Investigating Scale Errors: Independent Systems of Object Representation or Simple Motor Priming

Natalie Hiromi Brito
College of William & Mary - Arts & Sciences
Investigating Scale Errors: Independent Systems of Object Representation or Simple Motor Priming

Natalie Hiromi Brito
Stafford, Virginia

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Natalie Hiromi Brito

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Committee Chair
Dr. Peter Vishton, College of William and Mary

Dr. Jennifer Stevens, College of William and Mary

Dr. Jeanine Stefanucci, College of William and Mary
Deloache, Uttal, and Rosengren (2004) reported that 18-to-30-month-old children sometimes failed to use information about an object’s size and tried to perform impossible actions on miniature objects. The researchers believed this was a perception-action dissociation in the behavioral responses of normally developing young children and interpreted these scale errors as problems with inhibitory control and the integration of visual information for perception and action. In our current study we investigate the similarities between scale errors and other developmental errors to find which characteristics about these tasks cause children to make an inappropriate or inaccurate action responses. We attempt to determine which object characteristics increase or decrease the occurrence of scale errors and believe that children of all ages (and possibly adults) can commit these scale errors given a specific cue or situation.
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Investigating Scale Errors: Independent Systems of Object Representation or Simple Motor Priming?

People of all ages make use of visual information to guide their behaviors or responses while interacting with their environments. They are usually accurate in their judgments but when faced with certain situations, they sometimes make very salient errors in their responses. In these instances adults and children seem to be cognitively aware of things but fail to act appropriately on the basis of their knowledge. Researchers have labeled these unique situations as “dissociations” or “errors” and some researchers have even suggested there is a dissociation between the knowledge and action systems that is both neural and psychological. Many believe that this dissociation occurs when the action system is impaired or not fully developed whereas the knowledge system is fully functioning (Goodale & Milner, 1992; Diamond, 1991). Examining these errors from a developmental perspective can lead to a better understanding of motor, perceptual, and cognitive processes interact and how the environment influences these processes.

A-not-B-Error

A classic developmental error first described by Piaget (1954) is the A-not-B error. It has been demonstrated that before 7 or 8 months of age, infants seem to refuse to search for a toy that has been hidden under a cover. Early researchers described this phenomenon as if the toy stopped existing in the minds of the infants. After 12 months of age infants will continue to search for the toy, even if the toy is hidden in several different places. The A-not-B error occurs during 7-12 months when infants will search at one location and will continue to search at the first location even when they visibly see the experimenter hide the toy in an adjacent location underneath an identical cloth. This
error is very robust when assessed in this manner, but as soon as even small variations
take place, the error can be disrupted and the infant will search correctly at the second
location to obtain the toy. For instance, making the hiding covers more distinct in color
from one another can lead to an increase in accurate reaching (Wellman, Cross, &
Bartsch, 1986).

In his original observations of the A-not-B search task, Piaget (1954) reported that
infants would occasionally look to the correct location while reaching perseveratively at
the incorrect location. Perseveration is the repetition of previously performed but now
inappropriate act and has been attributed to strong motor memories. The more times an
infant reaches to a particular location, the stronger the motor memory and frequency of
that perseverative behavior (Diedrich, Thelen, Smith, & Corbetta, 2000).

Neural network models have demonstrated that perseveration could arise from
Hebbian learning mechanisms because the neural network will tend to strengthen
whatever response is made to a stimulus (Munakata, 1998). Perhaps this simple neuronal
tendency could provide an account for why these inappropriate action responses occur
and perseverative behaviors could result from the formation of a tightly bound ensemble
of neuronal activity created by highly similar and repeated responses (Diedrich, Thelen,
Smith, & Corbetta, 2000).

Edelman (1987) found that neural ensembles that are simultaneously and
repeatedly activated together become stronger and more likely to become activated again.
This is derived from the concept of Hebbian learning which states that a neuron’s
contribution to the firing of another neuron could increase if that cell is repeatedly
involved in the activation of the second (Hebb, 1949). This concept may be particularly
relevant for certain kinds of statistical learning that appear to occur without any overt task or directed effort to learn. This automatic or self-organizing nature of Hebbian learning could simply happen in response to a selection of inputs from the environment, without any consideration of what outputs or behaviors should be produced in response to those inputs (Munakata & Pfaffly, 2004).

There have been many studies using visual violation-of-expectancy measures to show that although infants will consistently make the A-not-B error when reaching for hidden objects, they do seem to expect that the objects will be found in the correct location when no action response is required (Baillargeon & Graber, 1988). In these studies looking time measures were employed and when the infant does not have to produce an action response and is only required to produce a looking response, infants seem to know the correct location of the hidden object. Longer looking times indicate a violation of expectancy and infants will look longer when the hidden object is not retrieved from the correct location. There have been many different explanations for this apparent dissociation. Some researchers believe that reaching involves a stronger object representation than looking (Munakata et al. 1997), while others believe it is the case that the "knowing" system is unable to control the "acting" system (Bertenthal, 1996).

Some researchers believe that these dissociations are failures of the child’s executive function system and could be attributed to an inability to inhibit inappropriate responding (Diamond, 2002; Zelazo & Frye, 1998). Executive function refers to processes responsible for higher-level action control (including inhibition, planning, coordination and the control of action sequences) that are necessary for maintaining a specified goal and avoiding distractions (Duncan 1986; Carlson, Mandell, & Williams,
The standard executive function task is characterized by the need to inhibit an interfering response inclination. Executive inhibition is necessary when automatic inhibition and high activation of the desired action schema fails (Perner & Lang, 1999).

There are two general kinds of tasks to assess children's inhibitory control and task performance improves as a function of age with both assessments. A widely used example of an executive function task is Luria's hand game. In this task the participant is instructed to do the opposite of what the experimenter does. The natural tendency to imitate the experimenter interferes with the objective of the game (Luria, Pribram, & Homskaya, 1964). A similar task is the Gift Delay Task where an experimenter instructs the participants to not peek while the experimenter noisily wraps a present for them. This kind of task measures a child's ability to suppress or delay an impulsive response (Carlson & Moses, 2001). Another task used to measure inhibitory control requires that children answer a certain way, even in the event of a highly salient and conflicting response option. Cards with pictures of either the sun or moon are presented to 3-to-7-year-old children and the participants are instructed to say "night" in response to the sun cards and "day" in response to the moon cards (Gerstadt, Hong, & Diamond, 1994).

Inhibitory control is the capacity to inhibit responses to irrelevant stimuli while pursuing a cognitively represented goal and this has been thought to be a factor in the developmental changes of a wide variety of cognitive abilities including intelligence, attention, memory, emotion regulation and social competence (Carlson, & Moses, 2001). Developments in inhibitory control mainly occur within the first six years of life, and this notion has been supported by both behavioral and neuropsychological evidence. Research
has identified the prefrontal cortex as a key component of inhibition and other aspects of executive functioning. Brain maturation research indicates that the prefrontal cortex is a slowly maturing brain area with the frontal lobes developing rapidly during infancy, a period of developmental delay, and then another growth spurt between the ages of four and seven (Carlson, & Moses, 2001; Luria, 1973). Behavioral and fMRI studies indicate that executive control processes such as response inhibition are not fully developed until adolescence (Luna & Sweeney, 2004).

These behavioral errors could be attributed not to dissociations in knowledge and action but to the type of response required of the child. For example, infants demonstrate much more knowledge of hidden objects when looking time is as used a dependent measure instead of reaching (Baillargeon, Graber, DeVos, & Black, 1990). Diamond (1985; 1988; 1990a; 1990b) completed a series of studies to explain this discrepancy and believed that the error results from both the infants’ poor memories for the hiding place and their inability to inhibit strong motor responses. The researcher concluded that the delay aspect of the task was very important to decrease memory of the hiding event and to decrease the ability to inhibit the prepotent response.

Another explanation for this inconsistency is that the infant simply makes a reach to the wrong location. This means that the infant may be knowledgeable of the location of the object but merely reaches to a different location. Previous studies have shown that infants usually represent space egocentrically rather than based on the target object’s position and infants who have been accustomed to reach to position A will continue to reach for the same location (relative to their own bodies) even if the table has been turned 180 degrees and the two locations have now been switched (Bremner & Bryant, 1977).
Slight variations in testing conditions will easily lead the infant to reach in the correct position. Clues within the environment that to help distinguish between the two targets (e.g. adding landmarks to the surrounding, making the hiding covers more distinct, testing the infants in a more familiar location, etc) have been shown to decrease the frequency of perseverative reaching (Acredolo, 1985; Wellman et al. 1986). There have also been studies to show that even the infants’ level of experience in self-locomotion was strongly related to the frequency of correct reaches in the A-not-B task (Bertenthal & Campos, 1990). It seems as though this “error” is a result of the infants’ response to a set of very specific parameters and the frequency of errors can be manipulated accordingly.

To account for the variability of results within the various A-not-B error tasks, Thelen, Schoner, Scheier, & Smith (2001) have presented a model to explain this inconsistency in results. The dynamic systems approach to the A-not-B error looks at the different motor, perceptual and cognitive processes contributing to the behavior as being coupled interactions which are continuous and based in time. The researchers believe that this model not only accounts for the search error but also how the perseverative responding changes due to age or environment. They believe that this error evolves from the same multiple processes that generate goal-directed reaching at any age.

Previous explanations have rooted the cause of the A-not-B error to infants’ deficits in object knowledge, spatial localization, memory, or inhibition (Marcovitch, & Zelazo, 1999; Munakata, 1997; Wellman et al., 1986) but in the dynamic systems approach the attention is focused on the reaching aspect of the error and the processes that lead to a directional reach to the incorrect and correct target locations. The
researchers of this model believe that the relative ambiguity of the task is a very important parameter in the model and the relative strength of the specific input is also an essential component. In their explanation, the error emerges in the context of the specific behavior or reaching and infants make perseverative location errors because the motor memory of one reach persists and influences subsequent behaviors (Thelen et al., 2001).

Card Sorting Error

Another paradigm that has been used frequently to investigate the occurrence of knowledge/action dissociations is the rule use paradigm (Luria, 1961; Zelazo & Reznick, 1991). In a rule task the children are given explicit instructions and must use the instructions to guide their actions. Zelazo and Reznick (1991) found that 3-year-olds were able to use a specific rule to guide their behavior (sorting all the triangle cards from the circle cards into the appropriate trays) but Frye, Zelazo, & Palfai (1995) found age related differences in the card sort task between the ages of 3- and 5-years of age when the child was asked to switch to a new rule. The 3-year-olds would successfully sort the cards based on the first rule (sort by color) but when asked to switch to a new rule (sort by shape), they persisted in sorting the cards according to the first rule even when they were repeatedly reminded of the new rule on every trial. Interestingly enough, the 4- or 5-year-olds were able to switch to the new rules almost immediately (Frye, Zelazo, Palfai, 1995). Just like the A-not-B-error, the card sorting error posed the question of whether the child is knowledgeable about the new rule and just cannot inhibit a motor response or if there is an expression of cognitive immaturity within the 3-year-olds.

Zelazo, Frye & Rapus (1996) wanted to see if the children who were not able to switch between rule pairs could identify the new rule. In this experiment the researchers
gave 3- and 4-year-old children the dimensional change card sort as in the previous study, and then had the children complete additional trials to assess the children’s understanding of the post-switch rules. After the post-switch trials, the children were asked two knowledge questions and one action question. For the knowledge questions the children were asked what the rules of the game were and the children were asked to point to the appropriate tray. For the action question the children were given another sorting trial similar to the post-switch trials where the child had to place the card in the appropriate tray according to the experimenter’s instruction.

The researchers found that regardless of which dimension (color or shape) was presented to the children first, 3-year-olds were more likely than 4-year-olds to continue using the first rules during the post-switch trials. The 3-year-olds (and a couple of the 4-year olds who failed during the post-switch trials) demonstrated during the additional trials that they understood the new rule (would point to the appropriate tray when questioned about a rule) but continued to sort based on the pre-switch rule even during the action question. This indicates that the 3-year-olds were cognitively aware of the new rule but could not inhibit the overwhelming perseverative motor response.

To challenge the idea of perseverative responses the researchers wanted to also examine whether this apparent dissociation between knowledge and action was due to a failure to inhibit overly learned responses to the test cards. The idea that response interference increases as a function of the number of pre-switch trials would support the notion of perseverative behaviors. Therefore the researchers in a second experiment gave the 3-year-olds one trial before a new rule was introduced. The results indicated that a majority of the 3-year-olds perseverated even after only one pre-switch trial. The
Researchers concluded that although a possibility, it is very unlikely that a 3-year-olds’ ability to inhibit is so weak that one pre-switch trial could provide enough interference to produce inhibitory failure and produce an inappropriate response. In a subsequent experiment, the researchers also determined that 3-year-olds continued to perseverate even when they were instructed to respond verbally to the task; this indicates that response modality is not a factor and the children continue to have difficulty switching rules even when they need to use verbal knowledge.

A more recent study involving the use of the card sorting task and the investigation into the knowledge-action dissociation revealed different results that challenged interpretations of previous study results. Munakata & Yerys (2001) believed that the key to the apparent dissociation lies in the degree of conflict presented to the child. They assert that the action measure has inherent conflict where the child must sort a card with conflicting cues of color and shape into the appropriate tray, whereas the knowledge measure does not provide a corresponding conflict (the children are simply asked to repeat the rule). To assess this theory the researchers tested the role of conflict in dissociations between knowledge and action in the card-sorting task.

The children were presented with the standard version of the task with nonconflict and conflict knowledge questions. An example of a conflict knowledge question would be, “Where do the red trucks go in the shape game?” The results indicated that knowledge and action measures were the same when the child was presented with a conflict knowledge question, demonstrating that the observed dissociations between knowledge and action in the previous card sorting tasks could be associated with the degree of object representation (Munakata & Yerys, 2001). The researchers theorize that
dissociations between knowledge and action may reflect relatively weak representations that are adequate for some types of tasks but not others. They believe that stronger representations are needed when children face conflicting cues and this apparent knowledge-action dissociation is not based on a child’s failure to use their knowledge appropriately. Like the previous A-not-B-error studies, a simple change in the way the task is presented to the child can reduce the instances of error and decrease the apparent dissociation between knowledge and action.

*Scale Errors*

A more recently investigated developmental “error” that is the basis for the present study is the scale error first described by DeLoache, Uttal, & Rosengren (2004). The study concept originated from informal observations of young children attempting to perform actions that were, due to the object’s size relative to the child, impossible. Parents and experimenters, in the research lab or from home accounts, witnessed children trying to get inside of small toy cars, putting doll shoes on their own feet, or trying to sit in dollhouse chairs. These children seemed to make serious attempts at these behaviors and the researchers believed that this was a failure or “error” by the children to use visual information about size when interacting with the objects.

In order to investigate these strange occurrences, the researchers set up a study to systematically examine the incidences of scale errors. The researchers recruited 54 children (29 girls, 25 boys) between 18 and 30 months of age (M = 22 months) to participate in the study. The children were observed in a laboratory playroom with various toys. There were three large target toys – an indoor slide, a child-size chair, and a child-size toy car but the room also contained many other toys and the children were free
to choose what toy to interact with. If the child did not spontaneously interact with the target toys, the experimenter prompted the child to play with the three target toys at least twice. The child was then lead out of the room and the three large target toys were replaced with three identical miniature target toys. The child was then returned to the room and allowed to play with the various toys again. If the child did not spontaneously interact with the miniature replicas, the experimenter would once again prompt the child to interact with them but did not comment on the size of the object.

Very conservative criteria were used in the identification of scale errors. All children were videotaped and a primary coder identified a behavior as a scale error if the following requirements were met: (1) the child attempted to perform part or all of the same action with the miniature toy as with the larger toy, (2) the relevant part of the child’s body for executing that behavior came into full contact with the relevant part of the miniature toy, and (3) the child made a serious attempt to perform the action. One or two additional coders then evaluated each potential scale error and 100% agreement was required between the coders for the behavior to be identified as a scale error.

The distinction between serious attempt to perform an inappropriate action and pretend play was carefully taken into account. All the videotapes were independently coded to identify for instances of pretend play and scale errors were reliably distinguished from pretend play where 58 pretend play episodes were identified. Examples of pretend play included pushing the toy car around on the ground while making car noises or sliding down the slide with their hand. The researchers pointed out that there was no overlap between the behaviors coded as scale errors and those coded as pretend play.
The results of this study indicated that scale errors were committed by 25 of the 54 children and the coders reliably identified 40 instances of scale errors. Fourteen of the scale errors occurred without the experimenter drawing attention to the target object and the results showed no relation between the amount of time spent with the larger target object and the probability of committing a scale error with the miniature target object. The number of errors did differ significantly by age with most of the scale errors occurring with children around 2 years of age.

DeLoache and colleagues speculated many reasons for this apparent inability of the toddlers to use visual information about the object’s size to guide their actions. The researchers first set up an independent control study to rule out that the children simply preferred to interact with the miniature object or that there is a general inability to make appropriate size judgments. The researchers recruited 8 children between 19 and 28 months of age and presented them individually with pairs of large and small objects simultaneously and asked the children to perform a target action. The various target actions included: “Come and sit in the chair,” “Can you go down the side,” and “Drive the car over here.” The results indicated that the children were able to distinguish between the two objects and were able to choose the correct object to interact with when prompted with a target action by the experimenter.

If children are capable of discriminating between the larger and smaller object and are able to choose the appropriate object that corresponds with a target action when the objects are presented together, then why do the children seem to fail at matching the correct response to the corresponding object size? DeLoache and colleagues pointed out that a special feature of these scale errors is that the children in fact do take into account
the object's size when interacting with the object. For example, when a child starts to initiate a scale error with the miniature car, instead of making large scale motions as with the larger toy car, the child bends down to get close to the miniature car and uses a smaller grasping action to open the small door and directs their foot toward the small door opening. The same general actions that were performed with the larger toy were attempted with the smaller toy but it seems as though the children adjusted their movements to the size of the smaller toy.

Similar to the various theories explaining the A-not-B error and the card sort error, DeLoache and colleagues proposed that the scale errors involve a dissociation when using visual information for planning vs. controlling of actions. They believe that when a child sees a replica of a highly familiar object, the visual information from that object activates the child's representation for the larger object. This activated representation also includes motor responses associated with the object and the child is unable to inhibit the activated motor responses and therefore commits a scale error. To account for the children's adjusted movements to the size of the smaller object, the researchers believe that it is after the action plan is initiated that the child uses the visual information about the object size to calibrate movements and motions directed at the object.

Just like the previous two developmental errors, there seems to be an emphasis on the failure of inhibitory control. DeLoache and colleagues recognize that infants and children have difficulty inhibiting prepotent responses but they do not believe that difficulty with inhibitory control can fully explain scale errors. The researchers also suggest that the dissociation between the use of visual information for planning versus
control could substantiate dual process theories of visual processing. There are many theories of visual processing but one of the most cited, and acknowledged by DeLoache and colleagues, is the two visual system hypothesis (Goodale & Milner, 1992; Underleider & Mishkin, 1982; Schneider, 1967). This theory speculates the existence of two neurally and functionally distinct visual systems for action and perception. The dorsal visual stream would mediate the control of visually guided actions whereas the ventral stream facilitates perceptual and cognitive representations of objects. Evidence for the existence of two visual systems has been supported by studies looking at apparent dissociations in action and perception expressed by brain-damaged individuals and normal responses to visual illusions (Glover, 2004; Goodale & Milner, 1992).

The two visual system hypothesis (TVSH) is supported, in part, by the finding that grip formation during grasping is largely immune to the influence of many pictorial illusions (e.g., Aglioti, DeSouza, & Goodale, 1995). Such results suggest that one visual stream controls illusion-susceptible perceptual judgments, while a separate stream controls illusion-resistant visually-guided actions (Glover, 2004; Milner & Goodale, 1995). Much of the evidence for the dissociation of the two visual pathways comes from studies with brain damaged patients who were either suffering form lesions in the posterior parietal lobe or the inferior temporal lobe. Patients with lesions in the posterior parietal lobe were impaired in visuomotor coordination while patients with inferior temporal lobe damage had trouble recognizing objects (Goodale & Milner, 1992).

Different variations of the judgment and reaching tasks using a commonly known visual illusion called the Ebbinghaus illusion have produced inconsistent results, leading many researchers to dispute conclusions regarding the two visual system hypothesis.
This hypothesis implies the presence of two relatively independent, parallel processing streams but recent results by Vishton, Stephens, Nelson, Morra, Brunick, and Stevens (2007) have suggested, however, that as a participant prepares to reach for a target, all visually-mediated responses become less sensitive to the illusion. There is evidence for different visual processing for reaching and non-reaching tasks, but the changes seem to happen on a system-wide basis, influencing all visually guided tasks to the same degree. Based on recent evidence it could be contended that the human visual system possesses two separate modes of processing, one for non-action, verbal responses, and another for visually-guided actions (Brito, Brunick, & Vishton, in prep; Vishton et al., 2007)

DeLoache and colleagues believe that scale errors imply an immaturity in the interaction of the two visual streams of processing which is exhibited by the intermittent failure to integrate the visual information processed by the two systems. In their description of a scale error, the information about the identity of an object, processed by the ventral stream, is not integrated with information about the object’s size, which is processed by the dorsal system. In a review article, Scott Glover (2004) indicated that the scale error research, “offers a unique example of how stored representations of object affordances combined with semantic category knowledge, can overpower immediate visual information in the undeveloped mind” (p. 442). Glover stated that the scale error explanation proposed by DeLoache and colleagues assumes that children (1) have a stored concept of the toy’s actual size in the real world, (2) are able to judge the actual size of the toy (demonstrated by the child’s calibrated movements toward the object), and
(3) experience an interference between the stored concept of the object and the toy itself when an action plan is prepared (Glover, 2004).

Another model presented to explain the occurrence of scale errors presented by DeLoache and colleagues (2004) and highly supported by Glover (2004) is the planning-control model. This model supports the idea that the planning portion of a behavior is influenced by numerous cognitive variables including semantics, visual illusions, and memories of past actions. Stored semantic knowledge for a target object evokes a specific response but once the movement is initiated, the on-line control system (which is uninfluenced by semantic knowledge) ensures correct movement based on the toy’s actual size (Glover, 2004; Glover, 2002; Glover & Dixon, 2001). The planning-control model argues that action planning involves a medial visual stream terminating in the inferior parietal lobes before a response is initiated (Boussaoud, Ungerleider, & Desimone, 1990). The hypothesized key difference between the planning-control model and the action-perception model is that the planning-control model predicts that the early portion of the child’s movement toward the object would be influenced by the stored object representation, movements are then adjusted in flight to the actual size of the toy, whereas the action-perception model predicts that movements toward the object are appropriately scaled from the beginning and there is no interference between stored knowledge and behavior towards the object (Glover, 2004).

Thesis Overview

The planning-control model and the action-perception model attempt to explain the unique intricacies of this developmental error but like the A-not-B error and card sort error, the definite cause(s) is still unclear. Could the occurrence of scale errors be
generally due to the perseveration of automatic responses or are children misperceiving the target object? In the following set of experiments we attempt to distinguish what cues or object characteristics will increase or decrease the chance of these scale errors. Studies have demonstrated that children will reach for objects with one- or two-handed grips that are matched to the size of the reaching target. Infants usually begin reaching around 4 months of age and at that time their reaching efforts are poorly controlled and are often performed with two hands regardless of the objects’ size (Thelen, Corbetta, Kamm, Spencer, Schneider, & Zemicke, 1993; von Hofsten, 1979) and by 8 months of age, infants can preshape their handgrip configuration to adapt to the object’s shape and orientation (von Hofsten & Fazel-Zandy, 1984).

We have replaced the three target toys from the original scale error research with identical objects (cylinders or rectangles) of varying size (See Figure 1) and have associated the occurrence of a scale error to the frequency with which a two-handed grip is selected for objects of different sizes. That is, a scale error (performing an inappropriate action based on the object’s size) is similar to a child using an inappropriate handgrip (one- versus two-handed reach) based on the object’s size. We have examined the role motor priming or perseverative reaching plays on the frequency of two-handed reaches and what cues (size versus shape) are more salient for the child in determining appropriate handgrip.

The last experiment looks to try to understand the child’s comprehension of the changing state of the object by convincing the child that one object is being transformed into varying sizes or that several independent objects (all fully visible) are presented to the child. Another key distinction between this study and the original scale error research
is that a much wider age range of participants has been recruited for the various experiments. Although DeLoache and colleagues found results that scale errors are committed more frequently around 2 years of age, we believe that children of all ages (and possibly even adults) can commit these errors given the precise cues and situation. The following experiments look at the various factors necessary for an individual to commit a scale error and how manipulating those factors can influence an individual’s behavioral response.

EXPERIMENT 1: FREQUENCY OF TWO-HANDED REACHES AS A FUNCTION OF OBJECT SIZE

The first experiment examined how experience reaching for an object of a particular size and shape influences later reaches for other objects. Specifically, we assessed the frequency of one-versus -two-hand reaches. The experimenter presented the participants with a series of objects that were identical in shape, but varied in size, and encouraged them to reach out and lift them. We predicted that familiarization with a particular size would impact how participants will reach for other objects that may differ in size but not shape. For example, if a child successfully has reached for the first object using a one-handed grip, he or she will tend to reach for all objects with that shape using a one-handed grip, even if the type of grip is inappropriate. To explore if the effect was only due to some characteristic of the particular stimuli, some participants were presented with rectangular blocks instead of cylinders. These rectangular blocks were constructed to match the height and width of the cylinder stimuli.
Method

Participants. We recruited forty children (21 males, 19 females) ages 2-to-5 years of age \((M= 34.00\text{ months}, \ SD= 13.00\text{ months})\) from the surrounding community for the cylinder condition and six children (3 males, 3 females) ages 1-to-4 years of age \((M= 27.47\text{ months}, \ SD= 11.79\text{ months})\) were recruited for the rectangle condition. There were five age categories with six children in the 1-year-old group, eighteen children in the 2-year-old group, nine children in the 3-year-old group, ten children in the 4-year-old group and two children in the 5-and-older group. We obtained parental informed consent at the start of the procedure and at the end of the study we offered the children a small toy or sticker for their participation.

Displays and Apparatus. Participants sat in a chair \((45 \text{ cm tall})\) in front of a table surface \((73 \text{ cm tall} \times 152 \text{ cm wide} \times 76 \text{ cm in depth})\). All the participants were presented with seven identical cylinders (identical in shape, color, and texture) of varying size. The ratio of width to height was always 1.35 cm. The seven widths were: (1) 2.7 cm, (2) 3.3 cm (3) 4.0 cm, (4) 5.8 cm, (5) 6.9 cm, (6) 10.1 cm, and (7) 12.7 cm in diameter. The largest object was too large for most children to grasp easily with one hand. We presented the target cylinders to the children on a thin rectangular wooden board \((45.5 \text{ cm tall} \times 61 \text{ cm wide} \times 5 \text{ mm thick})\).

Design. Participants completed 22 reaching trials. All participants began with five trials with the smallest cylinder, then each of the other cylinders in order of size up to the largest cylinder. The experimenter then presented the participant with five trials of the largest cylinder, then each of the other cylinders in order of size down to the smallest cylinder (or in reverse with the largest cylinder primed first). We randomly assigned each
participant, without replacement, to one of two size conditions (smallest cylinder primed first vs. largest cylinder primed first).

**Procedure.** The participants sat in the chair or in the caregiver’s lap. The height of the chair was adjusted so that the participants could easily reach for the objects. If the participant was seated in the caregiver’s lap, the caregiver was instructed to not interfere with the study procedure. The experimenter began the procedure by placing an occluding panel in position in front of the participant to obscure her view while the experimenter placed the first target object onto the middle of the presentation board. The start of the trial was indicated when the occluding panel was removed. The presentation board then was pushed toward the participant until the target object was within reach. The participant was then asked to reach and pick up the target object. The experimenter retrieved the object and the process was repeated for the other various sizes. The end of the trial was marked by the removal of the presentation board by the experimenter. If the participant lost interest or became agitated before all the trials were completed, the session was terminated. All trials were videotaped to record a side-view of the participant’s reaching behavior and the entire procedure lasted approximately 25 minutes.

**Data Scoring and Analysis.** The trials were coded from the videotapes by an independent observer using the Noldus Observer XT 7.0 (Wageningen, The Netherlands) program. The videotapes were coded for the observation of one vs. two handed reaches toward the object and whether the participant was successfully able to pick up the object. The start of a trial was coded with the forward movement of the presentation board and each hand was scored separately. A right and left hand reach within one second of each other within the same trial was coded as a two-handed reach.
We examined the frequency with which a two-handed grip is selected for objects of different sizes. A Repeated-Measures ANOVA was used with object size, prime direction (whether the objects were presented from smallest to largest or largest to smallest), and age category as the independent variables and percentage of two-handed reaches as the dependent variable.

**Results and Discussion**

The frequency of two-handed reaches was found to be a function of the object size. The size of the initial object prime did influence the type of reach performed for successive reaches. We did not find a significant difference for object shape (cylinders versus rectangles), $F(1,34) = 0.001, p = .981$, so for subsequent analyses we collapsed the data across these conditions. We found significant main effects for prime direction, $F(1,30) = 9.100, p = 0.005, \eta_p^2 = .233$ and object size, $F(4,120) = 13.394, p < .005, \eta_p^2 = .309$. Figures 1 shows a significant interaction for prime direction and object size, $F(4,120) = 5.933, p < .005, \eta_p^2 = .165$ for both the cylinder and rectangle condition. We did not find any significant differences between the age categories, $F(1,30) = 0.627, p = 0.647$. When children were primed with the smallest object and then presented with test objects varying in size up to the largest object, there was a strong tendency to reach with one hand (or vice versa for the large prime). These results would indicate that there is strong tendency to use the same type of reach after being primed with a specific sized target and these results were not due to a unique characteristic (specific shape) of the target object.

EXPERIMENT 2: FREQUENCY OF TWO-HANDED REACHES AS A FUNCTION OF OBJECT SIZE AND OBJECT SHAPE
The second experiment examined how object size and shape familiarity influenced the frequency of one or two-handed reaches when the participant is primed with a particular size and a particular shape. We predicted that familiarization with a particular size and shape would impact how participants would reach for other objects and that the frequency of one or two handed reaches would be more consistent if the shape did not change. We also predicted that changing the shape of the object would influence the participant's grip selection more than the size of the object.

**Method**

*Participants.* We recruited 102 children (52 males, 50 females) ages 1-to-4 years of age (M= 25.98 months, SD= 12.74 months) from the surrounding community. There were five age categories with forty children in the 1-year-old group, twenty-five children in the 2-year-old group, twenty-one children in the 3-year-old group, and sixteen children in the 4-year-old group. We obtained parental informed consent at the start of the procedure and at the end of the study we offered the children a small toy or sticker for their participation.

*Procedure.* The materials, study design, procedure, and analysis were identical to those described in Experiment 1 except as noted here. The participants completed 28 trials and were only presented with the smallest (1), largest (7), and middle-sized (5) objects. The ratio of width to height was always 1.35 cm and the three widths were: (1) 2.7 cm, (5) 6.9 cm, and (7) 12.7 cm in diameter. The experimenter presented the participant with five trials of the smallest object, then one trial of the middle-size and largest object each. The presentation of objects was repeated, and then the order was reversed with five trials of the largest object and one trial of the middle-size and smallest
object (or vice-versa with the participant starting with the largest prime). The shape of the two test objects either remained the same after the prime object or changed shape.

We examined the frequency with which a two-handed grip is selected for objects of different sizes. A Repeated-Measures ANOVA was used to assess how the frequency of two-handed reaches varied as a function of age, initial prime size, and object shape.

Results and Discussion

Across all five age categories we found a significant main effect for the initial prime size, $F(1,85) = 29.045, p < .005, \eta^2_p = .255$ and a significant interaction for initial prime size and object shape, $F(1,85) = 7.048, p < .005, \eta^2_p = .077$ (Figure 2). We did not find a significant main effect for object shape across all six age categories, $F(1,85) = 2.882, p = .093$ (Figure 3). These results indicated that like the previous experiment, the initial prime size is an influential factor in the frequency of two-handed reaches. An interesting finding in this experiment is the tendency to stay with the same reach type for objects with the same shape but not for objects with a different shape. When a child is primed with a particular sized object she is more likely to continue with that reach type (one versus two-handed reach) for objects with the same shape and will change reach type when a different shaped object is presented.

Further analyses revealed a significant main effect for shape, $F(1,91) = 8.813, p = 0.004, \eta^2_p = .88$, across all age categories for the smallest object prime but not for the largest object prime. We found no significant differences for object shape within each age category individually but when consecutive age groups were examined we did find significant differences: (1) One-year-olds & Two-year-olds $F(1,57) = 5.980, p = .018, \eta^2_p = .095$, (2) Two-year-olds & Three-year-olds $F(1,38) = 7.517, p = .009, \eta^2_p = .165$, and
(3) Three-year-olds & Four-year-olds $F(1,32) = 7.891, p = .008, \eta^2_p = .198$. The results demonstrated differences between adjoining age groups for object shape but there is no definite trend or peak frequency, which made it difficult to assess any developmental differences. The relationship between object shape and small prime size could be due to the small hand size of the children and this will be determined in future analyses.

The first two experiments look at how the object characteristics can influence the occurrence of one or two-handed reaches. Experiment 2 indicates the presence of shape-specific action perseveration and the following experiment explored whether it is simply shape-specific perseveration or individual object-specific perseveration that produced the observed trend.

EXPERIMENT 3: FREQUENCY OF TWO-HANDED REACHES AS A FUNCTION OF THE NUMBER OF OBJECTS VISIBLE

The third experiment explored the idea of scale errors further by examining the child’s knowledge of the object. In the previous experiments and in the original scale error research, the children were presented with various objects of different sizes to interact with, but how the child conceptualized the changing size of the object is unknown.

In this experiment, we attempted to bridge from the occurrence of scale errors (frequency of one vs. two-handed reaches and inappropriate grip type) to the child’s understanding of the changing state of the object. We presented the children with one of two extremes: (1) a “transformation machine” that seems to transform the same object from one size to another and (2) visual access to all three objects while performing the trial. That is, in the transformation condition, participants were led to believe that only
one object was used throughout the experiment. In the visual access condition, it was made clear that a collection of three objects was used. We predicted a higher occurrence of scale errors if the child believed that the object was the same, and we predicted that this would produce inappropriate grip types even if there were drastic changes in size.

Method

Participants. We recruited 146 children (73 males, 73 females) ages 2-to-6 years of age (M= 54.59 months, SD= 9.97 months) from the surrounding community. There were four age categories with thirteen children in the 3-year-old group, fifty children in the 4-year-old group, sixty-seven children in the 5-year-old group, and sixteen children in the 6-and-older group. We obtained parental informed consent at the start of the procedure and at the end of the study we offered the children a small toy or sticker for their participation.

Displays and Apparatus. Participants sat in a chair (45 cm tall) in front of a table surface (73 cm tall x 152 cm wide x 76 cm in depth). The participants were only presented with the smallest (1), largest (7), and middle-sized (5) cylinders. The largest object was too large for most children to grasp easily with one hand. The target cylinders were presented to the children on a rectangular board (27.0 cm long x 21.5 cm wide x 1 cm thick). A smaller board was used in this experiment to fit underneath of the transformation machine. The transformation machine consisted of 5 air condition vents assembled together around a wooden frame (53.5 cm long x 38.5 cm wide x 38.5 cm tall). The bottom of the crate was open in order for the machine to be placed over the target objects and there was a trap door on the back of the machine to covertly change the objects without the participant’s knowledge. The transformation machine made futuristic
mechanical noises and flashed a bright light when engaged with a switch on the front exterior. Two identical toy trains (big - 6.1 cm long x 3.2 cm wide x 4.2 cm tall and small - 13 cm long x 5.5 cm wide x 7.6 cm tall) were used to demonstrate how the machine worked and the transformation machine was only used in the transformation condition.

Design. Participants completed 21 reaching trials. All participants began with five trials with the smallest or largest cylinder, then each of the other cylinders in order of size. The process was then repeated twice more. We randomly assigned each participant, without replacement, to one of two size conditions (small prime vs. large prime) and to one of two experiment conditions (transformation vs. fully visible).

Procedure. The participants sat in the chair or in the caregiver’s lap. The height of the chair was adjusted so that the participants could easily reach for the objects. If the participant was seated in the caregiver’s lap, the caregiver was instructed to not interfere with the study procedure.

In the transformation condition the experimenter began the experiment by familiarizing the child with the transformation machine. All exterior sides of the machine were shown to the child and the capability of the machine was also explained. The researcher explained to the participant that the machine could make objects bigger or smaller (the red button on the machine made objects smaller and the blue button on the machine made objects bigger).

The researcher first performed a demonstration before the test trials. The experimenter placed an occluding panel in position in front of the participant to obscure their view while the experimenter placed the bigger toy train onto the middle of the presentation board. The occluding panel was removed and the experimenter stated to the
child that the machine was going to make the toy smaller. The transformation box was put over the train and the participant was instructed by a second experimenter to push the red button and turn on the switch to start the machine. While the participant was preoccupied with the lights and sounds, the first experimenter switched the bigger toy train for the smaller toy train through the trap door. When notified by the first experimenter, the second experimenter instructed the participant to turn off the machine. The transformation machine was lifted aside and the smaller toy train was revealed to the participant. The process was then repeated going from the smaller toy train to the bigger toy train (the participant this time was instructed to push the blue button in order to make the toy bigger again).

After the demonstration period ended the test trials began. The start of the trial was indicated when the occluding panel was removed and the presentation board was pushed toward the participant until the target object was within reach. The participant was then asked to reach and pick up the target object. The experimenter held the occluding panel to the side until the participant picked up the target object, after which the process was repeated for the other various sizes. The end of the trial was marked by the removal of the presentation board by the experimenter. The key point in the transformation condition is that anytime the target object changed size (big to small or small to big), the transformation machine was used to convince the child that the same object was being manipulated and presented.

In the fully visible condition, the procedure is identical to those described in the transformation condition except as noted here. The transformation machine is never used and there was no demonstration with the toy trains. All three cylinders were in plain view
on the table, but not within reaching distance, of the participant the at all times and were only hidden from the participant’s view by the occluding panel when a new object was being placed on the presentation board (in order to reduce experimenter influence of one or two handed grip selection of the object). To rule out the possibility of a delay effect in the transformation condition, in the fully visible condition the experimenter waited five to seven seconds (the same amount of time as the transformation condition) before presenting a different sized target object to the participant. The key point in the fully visible condition is that all three cylinders are in view when the participant is reaching for the target object, in an effort to make the size changes more apparent.

If the participant lost interest or became agitated before all the trials were completed, the session was terminated. All trials were videotaped to record a side-view of the participant’s reaching behavior and the entire procedure lasted approximately 25 minutes.

Data Scoring and Analysis. The trials were coded from the videotapes by an independent observer using the Noldus Observer XT 7.0 (Wageningen, The Netherlands) program. The videotapes were coded for the observation of one vs. two handed reaches toward the object and whether the participant was successfully able to pick up the object. The start of a trial was coded with the forward movement of the presentation board and each hand was scored separately. A right and left hand reach within one second of each other within the same trial was coded as a two-handed reach.

We examined the frequency with which a two-handed grip is selected for objects of different sizes. A 2x2 ANOVA was used to assess how the frequency of two-handed reaches varied as a function of initial prime size and experiment condition.
Results and Discussion

The frequency of two-handed reaches was a function of the object size and influenced by both the experimental condition and the initial object prime. We performed an ANOVA with condition and initial prime size as the independent factors and the percentage of two-handed reaches as the single dependent variable. Significantly more two-handed reaching was found in the fully visible (M=0.545, SE=0.038) than in the transformation condition (M=0.381, SD=0.039), $F(1,142) = 9.816, p = .003$, $\eta_p^2 = .057$ (Figure 4). This main effect was unexpected, but not central to the question at hand. At issue is the influence of target size increase and decrease on this measure.

We also found a significant difference between the initial prime size $F(1, 142) = 55.908, p < .005$, $\eta_p^2 = .289$. Children across all four age categories were significantly more likely to reach for the target object with two-hands in the fully visible condition and were more likely to reach with two-hands if they were primed with the larger cylinder first. Figure 5 shows a significant interaction between experimental condition and initial prime size $F(1,142) = 32.397, p < .005$, $\eta_p^2 = .181$ indicating that children in the fully visible condition were more likely than children in the transformation condition to continue with the same type of reach as the reach used during the initial prime.

Preliminary analyses indicated that there were no significant differences between the four age categories for the frequency of two-handed reaches but individual analyses were performed on each category to determine any developmental trends. We found significance for initial prime size in each of the four age categories: (1) Three-year-olds $F(1,8) = 11.191, p = .010$, $\eta_p^2 = .583$, (2) Four-year-olds $F(1,48) = 21.628, p < .005$, $\eta_p^2 = .311$, (3) Five-year-olds $F(1,65) = 18.015, p < .005$, $\eta_p^2 = .217$, and (4) Six-year-olds
F(1,9) = 6.997, \( p = 0.027, \eta_p^2 = .437 \). We did not find a significant main effect for condition or an interaction effect for the three-year-olds and the six-year-olds but did find a significant interaction of condition and initial prime size for the four-year-olds, F(1,48) = 7.867, \( p = 0.007, \eta_p^2 = .141 \). The five-year-old age group was the only age category to have significant values for the experiment condition, F(1,65) = 9.002, \( p = 0.004, \eta_p^2 = .122 \), and the interaction, F(1,65) = 17.219, \( p < .005, \eta_p^2 = .209 \), as well as the initial prime size. These results suggest that the effects of condition and initial prime size are the most influential within the five-year-old category but it should be noted that the five-year-old category also had the highest number of participants and the age differences could be attributed to sample size differences. Further trials to even the sample sizes need to be performed before any conclusive developmental trends can be assessed.

General Discussion

The demonstration of scale errors in the original research by DeLoache and colleagues is a unique observation of the intricacies of the cognitive, perceptual, and motor systems. It has been shown that from the age of three, children are capable of perceiving what objects afford action for themselves or others (Rochat, 1995) but clearly the scale error studies exhibit failure to either demonstrate this knowledge or inhibit a strong motor tendency. In our current set of studies we have tried to systematically tease apart the distinctive characteristics that make up this developmental error. Like both the A-not-B-error task and the card sort task, the incidences of scale errors can be influenced by slight changes in task ambiguity or difficulty, which could suggest that the cause of scale errors can be explained better by motor priming or perseverative behavior accounts.
In the first experiment we looked at the frequency of two-handed reaches as a function of the object size. To reach accurately toward an object involves encoding its location and grasping an object requires coding of the intrinsic features of the object such as its size, shape, and orientation (Arbib, 1985; Jeannerod, 1988). Newell, Scully, McDonald, and Baillargeon (1989) demonstrated a systematic relationship between the size of the object and the number of fingers used in the grip for infants as young as four months of age. We found a definite relationship between object size and the number of hands used to pick up the object and there was a strong motor priming tendency where children were inclined to stay with the same reach type after the priming trials. The results also indicated that this relationship was not particular to a specific object shape. We did not find any significant age differences between groups for the frequency of two-handed reaches, which could indicate that the error of using an inappropriate reach type could be demonstrated across all ages (even with adults) if a particular situation is presented.

The second experiment looked at the frequency of two-handed reaches as a function of both size and shape of the object. Studies have indicated that infants can process feature information and use this information to individuate objects (Wilcox & Baillargeon, 1998; Wilcox & Schweinle, 2002). Wilcox (1999) demonstrated that infants could use characteristics of shape at seven months, texture at eleven months, and color at twelve months of age to distinguish objects. We found the same relationship between object size and two-handed reaches, but our results also indicated that the tendency to continue reaching with the same reach type decreases when presented with a different shaped object.
The ability to discriminate objects based on properties/characteristics has been demonstrated in many studies. Bushnell and Boudreau (1993) found that some properties such as size and temperature demand minimal control of the hand and fingers, whereas other properties such as weight and shape require much greater control and attention. The researchers also reviewed ages at which infants first discriminate different object properties and concluded that the sequence corresponds to developmental changes in the control of the hand and fingers. Needham and Baillargeon (1995) found that infants by the age of eight months can use object properties, such as color and shape, to help them interpret ambiguous arrangements of objects and this ability was shown for four and five month old infants when infants were given prior experience with the objects.

Our results indicate that the object property of shape is salient enough to decrease the perseverative behavior across all ages. Cook and Odom (1992) found that 5-year-olds, 11-year-olds and adults all avoided classifications based on overall similarity of objects and instead paid attention to single dimensions. Many classification studies have shown that some dimensions are more salient to individuals than others (Odom & Cook, 1984; Thompson & Massaro, 1989). Perhaps the greater control needed to grasp for different shaped objects (or change of grip formation) and the higher salience for the property of shape lead to the disruption of the motor priming in this task. We are currently conducting a study on the relationship between two-handed reaches as a function of object size, object shape, and object color to assess what properties decrease perseverative behavior and to what extent.

The last experiment examined reaching responses based on the number of known or visible objects. In the fully visible condition all the objects, and the apparent size
differences between the three objects, were visible to the participant. The perseverative reaching behavior still occurred across all age groups and this result supports the motor priming explanation. The children had access to size difference information but could not make appropriate reaches after being primed with the small or large prime. Prior studies have found that infants who reach immediately after the cue (no time delay) in the A-not-B-error task were less likely to perseverate and more likely to make the correct choice (Wellman, et al., 1986). In the fully visible condition, after the priming the children were exposed to a delay before being presented with the target object and the frequency of two-handed reaches was still related to the initial prime object size.

In the transformation condition we wanted the child to believe that the same object was being presented each time but in varying sizes. This concept originated from a study conducted by DeLoache, Miller, and Rosengren (1997) where the researchers compared the performance of 2 ½-year-olds in symbolic and nonsymbolic versions of a search task. The children in the symbolic condition had to watch the experimenter hide a toy in the larger room and then find the toy in a scale model of the room, which was located in an adjoining room. The children in the nonsymbolic condition were told that a shrinking machine could make the room (and all the components of the room) larger or smaller. The children in the nonsymbolic condition first watched the experimenter hide the toy in the larger room, and then were escorted out of the room while the shrinking machine transformed the room. The children returned to the room to find the scale model and were instructed to find the toy. The children in the nonsymbolic search task were much more successful retrieving the toy than the children in the symbolic condition. The researchers reasoned that 2 ½ - year-olds have difficulty representing symbolic relations
and therefore the children in the symbolic condition were not able to use the scale model as a symbol for the larger room.

In the original scale error research and in the first two experiments presented, the number of objects presented to the child is not explicit. In the transformation condition we wanted the child to believe that the same object was being presented with the reasoning that if the child thinks it’s the same object, then they would be more inclined to use the previous reach style. One possibility is that the transformation condition heightened their attention and therefore made the children more aware of the size differences. Diamond (1998) found that infants made significantly fewer A-not-B-errors when the toy was different from the toy used on previous trials and when the infants’ interest in that toy was high. In the same study, all infants reached correctly, even with a delay, if the researcher substituted pieces of cookie for the hidden toys in the task.

Another explanation for the decrease in perseverative reaching could be attributed to the verbal cues in the transformation condition. The children could have associated the appropriate reach with the words “bigger” and “smaller” used by the experimenter. In a future study we would like to perform the transformation condition without the verbal cues and analyze the frequency change of reach type. If more errors occur we can attribute our results to the verbal cues, and no change in errors or fewer errors would support the attention explanation. In future studies we would also like to increase our sample size, especially for the younger age groups, to not only assess developmental trends but to also look for similarities and differences between our set of studies and the original scale error research.
A key difference between our studies and the original scale error research is the idea of object representation. We viewed the original scale errors as a visuomotor phenomenon where the child identified the object’s shape, color and texture but ignored the size of the object when producing a behavioral response. An alternative explanation is that this is a cognitive phenomenon and this alternative would predict that the child identified the object’s name or purpose and this representation influenced the occurrence of the errors. The target objects used in the original scale error research were all highly familiar objects and it could be assumed that many of the children had various levels of experience with these objects. The target objects in our research were not as familiar to the children and the low level of experience could be a factor in the rate of perseveration. In a future study we would like to explore the idea of scale errors as a cognitive phenomenon and present children with the target objects but label the objects to make the object’s identity more salient to the child.

As Thelen, Schoner, Scheier, and Smith (2001) suggest, information is not as simple as the traditional input-transduction-output stream, and because perception, action, decision, execution, and memory all work together, information is often time-based and responses reflect patterns of cooperative and competitive interactions. The failure or error in the A-not-B, card sort, and scale error tasks all come from the same multiple processes that produce goal-directed reaching at any age. The experiments in this thesis aimed to further add to the existing literature to fully understand what features or characteristics infants/children look at to help them understand how to interact with objects and the developing relationship between the perception and motor systems.
References


temporal visual areas in the macaque. *Journal of Comparative Neurology, 296*, 462-495.


Figure Captions

*Figure 1.* Study Stimuli.

*Figure 2.* Percentage of two-handed reaches as a function of prime direction and object size across all ages for both cylinder and rectangular objects.

*Figure 3.* Percentage of two-handed reaches as a function of initial prime size and object shape.

*Figure 4.* Percentage of two-handed reaches as a function of object shape across all ages when primed with the smallest object.

*Figure 5.* Percentage of two-handed reaches for both transformation and fully visible conditions across all ages.

*Figure 6.* Percentage of two-handed reaches for experimental condition and initial prime size across all ages.
Percentage of Two-Handed Reaches

Object Size

- All Cylinder
- All Rectangle
Percentage of Two-Handed Reaches

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<tr>
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<th>Small Object Prime</th>
<th>Large Object Prime</th>
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<tr>
<td>Same Shape</td>
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Shape Change

Percentage of Two-Handed Reaches

0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

Different Shape

Same Shape
Percentage of Two-Handed Reaches

Age (Years)

Same Shape
Different Shape
Percentage of Two-Handed Reaches

Age (Years)

Fully Visible
Transformation
Vita

Natalie Hiromi Brito

Natalie Brito was born in Okinawa, Japan on August 29, 1983. She completed her undergraduate studies at the University of Virginia in May of 2005 earning a bachelor’s degree in Psychology. In August 2006, she entered the College of William and Mary to pursue a Master’s degree in Experimental Psychology. Natalie defended her thesis in July of 2008 and will attend Georgetown University to pursue a PhD in Human Development and Public Policy.