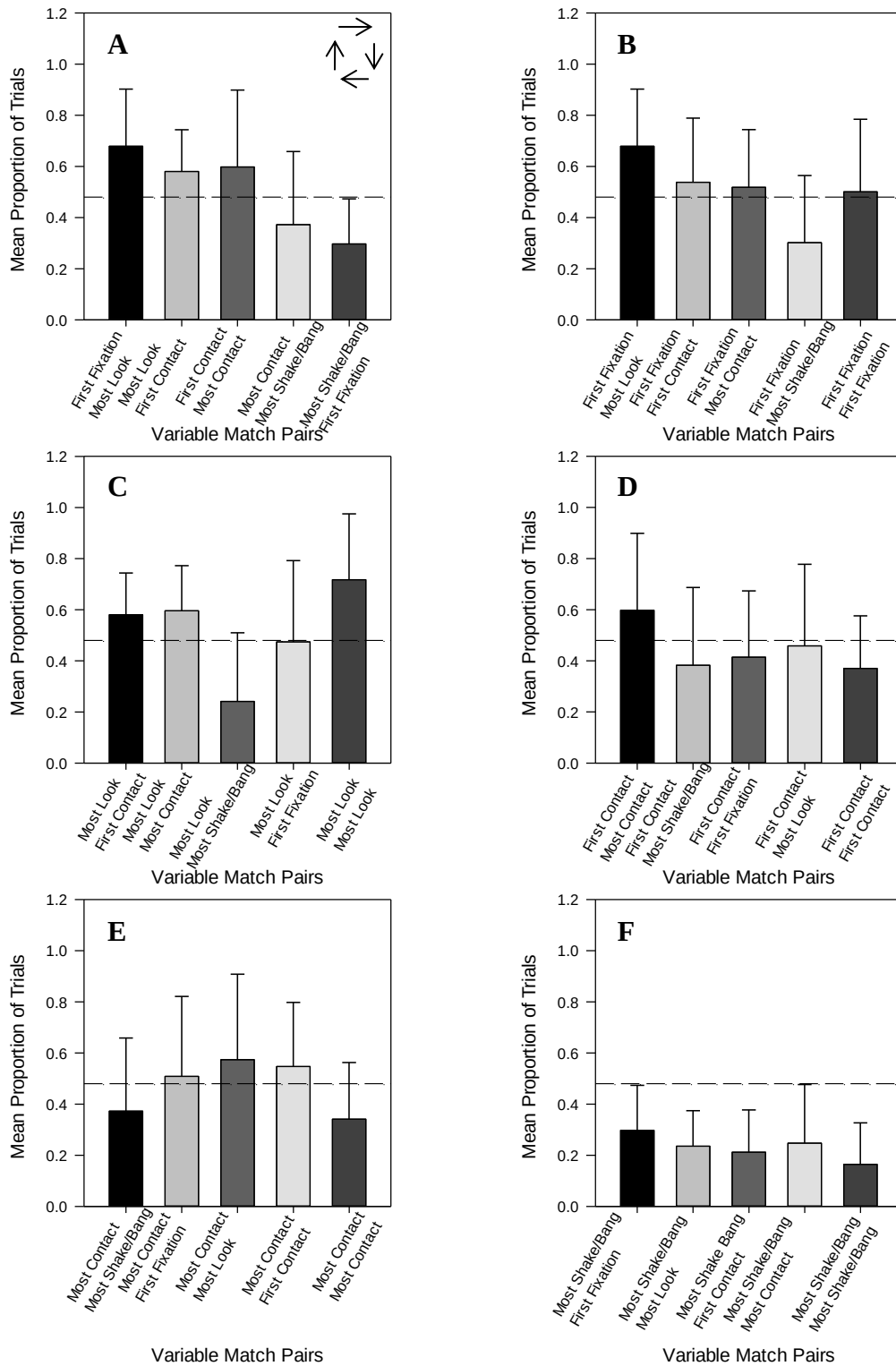


Figure 31. Mean proportion of match pairs (SD) on both objects for generalization phase trials (study 2): a) perception-action sequence of match pairs, b) first fixation match pairs, c) most look match pairs, d) first contact match pairs, e) most contact match pairs, f) most shake/bang match pairs.

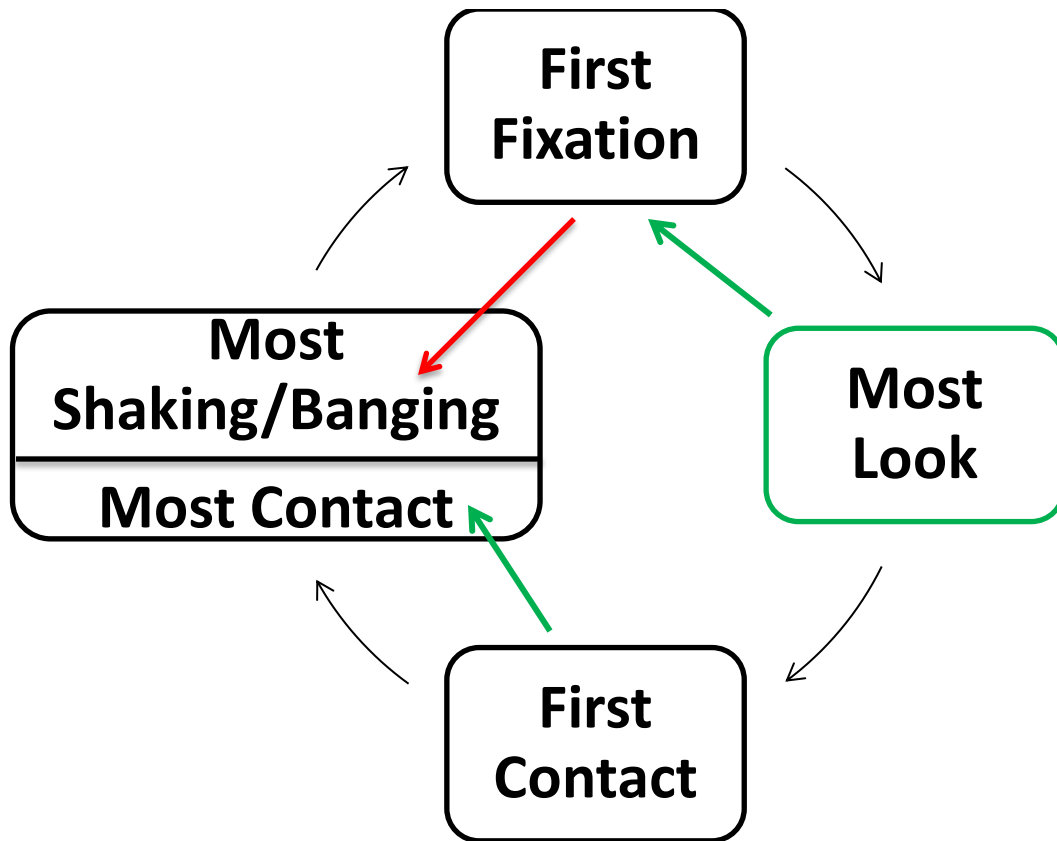


*Figure 32.* Summary of significant match pairs with both objects (study 2). Green arrows represent match proportions higher than the other variable pairs; red arrows represent match proportions lower than the other variable pairs.

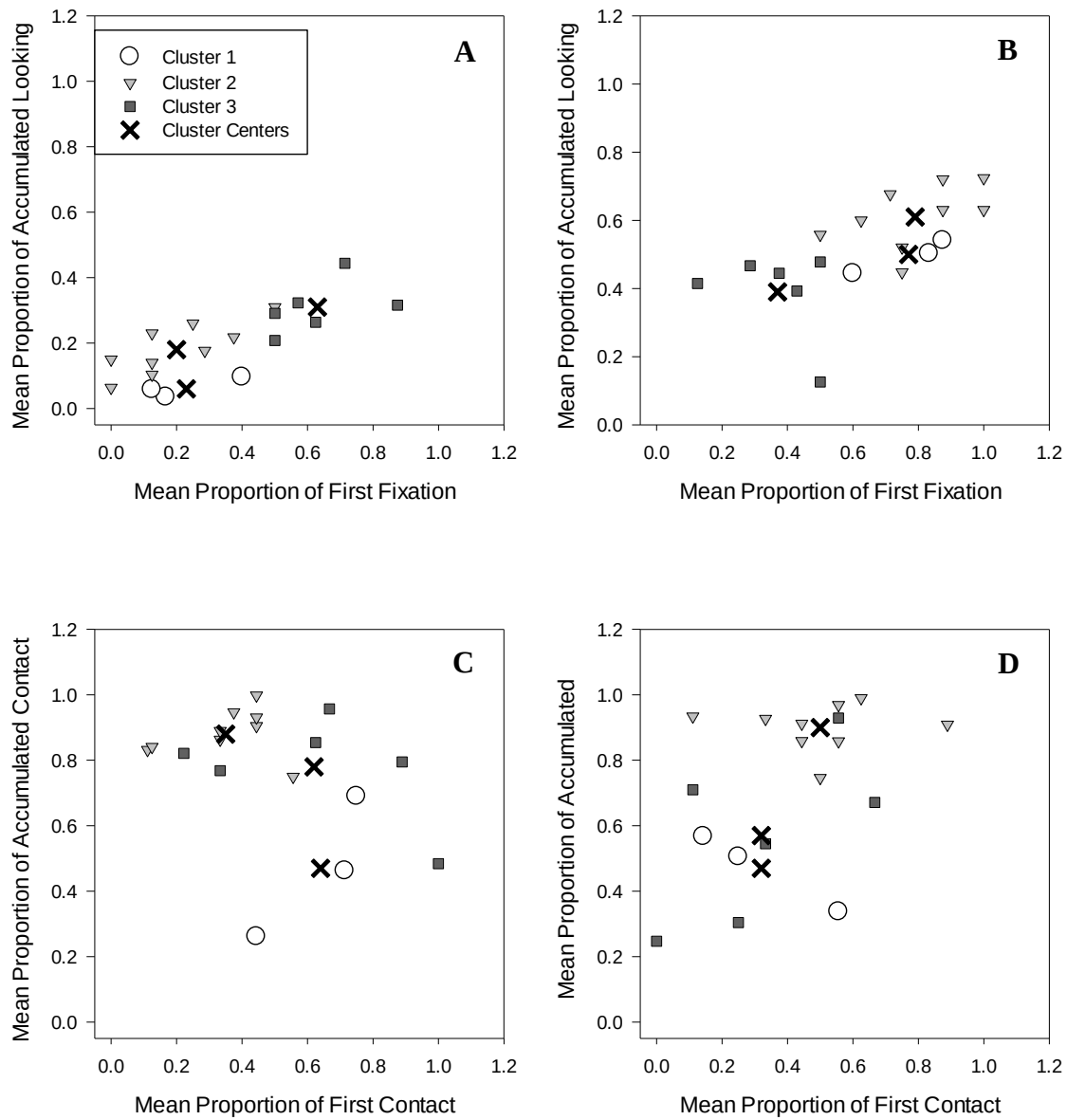


*Figure 33.* Mean proportions of trials and durations by cluster for discovery phase trials (study 2): a) first fixation by accumulated looking for filled object, b) first fixation by accumulated looking for unfilled/detailed object, c) first contact by accumulated contact for filled object, d) first contact by accumulated contact for unfilled object.

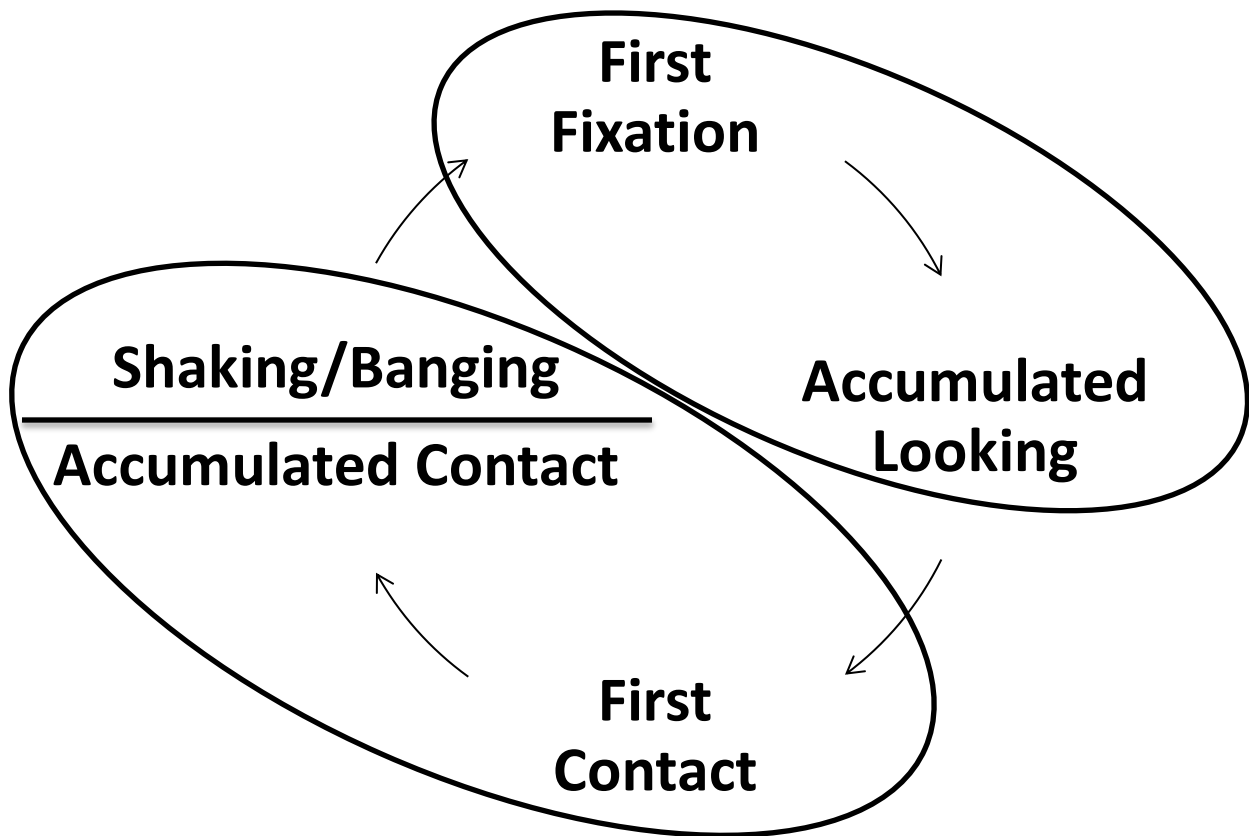


*Figure 34.* Perception-action sequence highlighting exploration within visual and within manual modalities.

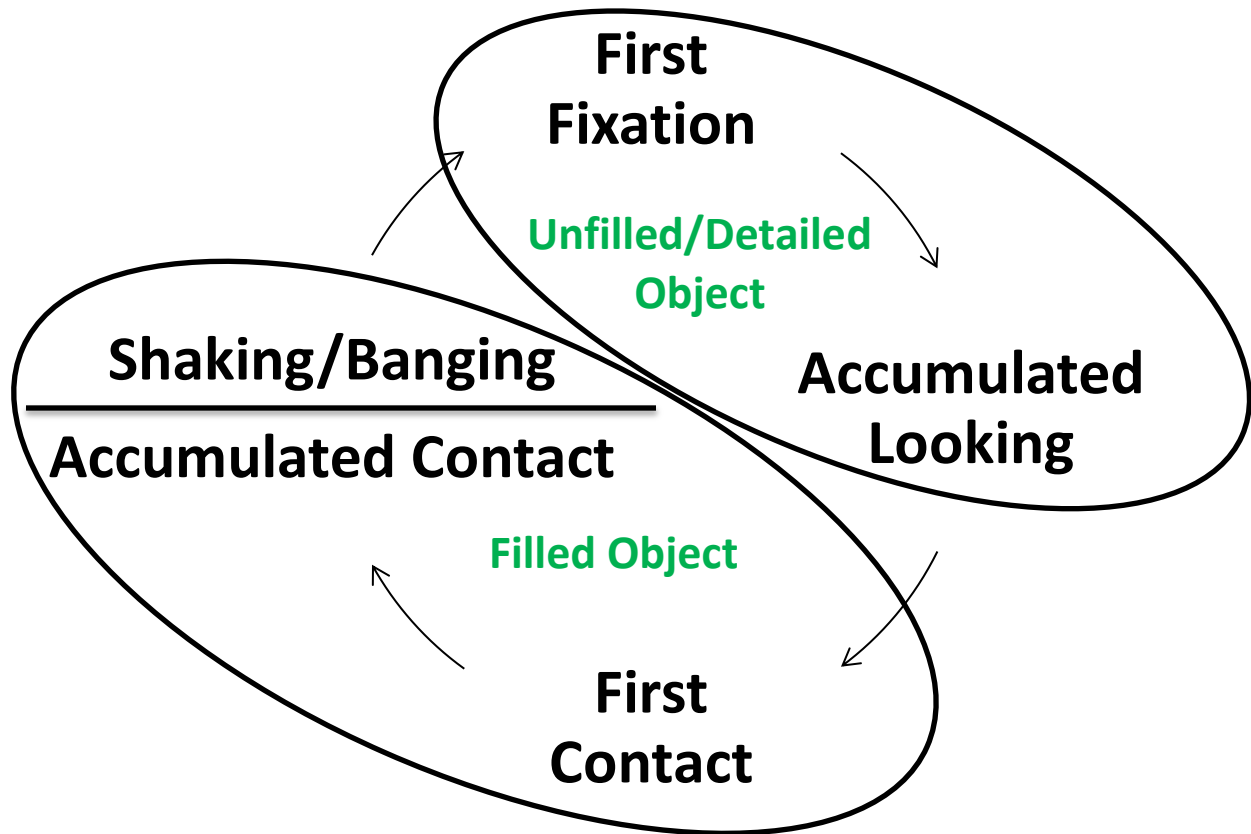


*Figure 35.* Perception-action sequence highlighting exploration within visual modalities for the unfilled/detailed object and within manual modalities for the filled object.

## VITA

Rebecca Faith Wiener was born in Abington, Pennsylvania and grew up in Dresher, Pennsylvania, a suburb of Philadelphia. Rebecca attended Thomas Fitzwater Elementary School, followed by Sandy Run Middle School, and Upper Dublin High School in Fort Washington, Pennsylvania, where she graduated in June of 2008. Next, Rebecca traveled south to attend Clemson University in Clemson, South Carolina, where she completed a Bachelor of Arts degree in Psychology in May 2012. Following graduation, Rebecca began her graduate program in Experimental Psychology at the University of Tennessee in Knoxville, Tennessee, with a developmental concentration. Under the supervision of her graduate advisor, Daniela Corbetta, her graduate work focused on studying perceptual-motor development in typically developing infants within their first year of life. She received her Master of Arts degree in Psychology in May 2016 from the University of Tennessee and continued on there to pursue her Doctor of Philosophy degree in Experimental Psychology.