CHAPTER FIVE

Action Errors: A Window Into the Early Development of Perception—Action System

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Abstract

In this chapter, we explore an interesting class of behaviors, referred to as action errors, which, we argue, provide a window in to the early development of the perception—action system. As we examine these behaviors, we discuss how acquisition of motor and cognitive skills interact at particular periods of development to make children more likely to perform action errors. However, we also provide evidence that even adults perform action errors under certain task demands. We argue that it is fruitful to examine the developing perception—action system in terms

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of the dynamic interplay of constraints within the environment, the individual child, and the task that they are attempting to complete. This interaction of constraints is dynamic and multiply determined, which is why action errors do not occur whenever a child sees a photograph of an object, views a tiny chair, or interacts with grandparents over interactive media. We argue, however, that not all constraints are weighted equally in the emergence of a specific behavior. Rather, the child's goal or intention plays a key role in organizing factors that lead to a specific behavior.

1. INTRODUCTION

Young children exhibit incredible variability in behavior over the first few years of life, as they explore the complex dynamics between their growing and changing bodies and the environment. As children acquire greater control of their developing bodies, they gain sufficient control over their muscles to coordinate limbs and joints in purposeful actions, enabling them to successfully initiate and complete a desired course of action. However, successful completion of any action also involves accurately perceiving what the environment affords for action. While some of these affordances may be derived from adaptation to environmental pressures over the course of human evolution, others may need to be learned in an increasingly designed and technologically complex environment. In this manner the developing perception–action system is also influenced by gains in cognitive skills related to executive function, conceptualization, and learning more generally. While much of the gains in the perception–action system may lead to an overall decrease in variability in behavior as children develop and acquire preferences for particular forms of action (e.g., crawling, walking, running), variability in behavior is common as children acquire new skills. Children often exhibit a wider range of behaviors than adults as they come to learn what the environment affords for their actions, and some of these behaviors are quite interesting to explore from a researcher's perspective.

In this chapter, we explore an interesting class of behaviors, referred to as action errors, which, we argue, provide a window into the early development of the perception–action system. As we examine these behaviors, we discuss how acquisition of motor and cognitive skills interacts to lead children at particular periods of development to be more likely to perform action errors than children at other periods of development and adults. However, we will also provide evidence that even adults perform action errors under certain task demands.

We begin this chapter by defining what we mean by the term action error and distinguish these types of errors from other motor errors. We then provide evidence for different types of action errors—grasp, scale, and media errors—and then describe, based on current evidence, the likely developmental time course of these behaviors. We then turn to explain how a study of action errors may illuminate interesting aspects of the development of the perception–action system. In this explanation, we outline how action errors emerge from a dynamic interaction of constraints within the environment, the developing child, and the tasks that they are attempting to accomplish. We also highlight that to understand the development of the perception–action system, it is important to consider cognitive development and symbolic understanding.

2. WHAT ARE ACTION ERRORS?

We define action errors as a class of behaviors that involve attempts to perform a desired action, but the behaviors cannot be successfully carried out because aspects of the environment do not afford the desired action. A prototypical example of an action error is when a young child attempts to sit unsuccessfully in a tiny doll-sized chair that is way too small to accommodate his or her body. DeLoache, Uttal, and Rosengren (2004) labeled these behaviors, "scale errors," as it appears that when children perform these actions they do not take in to account the scale of the object with respect to the size of their bodies. Two other forms of action errors have been proposed by Rosengren and French (2011), Rosengren et al. (2018): grasp errors and media errors. Grasp errors are defined as actions where an individual attempts to pick up or grasp at an object that is depicted on a two-dimensional surface, such as a photograph, or an electronic screen. An example of this behavior is when a young child attempts to pick up a toy that is shown in a photograph (DeLoache, Pierroutsakos, Uttal, Rosengren, & Gottleib, 1998). Media errors occur when an individual attempts an action with some form of technology that cannot be completed because the action is attempted through the media. An example of this behavior occurs when a child tries to pass or receive something from an individual interacting with the child using interactive technology. In the sections that follow, we first justify the use of the label "error" with respect to these behaviors, contrast these behaviors with other types of errors, and then provide an outline of what we know about these behaviors with respect to their developmental time course.

2.1 Why Call These Behaviors "Errors"?

Is it appropriate to label children's unsuccessful actions as "errors?" The term "error" often conjures up the idea of a mistake or a blunder. Our use of "error" is deliberate and is based on the work of James Reason, a human factors researcher, who defined an error as "an occasion in which a planned sequence of mental or physical activities fails to achieve its intended outcome and when these failures can't be attributed to intervention of chance agency" (Reason, 1990, p. 9). We label the behaviors as "action errors," as our focus is on physical activities that fail to achieve an intended outcome. A central part of the use of the term "error" to describe these behaviors is that behavior is goal-directed. That is, in attempting these actions, a young child is intending to perform a specific action to accomplish a desired outcome. For example, in performing a scale error with a tiny chair, the child acts as to actually sit in the chair but is unsuccessful owing to the small size of the chair with respect to their own body. The issue is that the child is *intentionally* making an attempt to fit his or her onto an object that is too small to accommodate him or her. Children who perform grasp errors are also *intentionally* attempting to pick up a photographed or pictured object. Reason's definition of "error" can be appropriately applied to both these scenarios, as children are executing a planned sequence of motor actions that fail to achieve an intended outcome.

2.2 Action Errors Versus Motor Errors

Action errors differ from a number of other types of motor errors. For example, a child might attempt to throw a bean bag into a bucket. However, their attempt misses the target. Errors such as this may stem from lack of skill on the part of the child. As they become more proficient at tossing the bean bag in to the bucket, but miss only every once in a while, the miss may be due to random variability within their motor system. Schmidt (1982, pp. 201–202) has referred to these types of motor behaviors as "errors in execution." A key difference from our view of action errors is that these errors do not involve an attempt to accomplish a goal that is not afforded by aspects of the environment. Errors of execution may be reduced by practice, heightened attention to the goal, or specific training with respect to sports.

Schmidt (1982, pp. 201–202) also discussed "errors in selection." He defines these errors as a situation where an individual chooses a course of action, initiates the action, but the action is wrong for the particular environmental situation. In this case, they are wrong in terms of the action leading to an undesirable outcome and not wrong because the environment does not afford the action. For example, a tennis player may expect that his or her opponent is going to attempt to hit a drive past his or her on the left side of the court and so the player starts to move in that direction. However, the opponent hits a drop shot to the right side of the court and the tennis player is unable to return the shot because they have chosen the wrong action for this particular situation. Errors in selection can be reduced by choosing to change the action that was initiated (e.g., the tennis player could start moving left and then correct their movement to move to the right) or potentially delaying the initial action until more information is available (e.g., waiting until it is clear where the opponent plans to hit the tennis ball).

Both errors in execution and selection were framed by Schmidt (1982) in terms of motor programs. For errors in execution he suggested that the error stems from variability in the motor system. For errors in selection, he suggested that the error stems from choice of the wrong motor program. Neither of these errors was viewed by Schmidt as stemming from aspects of the perception—action system, rather they focus only on the function of the motor system. In contrast, we view action errors as stemming from the interaction of cognition and the perception—action system.

2.3 Action Errors Versus Slips of Action

Action errors are conceptually different from another form of errors involving actions. For example, Norman (1981) labeled another class of behaviors that involve action but are not intended as "slips of actions." We want to emphasize that the key part of this definition is that these action slips are unintended. These behaviors have generally been studied in adults performing routine, everyday tasks, such as taking a shower or making coffee (Heckhausen & Beckmann, 1990; Norman, 1981; Reason & Mycielska, 1982).

Slips of action are common when a desired action deviates from some sort of routine behavior that has been carried out on numerous occasions. For example, an individual might use the same walking route almost every day to go from home to his or her office and back home at the end of the day. However, one day he or she may want to stop on the way home to buy a gallon of milk. A slip of action occurs when the individual completes his or her daily routine and fails to stop to buy milk. The distinction between action errors and slips of action hinges on whether the "error"—attempting to sit in tiny chair or failing to buy milk—is intended. In the case of attempts to sit in the tiny chair, the action, sitting, is intended. In the case of failing to buy milk, the action, continuing to walk home without the milk, is not intended.

Norman (1981) suggested that slips of actions appear to result from: (1) conflicts between different possible actions or thoughts, (2) mixing up the sequence of a particular action sequence, and/or (3) selection of an appropriate action but in a situation or context where the action is inappropriate for the context or situation in some manner. The third group of slips of action seem similar to what we have defined as action errors, but the two actions differ in terms of whether the action itself is intended or not. Norman (1981) has suggested that these action slips are most likely caused by multiple factors, with potentially different factors playing roles in the different types of action slips.

Human factors researchers have been particularly interested in action slips, as even a minor action slip may have serious consequences if it occurs while driving a car or flying a plane (Botvinick & Blysma, 2005). Researchers have also been interested in action slips under the assumption that by understanding the characteristics of them and the situations where they occur, researchers can gain insight in to the processes and mechanisms involved in the control of routine behaviors that involve a series of steps or sequences (Heckhausen & Beckmann, 1990; Schwartz, 1995). Similarly, we suggest that by studying action errors, we may gain insight in the development of the perception–action system more generally. Slips of actions and action errors may also have some characteristics in common—an issue we will pursue further in a later section.

3. SPECIFIC TYPES OF ACTION ERRORS

As described in the introduction, three different types of action errors have been identified: grasp errors, scale errors, and media errors. In this section, we provide a review of research describing each of these different types of action errors and then provide a tentative time course for their developmental progression.

3.1 Grasp Errors

Of the action errors that we have described, grasp errors were the first to be documented formally (DeLoache et al., 1998), although anecdotal reports of their occurrence were reported quite a bit earlier (Murphy, 1978; Ninio & Bruner, 1978). They have also been documented to occur earlier in development than the other types of action errors. As described above, we define these behaviors as attempts to pick up or grasp an object that is depicted on a two-dimensional surface. We refer to these behaviors as "errors" because the two-dimensionality of the pictures does not enable the successful performance of the action, and from all appearances, they are intentional actions. Although the original work by DeLoache et al. (1998) described young children's grasp errors while young infants were interacting with realistic photographs of common objects and toys, these behaviors can occur with touch pads, video monitors, and other forms of technology.

DeLoache et al. (1998) reported four studies investigating the manual exploration of color photographs in infants between the ages of 9 and 19 months. In the first three studies, they found that all 10 9-month-olds explored the photographs as if they were real objects. Eight of the 10 children were reported to attempt to grasp at the pictured object, with a number of infants making repeated attempts to grasp the depicted objects in the photograph. This finding that some infants are highly persistent in making action errors is consistent with results found by other investigators (Rosengren, Schein, & Gutiérrez, 2010) and will be discussed in further detail in a later section. A second study presented 9-month-olds simultaneously with actual toys and photographs of the same toy. The infants overwhelmingly made their initial reach toward the real object rather that the photograph and spent much more time interacting with the real object than the photograph, suggesting that children can perceptually differentiate real objects from their photographic referent and that they prefer the real objects over the photographs. An additional study by these researchers established that manual exploration of photographs decreased from 9 to 19 months of age and was replaced by pointing at the depicted objects.

A final study in this initial report examined whether manual exploration of photographs could be found in a culture where photographs were not at all common. For this study, DeLoache et al. (1998) examined whether Beng infants, from a culture living in the Ivory Coast, would also manually explore photographs. They provided picture books containing photographs of both Western infant toys and common objects found in the Beng culture to 8- to 18-month-old infants. DeLoache et al. (1998) reported that the Beng infants behaved similarly to the 9-month-olds in the United States, manually exploring and attempting to grasp some of the depicted objects.

DeLoache et al. (1998) interpret young infants' manual exploration, and attempts to grasp at objects in the photographs, as indicative of young infants' uncertainty of what a photograph affords for action. They further suggest that it is through experience with investigating the nature of photographs that children acquire a concept of "picture." Part of this concept involves understanding that a picture or photograph can both be an object in itself but can also represent something else (i.e., the depicted object). This is a central part of DeLoache's model of dual representation (DeLoache, 2000; DeLoache, Miller, & Rosengren, 1997). We suggest that learning about the dual nature of symbols is a key aspect to the decline of action errors, a point we return to in a later section.

The existence of grasp errors, and whether they occur in many if not all children, is not without controversy. Yonas, Granrud, Chov, and Alexander (2005) argue that children actually do not grasp at pictures and treat objects and photographs differently. Note though, DeLoache et al. clearly do state that infants prefer the real object to its photographic referent. Others have questioned what it means when infants sometimes grasp at objects in photographs and whether this indicates that infants must learn what pictures and photographs afford for action (Ziemer, Plumert, & Pick, 2012).

Part of the discrepancy in whether children can be interpreted as making grasp errors can be explained by differences in methodology and part can be explained by different theoretical orientations. From an empirical perspective, we would argue that given highly realistic photographs, young infants do make grasp errors, at a relatively high rate under some conditions (Rosengren & French, 2011). Indeed, if one examines the behavior of young infants to objects and their photographic referents, one finds that the same actions are in fact attempted with the real object and the depicted one. Figs. 1 and 2 provide examples of three infants performing actions that lead them to successfully grasp an object and unsuccessfully attempt to grasp a depicted object. As can be seen in Fig. 1, the infants are using the same hand configurations for both the real object (Fig. 1A) and object depicted in the photograph (Fig. 1B). Fig. 2 shows, with the same infant captured in successive frames, that the sequence of actions directed toward the real object (Fig. 2A) and depicted one (Fig. 2B) are highly similar.

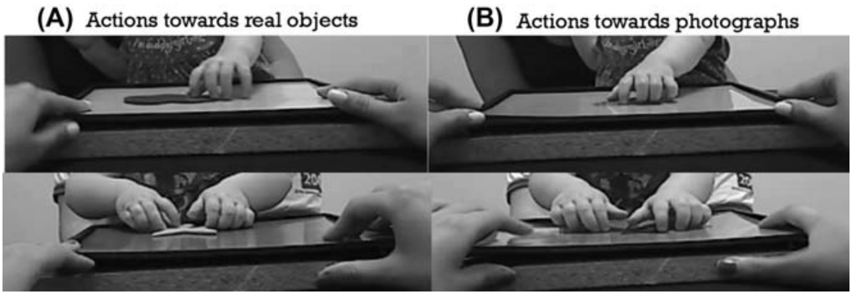

Figure 1 Examples of two young infants' behavior directed toward real objects (A) and photographs of objects (B).

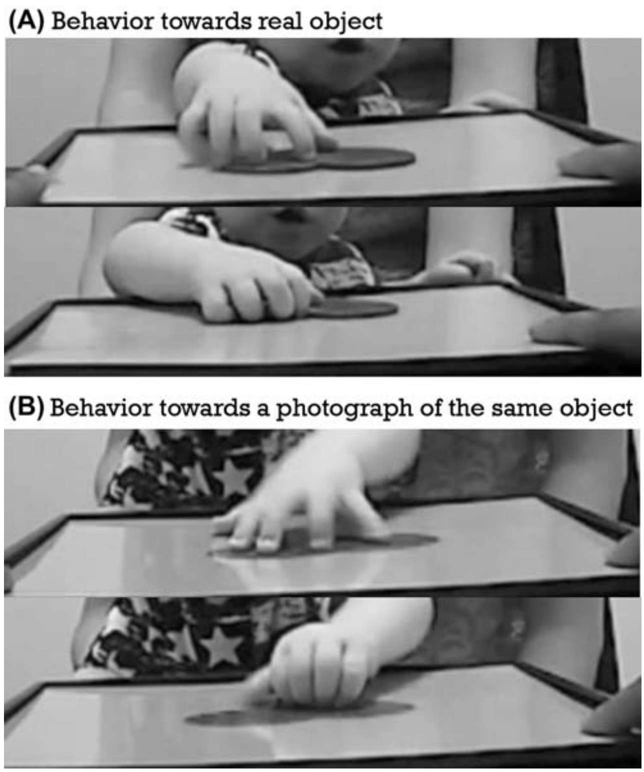

Figure 2 An example of the same infant picking up a real object (A) and making similar hand movements to the same object depicted in a photograph (B). The figure demonstrates similar sequential actions directed toward the object and photograph.

Furthermore, there is anecdotal evidence that adults perform grasp errors under certain conditions. One example was reported to the second author. In this report, another researcher explained that she was late to run an experiment and went to grab a pencil to have a participant complete a survey. She grasped at what she thought was a pencil, only to find that it was in fact a photograph of a pencil. Another anecdotal example of a grasp error was provided by the editor of this volume. One day she was in a hurry cleaning up her desk, and she went to grasp an object that she wanted to throw away. However, the object turned out to be a picture on a flyer rather than a real object. We have also confirmed that under time constraints, adults in a laboratory study can be induced to make grasp errors (Rhoad, Bruton, French, Gutiérrez, & Rosengren, 2012).

Grasp errors have not only been found in humans. Certain species of primates (e.g., baboons) have been shown to grasp at food items depicted in photographs (Bovet & Vauclair, 1998; Parron, Call, & Fagot, 2008). Parron et al. (2008) suggest that the baboons failed to process the photographs as representations and treated the photograph as if it were a real banana, in some cases, actually eating a photograph of a real banana. Taken together, these and related studies suggest that manual exploration of photographs (e.g., grasp errors) are sometimes produced by infants between the ages of 8 and 15 months (DeLoache et al., 1998) and that they are more likely to occur when infants are presented with highly realistic two-dimentional representations (Pierroutsakos & DeLoache, 2003).

An important thing to note with respect to grasp errors is that infants' behavior appears to be elicited by a representation depicted on a two-dimensional surface. Children's reach to the representation is visually guided—in that the action is accurately directed to the space on the surface where the object is depicted. Finally, the perceptual information present in the depiction leads children to act in a similar way as with certain real objects (see Figs. 1 and 2).

While we would argue that the evidence does support that young infants (and certain species of primates) commit grasp errors, the meaning of these behaviors is still controversial. As mentioned above, there are theoretical reasons for this controversy. On the one hand, supporters of James Gibson's ecological perspective argue that infants have no difficulty distinguishing photographs from real objects (Yonas et al., 2005) and that infants rarely if ever make grasp errors and when they do make grasp errors it stems from the complex self-organization "from elements of the environment, infant, and task coming together in the moment" (Ziemer et al., 2012, p. 496).

We agree that the grasp errors, and indeed all of the action errors that we describe here, are relatively rare but argue that even rare events can shed insights into development of the perception–action system. Where we differ from these other researchers is with respect to the elements of the infant that come to play when these behaviors are observed. Gibson et al. (Gibson, 1971; 1979; Kennedy, 1974) argued there was sufficient information in the environment for infants to accurately perceive what pictures afford for action, suggesting that learning was not necessary. In contrast, we argue that one element of the infant that needs to be considered in the production of action errors is the cognitive development of the young infants, an aspect of the child that is generally not considered from an ecological perspective. We address this issue in more detail in a later section.

3.2 Scale Errors

As in grasp errors, anecdotal reports of children doing odd things with objects led to the formal study of scale errors. In one case, the second author observed one of his children attempting to get in to a tiny car (see Fig. 3) and another one of his children attempting to sit on a tiny chair. Likewise, Judy DeLoache reported that she sometimes observed children in her studies of symbolic reasoning attempting to climb in and sit on furniture in the small scale models used in her research. These observations led us to formally investigate whether these behaviors could be elicited in a controlled environment.

In the original study of scale errors, children between 15 and 30 months of age were first presented with appropriately child-sized toys (i.e., ones

Figure 3 Child-sized car with occupant (right) and child-sized car and miniature toy replica (left). For much of the 1990s, the Cozy Coupe, made by Little Tikes, was the best-selling car in the world with over 450,000 sold in 1998 (http://www.nytimes.com/1998/10/21/automobiles/very-big-seller-in-a-very-small-market.html).

designed for 2- to 3-year-olds) including a version of the car (see right side in Fig. 3), a slide, and a chair. The children were encouraged to play with the toys and then left the room with an experimenter. While the children were gone, another experimenter switched each of the child-sized toys with miniature replica toys and then the children returned to the room (see the toy shown on the far left of Fig. 3). The child's behavior was video-recorded as they spontaneously, or with an experimenter prompting, interacted with the replica toys. Later studies have shown that scale errors occur without any form of prompting. Of the 54 children included in the study, 25 (46%) attempted to climb into the tiny car, sit in the tiny chair, or slide down the tiny slide with children performing between zero and four scale errors. A follow-up study presented the replica objects along with the child-sized toys to a group of eight children. When prompted to "sit in the chair," "go down the slide," or "drive the car" all of these children chose the larger object. This suggests that when presented simultaneously, children have no difficulty perceiving which of the objects affords the requested action. But why then do children sometimes attempt to act on the miniature toys? We return to this issue shortly.

Since the original laboratory study, scale errors have been reported using slightly different laboratory conditions (Brownell, Zerwas, & Ramani, 2007; DeLoache, LoBue, Vanderborght, & Chiong, 2013), observational studies in preschool classrooms seeded with miniature replica toys (Rosengren, Carmichael, Schein, & Anderson, 2009; Rosengren et al., 2010), retrospective online surveys of parents (Ware, Uttal, & DeLoache, 2010), and a prospective parental diary study (Rosengren, Gutiérrez, Schein, & Anderson, 2009). Rates of scale errors vary greatly across these methods with retrospective reports providing the lowest estimate (18% of 220 parents reported at least one scale error; Ware et al., 2010) and prospective reports providing the highest estimate (97% of 30 parents reported at least one scale error; Rosengren, Gutiérrez,etal., 2009). Observational studies in preschool classrooms provide estimates ranging from 53% (Rosengren, Carmichael, et al., 2009) to 88% (Rosengren et al., 2010) depending on the age of the children observed in the classroom. Additional laboratory studies report similar rates as the original laboratory study (Brownell, Zerwas, & Ramani, 2007; DeLoache et al., 2013). These studies provide strong evidence using very different methods and independent research teams that young children do attempt actions on objects that are too small to accommodate their bodies. In addition, many of these studies have reported that some children persist in their attempts to perform these actions. We return to the issue of individual differences when we explore why children might commit action errors in a later section.

Similar to what we have argued for grasp errors, scale errors are also visually guided. In video records, it can be clearly seen that children visually guide and align their bodies, so as to complete the desired action. In this manner, there exists a tight coupling between the perception of the object and action being attempted.

Researchers (Casler, Eshleman, Greene, & Terziyan, 2011; Ware, Uttal, Wetter, & DeLoache, 2006) have also shown that young children make scale errors involving two objects. For example, Ware et al. (2006) found that children make scale errors with dolls, attempting to fit relatively large dolls into chairs or cars that were way too small to accommodate the dolls. Casler et al. (2011) also found that children make scale errors with tools. In a series of studies, children sometimes chose a tool that was too large or too small to accomplish the task. For example, children would sometimes attempt to get a large toy fish out a fish tank using a net that was way too small to complete the task. They also sometimes attempted to use a net that was way too big to get a small toy fish out of a small fish tank as well. To our knowledge, Casler et al. are the first to show that scale errors can occur when the target object is substantially smaller or bigger than the child's body or tool. She and her colleagues (Casler, Hoffman, & Eshleman, 2014) have also shown that under speeded conditions adults can be induced to make scale errors with tools. Casler et al. argue that scale errors with tools are elicited by teleofunctional (purpose-based) reasoning, suggesting that cognitive reasoning plays an important role in their occurrence.

3.3 Media Errors

Interactive media errors are the least studied of the three action errors described in this chapter, but they also have been reported anecdotally. For example, a collaborator of both authors reported (Kirkorian, personal communication) that during an interactive video chat with her young niece, her niece retrieved a book and attempted to sit on her aunt's lap. The problem was that the two were separated by many miles and a computer screen! Instead of actually sitting on her aunt's lap, she sat on the computer keyboard. This is one example, similar to a number of different types of interactive media errors that we have been collecting in a prospective diary study with parents of children over a 6-month interval (Rosengren et al., 2018).

Use of digital media by young children has increased dramatically in recent years. At present, nearly all families in the United States with children younger than 8 years have some sort of digital media that is used by children (Rideout, 2017). Almost 80% of families in this category own a tablet computer, with roughly 40% reporting that their child under the age of 8 years has his or her own tablet. As the use of digital media by children continues to increase, we expect that the occurrence of different types of media errors will also increase.

As in grasp and scale errors, interactive media errors involve attempts by young children to perform a desired action that the media does not enable the child to complete successfully. In one of the few published reports of media errors, Pierroustakos and Troseth (2012) reported evidence of children manually exploring information presented on digital screens. Similar to both grasp and scale errors, the researchers showed that infants appeared to differentiate between three-dimensional objects from objects in two-dimensional screens and preferred interacting with real objects when presented statically in the real world or on a digital screen. However, the evidence does suggest that young children do display grasping behaviors toward objects appearing on a digital screen but to a much lesser extent than they do toward three-dimensional objects (Ziemer & Snyder, 2016). In this case, we have chosen to include these behaviors in the media category, even though they involve attempts to grasp objects that are not graspable. We would argue that these behaviors could be categorized as either grasp or media errors. Indeed, grasp errors can occur across different kinds of media (print, digital) whereas some media errors only can involve digital media (e.g., attempts to hand something to someone viewed on a digital screen).

In our prospective diary study that is investigating media errors (as well as grasp and scale errors), we have found that about 30% of our sample has reported that their child performed at least one media error over a 6-month interval, with the most common form of media error occurring while children were engaged with interactive media. For example, parents reported that their children attempted to share their dinners over video-chat sessions and attempted to grab items out of television broadcasts. With the proliferation of different types of digital media, parents have also reported that children confuse the affordances of different digital mediums, with some children treating traditional laptop screens as touch screens. In these cases, some children would persist, attempting to "play" videos by touching the corresponding button on the screen. We do not include these latter behaviors as action errors as they stem more from lack of information about what the technology itself is capable of and not really from a lack of understanding of what the technology itself is capable of in terms of action.

As in grasp and scale errors, there appear to be large individual differences in children's production of media errors. We suggest that media errors clearly show that some children do not understand what electronic media afford for action. In this sense, we suggest, as we have for grasp errors, that children must learn what the media afford for actions, and that this is not spontaneously perceived by young children. We suggest that, just as with grasp and scale errors, children must explore what different electronic media and technology afford for action. A recent anecdote about a young child, whose family bought a digital smart assistant (e.g., Alexa) for the home, reinforces this idea of exploration. The parent reported that their 2-year-old child had begun to talk to coasters and other cylindrical devices in the home that looked similar to the digital assistant, exploring whether they would respond to his inquiries (Rosenwald, 2017).

3.4 Tentative Developmental Time Course of Different Action Errors

The time course of different action errors is driven by a number of different factors. First, children must have acquired certain motor skills to attempt the actions. To perform a grasp error, children must be able to reach and successfully grasp objects. This behavior requires a certain level of fine motor skill that is not present in many young infants before about 8 months of age. For this reason, we can place the initial onset of these behaviors around this time period. We have demonstrated that there are large individual differences in the production of action errors. Some of these individual differences stem from differential experiences available for young children. For example, there is large variation in the extent that parents provide books or read to their children. There is also wide variation in families with respect to whether photographs and other two-dimensional images are available for children to look at and manually interact with in homes. Clearly, without providing stimuli that might elicit grasp errors (e.g., picture books with realistic images of small toys or food) these behaviors will not be observed. We would suggest that depending on children's experiences, those children with more rather than less experience interacting with and exploring photographs and other two-dimensional displays will learn more quickly what pictures and photographs afford for action. At the same time, gains in cognition, most notably, the acquisition of symbolic understanding and improvements in executive function, likely also lead to a decrease in the propensity to make grasp errors. These factors likely lead to the early emergence of grasp errors around 8 months of age, an increase in their likelihood over the next 6–8 months, and then a decrease in their frequency as children gain sufficient experience exploring photographs and make gains in cognitive development.

Like grasp errors, scale errors are also limited at first by fine and gross motor skills and experience with the environment. To make many of the scale errors that have been reported, such as attempting to climb in to a tiny car or sit on a tiny seat, requires children to be able to successfully stand, sit, and walk. These are skills that generally emerge around the first year of life and improve substantially over the next 6–8 months of life. For this reason we would expect the earliest scale errors to occur around this period of time, which is around the time period that researchers have documented their first appearance (Rosengren, Carmichael, et al., 2009; Rosengren, Gutiérrez, et al., 2009). As in grasp errors, scale errors require an environment that contains miniature toys that are similar to some degree to more child- and adult-sized functional objects in the environment. That is, children need to experience both appropriately scaled chairs, slides, and cars and miniature versions of similar objects to make scale errors. As in grasp errors, the frequency in the production of scale errors will likely increase and then decrease as children explore the affordances of objects of different sizes and as they achieve gains in symbolic understanding and cognition.

The developmental time course for various types of scale errors involving the child's own body (e.g., body scale errors: DeLoache et al., 2004; Brownell et al., 2007), children interacting with dolls and other objects (e.g., object scale errors: Ware et al., 2006), and functional tools (e.g., tool scale errors: Casler et al., 2011) appears to be somewhat different. At present, evidence suggests that body scale errors emerge first, followed by object scale errors, and then tool scale errors. This progression is parallel to advances in fine motor skills and cognition. Specifically, controlling two objects to attempt to fit a large doll into a tiny high chair involves greater fine motor skill than attempting to sit on a tiny rocking chair. Likewise, using a tool in a functional manner requires both relatively sophisticated fine motor skill and some specific conceptual knowledge about what the tool is designed to accomplish.

At present, media errors have not been explored to the same extent as the other action errors discussed in this chapter. However, we would argue that similar factors are at play in the developmental time course of these behaviors. That is, a certain level of fine motor skill is required to use a tablet or other electronic device. This level of fine motor skill comes in after children acquired the ability to reach and grasp objects but requires a level of fine motor control that goes beyond the ability to reach and grasp. At present, some children are beginning to interact with tablets and smart phones around 8 months of age, but most children are not likely being exposed on a regular basis to these devices until a year and a half or older. Thus, we would expect media errors to emerge sometime around the first year of life, increase in likelihood over the second year of life, and then decrease in frequency in children over the age of 3 years. Like the other action errors described, the developmental time course will be determined in part by exposure to particular stimuli in the environment (e.g., smart phones, tablets) and the child's level of cognitive development. One factor that also seems to come in to play with respect to media errors is their social experience. That is, a number of the reports that we have received from parents involve media errors where children are interacting with other people remotely using technology. Thus, this form of action error also requires the development of interactive social skills, such as sharing toys, food, or other interesting objects with another person; these are skills that are emerging over the second year of life into the toddler period.

4. HOW MIGHT ACTION ERRORS INFORM US ABOUT THE DEVELOPMENT OF THE PERCEPTION–ACTION SYSTEM?

To address this question, it is important to examine why children might produce action errors. As described earlier, Ziemer et al. (2012) have suggested that grasp errors occur owing to a complex interaction of factors in the environment, infant, and task. We have argued a similar point about motor behavior more generally (Rosengren & Braswell, 2003; Rosengren, Savelsbergh, & van der Kamp, 2003; Savelsbergh, van der Kamp, & Rosengren, 2006), suggesting that the interaction of environmental, organismic (i.e., individual), and task constraints lead to both the production of a specific behavior in a particular situation and provide important sources of variability in the behavior. From this perspective, constraints are viewed as factors that both limit and facilitate certain behaviors (Newell, 1986). One can think of these constraints as similar to a canal that both limits water to moving in a certain direction and also facilitates the movement in water in that direction.

4.1 Constraints on Action Errors

In terms of environmental constraints, we have already mentioned that for action errors to occur the environment must contain certain objects. For grasp errors, realistic two-dimensional depictions of three-dimensional objects must be present in the environment to elicit an attempted grasp. It is also true that infants likely need to have experience with grasping actual objects in the real world. For scale errors, the environment must contain appropriate-sized objects and miniature versions of similar objects. Given DeLoache et al.'s (2013) finding that when presented with the appropriately scaled and tiny replica version of a car, chair, or slide children choose the appropriately scaled item, we would suggest that scale errors are unlikely to occur when the environment contains both an appropriately scaled object and a highly similar replica miniature in close proximity. Although some researchers have suggested that the familiarity with the actual appropriately sized object and tiny replica version of the same object may increase the likelihood of scale errors, our own experience based on parental diaries and observations in preschool classrooms suggests that children need to merely recognize the tiny object as a member of a class of objects (e.g., chairs) that is familiar. For media errors, certain forms of technology need to be present in the environment and available for children to interact with. Taken together, the idea is that the developing perception—action system cannot be separated from the environment in which the child is developing.

Organismic constraints include such things as the individual child's body size, his or her rate of growth and physical maturation, his or her past experiences, and his or her cognitive development. We have already discussed at length the role of experience, and in particular children's exploration of what the environment affords for action, as a key aspect in the production of action errors and the decline in frequency of them over time. In the next section, we examine in more depth aspects of cognitive development that may play an important role in action errors. In particular, we focus on conceptual development, symbolic understanding, and aspects of executive functioning.

Task constraints are another factor that might influence the production of action errors. For young children, the task is the behavior that is intended. For grasp errors, the task involves picking up something. For scale errors, the task involves sitting on or climbing in to an object. For media errors the task involves interacting with someone or something. A key issue is that in all cases the task involves an intended action. In our view, this goal or intended action serves to organize the behavior in the moment.

4.2 Conceptual Development and Symbolic Understanding

We suggest that conceptual development plays a relatively large role in the emergence of children's action errors. In many ways, aspects of conceptual development can be described as learning what the environment affords for action, but we argue that it is also important to recognize that certain items in the environment are objects that can be picked up to be explored or eaten. Other objects in the environment can be sat in or on or slid down. One reason why we argue that acquiring these concepts is important for eliciting action errors is based on an explanation provided by DeLoache et al. (2004). Their explanation is derived in part from Milner and Goodale's (1995; see also Glover, 2004) theory of two different neural pathways, labeled as the dorsal and ventral streams. DeLoache et al. (2004) suggested that scale errors might occur because in young children the ventral stream, which processes information relevant for object recognition, and the dorsal stream, which processes information relevant for the control of action, are not fully integrated. They suggest that when a child perceives a tiny scale replica (e.g., a small chair), this visual information activates parts of the brain associated with visual recognition of the representation of the larger object or class of objects that the small object represents (more general concept of chair). They suggest that this representation also activates an action plan associated with the larger object or category (e.g., sitting). The action, even though it cannot be completed successfully, is visually guided in a manner that is appropriate for the scale of the object.

Converging evidence for this overall explanation is provided by research that has shown that motor and cognitive systems are coupled (Barsalou, Kyle Simmons, Barbey, & Wilson, 2003; Tucker & Ellis, 1998; 2001). For example, viewing an object such as a key has been found to activate, in some situations, the motor behavior commonly associated with that object (Klatzky, Pelligrino, McCloskey, & Doherty, 1989). Additional brain imaging studies have shown that motor areas in the brain are activated in concert with related conceptual areas when individuals view objects (e.g., a hammer) with a strongly associated motor action (e.g., hammering; Martin, 2001; Martin & Chao, 2001; Simmons, Martin, & Barsalou, 2005).

We argue that action errors in general may occur when a conceptual representation of an object or an event activates an action plan commonly associated with that object or event. In adults, however, the action plan is generally inhibited in situations where it is not appropriate owing to characteristics of the object or context. In the case of a photograph, the symbolic aspect of the photograph, that the photograph is a representation of an object and not a real object to be grasped, serves to inhibit the associated action plan. In young children whose inhibitory skills are not as well developed, inhibition of the activated action plan does not occur, and a grasp error results. Similarly, for scale errors, when children view a small replica object (e.g., a tiny chair) from a category of objects the child is familiar with (e.g., chairs in general), the visual stimuli activates a representation (e.g., concept of chair) that also activates an action plan (e.g., sitting) associated with that conceptual representation. In adults, this behavior is inhibited, but it is not so in young children. Although less well investigated, we suggest a similar argument can be made for media errors. In this case, interacting with a person over interactive video may activate a script associated with social interaction (e.g., giving another person a toy) that activates the specific action plan associated with that script (e.g., attempting to pass the toy to the person depicted on the screen). In adults, the activated action plan is inhibited but not in young children who are just learning what the interactive media affords for action. The fact that adults under task demands that require a rapid response commit grasp (Rhoad et al., 2012) and scale errors (Casler et al., 2014) suggests that lack of inhibitory control is one factor associated with the production of action errors. This aspect of executive function undergoes substantial development over the first few years of life, the same time period where action errors occur.

Symbolic understanding may also be important for the developmental progression of action errors. Acquiring knowledge that a photograph is a representation (e.g., symbol) of something else may help children inhibit the motor action associated with object depicted. DeLoache (2000) has referred to this issue as the problem of dual representation. Dual representation refers to the idea that a symbol can both represent something and be an object in and of itself. Although most of DeLoache's research has focused on young children's difficulty with understanding that scale models can represent a larger space, the dual representation model can be applied to children's difficulty in understanding that a photograph can both be an object and a representation of an object. Likewise, tiny replica objects can both be representations of larger objects, as is the case for doll furniture, and can also be objects themselves. Recognizing that small replica objects can have these dual roles—as a symbol and as an object—may lead slightly older children to inhibit the action plans associated with the larger object. Likewise, learning that video can represent an individual in a different time and or place may lead children to inhibit the behaviors associated with media errors.

As we have mentioned, researchers from an ecological perspective generally do not advocate that cognitive representations are needed to explain aspects of motor behavior, arguing that even infants and young children accurately perceive what the environment affords for action (e.g., Yonas et al., 2005). The argument is that perception and action are tightly coupled in the moment and there is no need to invoke cognitive representations in the guidance of action (Thelen & Smith, 1994). Rather, behavior is self-organized in the moment from the interaction of environmental, individual, and task constraints.

We argue, however, that the child's goal acts as an overall cognitive constraint that serves to organize the behavior at a higher level of functioning (see Rosengren et al., 2003 for a more detailed argument). In addition, we argue that symbolic understanding serves as an additional constraint on children's behavior that cannot be reduced to self-organization in the moment. Evidence in support of this argument comes from the "shrinking room study" (DeLoache et al., 1997). This study was designed to test DeLoache's dual representation model. In this task, children were presented with a symbolic task where they were shown a small toy hidden in a scale model, instructed that the model represented a larger space, and then asked to find a corresponding larger toy in the same location in the larger space. Before understanding that the small space represents the larger space, young children (under about age of 3 years) generally have little difficulty remembering where the object was hidden originally (~80% accurate in retrieval), but generally fail to find the object in the larger space (~20% successful). However, in the shrinking room study, the symbolic relation between the scale model and the larger space is broken by convincing children that the large room was shrunk to the scale model (or vice versa). By shrinking the room, the task becomes a memory task involving the "identical" but shrunken room. When this occurs, children respond similarly to the memory task, finding the hidden toy in the shrunken room at about the same rate as is found in older children in the symbolic task. Thus, by removing the symbolic aspect of the task, young children are able to perform successfully.

It is not clear how the results of this study can be interpreted without invoking the importance of symbolic understanding in older children. Likewise, we argue that it is more parsimonious to argue that conceptual representations and symbolic understanding are involved in the decline of action errors with age and experience than to suggest that they can be entirely explained in terms of self-organization. Instead we argue that children learn that objects can be both objects and representations and that this realization leads children to inhibit actions that have been activated along with conceptual representations.

To some extent, this argument is similar to one that Norman (1981) proposed for slips of action. Norman described one form of action slips, those that result from a thought that was not meant to be performed but that gets carried out anyway. He suggested that the thought causes the action in these cases. In this way, aspects of the action errors we have described in young children may be similar to some action slips in adults. Norman also points out that many action slips are caught at the time they are made, while others are caught just before their occurrence. He suggests that catching a slip that has been started requires some monitoring mechanism. As most of the action errors we have observed unfold unimpeded, it is likely that this monitoring mechanism is either not present or poorly developed in most young children who perform action errors. Norman (1981) proposed that action slips could be described as part of an activation-trigger-schema (ATS) system where once a high level schema (representation) is triggered, lower level action sequences get triggered, and the action is performed.

4.3 Individual Differences and Executive Function

The large individual differences in the performance of action errors also implicate issues of executive function and inhibitory control. Some children appear to perform different types of action errors rarely, while other children perform action errors persistently in a single session and over an extended period of time (Rosengren et al., 2009). Children who perform particular action errors rarely or only on one occasion may have relatively advanced executive functioning and may quickly learn that a photograph, tiny object, or video image does not afford actions normally associated with the object depicted, the larger object, or live individual. In contrast, children who persistently perform action errors, either in a single session, or over time, may not attend to affordances of the situation, effectively learn from their failed attempts to perform intended actions, or fail to inhibit motor actions activated by representations. We have collected some preliminary evidence suggesting that the frequency of children's grasp errors is related to measures of inhibitory control (Rhoad et al., 2012).

4.4 The Developing Perception—Action System

We argue that it is fruitful to examine the developing perception—action system in terms of the dynamic interplay of constraints within the environment, the individual child, and the task that they are attempting to complete. This interaction of constraints is dynamic and multiply determined, which is why action errors do not occur whenever a child sees a photograph of an object, views a tiny chair, or interacts with grandparents over interactive media. We argue, however, that not all constraints provide equal weight in the emergence of a specific behavior. Rather, the child's goal or intention to act plays a greater role in organizing factors to lead to a specific behavior.

Eleanor Gibson (1970, 1992) argued that visual input drives learning through the perception of affordances in the environment. These perceived affordances also provide the context in which children and adults act on the environment. Adolph and Kretch (2015) suggest that an important aspect of development involves perceptual learning. In the process of perceptual learning, children come to identify what the environment affords for action. By exploring the environment, the child can more effectively perceive what in the environment affords action. With development, and physical growth and maturational changes of their bodies, children must continue to explore the nature of affordances. In our view, this exploration is also guided by important changes in children's cognitive and symbolic understanding. To the extent that affordances can be viewed as possibilities for action that are dependent on the characteristics of the individual and properties of the environment, it is important to consider children's cognitive and symbolic understanding of the world to be an important aspect of perceiving the possibilities for action. Technology and manufactured artifacts have made this exploration both more interesting and more challenging for young children, as they are confronted with stimuli that provide different types of affordances than their perceptual systems have evolved to pick up. In this way, the interaction between the child and environment in some cases may lead to a misperception of affordances.

5. CONCLUSION

Based on the evidence that we and others have collected, we argue that all or almost all children likely perform action errors over the course of early development. From prospective diary studies, observations in preschools, and laboratory studies we have found that if certain stimuli are made available to young children over a course of time the likelihood that they will perform an action error is relatively high. This is not to say that action errors are common or frequent. However, we do argue that their existence—even fleeting existence—indicates that children must actively explore the environment to determine what it affords for their own actions on a particular object, their actions involving more than one object, and their actions involving technology and media. We would strongly suggest that our perceptual apparatus has not evolved to spontaneously pick up the affordances of tiny manufactured objects, photographs, or technology and that children must explore with their bodies and hands what these artifacts afford for action. However, we argue that the developing perceptual—action system cannot be completely understood without considering how young children's cognitive development and symbolic understanding influence the learning of what the environment affords for action.

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REFERENCES

Adolph, K. E., & Kretch, K. S. (2015). Gibson's theory of perceptual learning. In H. Keller (Developmental Section Ed) (Ed.), *International encyclopedia of social and behavioral sciences* (2nd ed., Vol. 10, pp. 127—134). New York: Elsevier.

Barsalou, L. W., Kyle Simmons, W., Barbey, A. K., & Wilson, C. D. (2003). Grounding conceptual knowledge in modality-specific systems. *Trends in Cognitive Sciences, 7*(2), 84—91.

Botvinick, M. B., & Bylmsa, L. M. (2005). Distraction and action slips in an everyday task: evidence for a dynamic representation of the task context. *Psychonomic Bulletin & Review, 12*, 1011—1017.

Bovet, D., & Vauclair, J. (1998). Functional categorization of objects and of their pictures in baboons (*Papio anubis*). *Learning and Motivation, 29*, 309—322.

Brownell, C. A., Zerwas, S., & Ramani, G. B. (2007). "So Big": The development of body self-awareness in toddlers. *Child Development, 78*, 1426—1440.

Casler, K., Eshleman, A., Greene, K., & Terziyan, T. (2011). Children's scale errors with tools. *Developmental Psychology, 47*, 857–866. http://dx.doi.org/10.1037/a0021174.

Casler, K., Hoffman, K., & Eshleman, A. (2014). Do adults make scale errors too? How function sometimes trumps size. *Journal of Experimental Psychology General, 143*, 1690–1700.

DeLoache, J. S. (2000). Dual representation and young children's use of scale models. *Child Development, 71*(2), 329–338.

DeLoache, J. S., LoBue, V., Vanderborght, M., & Chiong, C. (2013). On the validity and robustness of the scale error phenomenon in early childhood. *Infant Behavior & Development, 36*, 63–70.

DeLoache, J. S., Miller, K. F., & Rosengren, K. S. (1997). The credible shrinking room: very young children's performance with symbolic and nonsymbolic relations. *Psychological Science, 8*(4), 308–313.

DeLoache, J. S., Pierroutsakos, S. L., Uttal, D. H., Rosengren, K. S., & Gottlieb, A. (1998). Grasping the nature of pictures. *Psychological Science, 9*(3), 205–210.

DeLoache, J. S., Uttal, D. H., & Rosengren, K. S. (2004). Scale errors offer evidence for a perception-action dissociation early in life. *Science, 304*(5673), 1027–1029.

Gibson, E. J. (1970). The development of perception as an adaptive process. *American Scientist, 58*, 98–107.

Gibson, E. J. (1992). How to think about perceptual learning: twenty-five years later. In H. L. Pick, P. van den Broek, & D. C. Knill (Eds.), *Cognition: Conceptual and methodological issues* (pp. 215–237). Washington, DC: American Psychological Association.

Gibson, J. J. (1971). The information available in pictures. *Leonardo, 4*(1), 27–35.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Boston: Houghton Mifflin.

Glover, S. (2004). What causes scale errors in children. *Trends in Cognitive Science, 8*(10), 440–442.

Heckhausen, H., & Beckmann, J. (1990). Intentional action and action slips. *Psychological Review, 97*, 36–48.

Kennedy, J. M. (1974). *A psychology of picture perception*. San Francisco, CA: Jossey-Bass.

Klatzky, R. L., Pelligrino, J. W., McCloskey, B. P., & Doherty, S. (1989). The role of motor representations in semantic sensibility judgments. *Journal of Memory and Language, 28*, 56–77.

Martin, A. (2001). Functional neuroimaging of semantic memory. *Handbook of Functional Neuroimaging of Cognition, 1*(3), 153–186.

Martin, A., & Chao, L. L. (2001). Semantic memory and the brain: structure and processes. *Current Opinion in Neurobiology, 11*(2), 194–201.

Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action*. Oxford: Oxford University Press.

Murphy, C. M. (1978). Pointing in the context of shared activity. *Child Development, 49*, 371–389.

Newell, K. M. (1986). Constraints on the development of coordination. In M. Wade, & H. T. A. Whiting (Eds.), *Motor skill acquisition in children: Aspects of coordination and control* (pp. 341–360). Dordrecht: Martinus Nijhof.

Ninio, A., & Bruner, J. (1978). The achievement and antecedents of labeling. *Journal of Child Language, 5*, 1–15.

Norman, D. A. (1981). Categorization of action slips. *Psychological Review, 88*, 1–15.

Parron, C., Call, J., & Fagot, J. (2008). Behavioural responses to photographs by pictorially naïve baboons (*Papio anubis*), gorillas (*Gorilla gorilla*) and chimpanzees (*Pan troglodytes*). *Behavioural Processes, 78*, 351–357.

Pierroutsakos, S. L., & DeLoache, J. S. (2003). Infants' manual exploration of pictorial objects varying in realism. *Infancy, 4*, 141–156.

Pierroutsakos, S. L., & Troseth, G. L. (2012). Video verite: infants' manual investigation of objects on video. *Infant Behavior & Development, 26*, 183–199.

Reason, J. (1990). *Human error*. Cambridge: Cambridge University Press.

Reason, J. T., & Mycielska, K. (1982). *Absent minded? The psychology of mental lapses and everyday errors*. Englewood Cliffs, NJ: Prentice Hall.

Rhoad, A., Bruton, C. M., French, J. A., Gutiérrez, I. T., & Rosengren, K. S. (May 2012). Evidence for grasping errors in adults. In *Poster presented at the association for psychological science, Chicago, IL*.

Rideout, V. J. (2017). *The common sense census: Media use by kids age zero to eight*. San Francisco, CA: Common Sense Media.

Rosengren, K. S., & Braswell, G. (2003). Learning to draw and to write: issues of variability and constraints. In G. Savelsbergh, K. Davids, J. van der Kamp, & S. Bennett (Eds.), *Development of movement coordination in children: Applications in the field of ergonomics, health sciences and sport* (pp. 56–74). London: Routledge.

Rosengren, K. S., Carmichael, C., Schein, S. S., Anderson, K. N., & Gutiérrez, I. T. (2009). A method for eliciting scale errors in preschool classrooms. *Infant Behavior and Development, 32*(3), 286–290.

Rosengren, K., & French, J. A. (March 2011). Action errors in childhood: the role of representations and inhibitory control. In *Invited symposium presentation at the Biennial Conference for the Society on Research on Child Development, Montreal, Canada*.

Rosengren, K. S., Gutiérrez, I. T., Anderson, K. N., & Schein, S. S. (2009). Parental reports of children's scale errors in everyday life. *Child Development, 80*(6), 1586–1591.

Rosengren, K. S., Kirkorian, H., Choi, K., Jiang, M. J., Raimer, C., Tolin, E., et al. (2018). *Scale errors and beyond: A diary study of children's action errors with toys, photographs, and screens* (in preparation).

Rosengren, K. S., Savelsbergh, G. J., & van der Kamp, J. (2003). Development and learning: a TASC-based perspective of the acquisition of perceptual-motor behaviors. *Infant Behavior and Development, 26*(4), 473–494.

Rosengren, K. S., Schein, S. S., & Gutiérrez, I. T. (2010). Individual differences in children's production of scale errors. *Infant Behavior and Development, 33*(3), 309–313.

Rosenwald, M. S. (March 2, 2017). How millions of kids are being shaped by know-it-all voice assistants. *The Washington Post*. Retrieved from https://www.washingtonpost.com/local/how-millions-of-kids-are-being-shaped-by-know-it-all-voice-assistants/2017/03/01/c0a644c4-ef1c-11e6-b4ff-ac2cf509efe5_story.html?utm_term=.466f0f3acbc7.

Savelsbergh, G. J. P., van der Kamp, J., & Rosengren, K. S. (2006). Functional variability in perceptual-motor development. In K. Davids, S. J. Bennett, & K. Newell (Eds.), *Variability in the movement system: A multi-disciplinary approach* (pp. 185–198). Urbana-Champaign: Human Kinetics.

Schmidt, R. A. (1982). More on motor programs. In J. S. Kelso (Ed.), *Human motor behaviour: An introduction* (pp. 189–217). Hillsdale, NJ: Lawrence Erlbaum Associates.

Schwartz, M. F. (1995). Re-examining the role of executive functions in routine action production. In J. Grafman, K. J. Holyoak, & F. Boller (Eds.), *Annals of the New York Academy of sciences: Vol. 769. Structure and functions of the human prefrontal cortex* (pp. 321–335). New York: New York Academy of Sciences.

Simmons, W. K., Martin, A., & Barsalou, L. W. (2005). Pictures of appetizing foods activate gustatory cortices for taste and reward. *Cerebral Cortex, 15*(10), 1602–1608.

Thelen, E., & Smith, L. B. (1994). *A dynamic systems approach to the development of cognition and action*. Cambridge: MIT Press.

Tucker, M., & Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human Perception and Performance, 24*(3), 830.

Tucker, M., & Ellis, R. (2001). The potentiation of grasp types during visual object categorization. *Visual Cognition, 8*(6), 769–800.
Ware, E. A., Uttal, D. H., & DeLoache, J. S. (2010). *Developmental Science, 13*, 28–36.
Ware, E. A., Uttal, D. H., Wetter, E. K., & DeLoache, J. S. (2006). Young children make scale errors when playing with dolls. *Developmental Science, 9*, 40–45.
Yonas, A., Granrud, C. E., Chov, M. H., & Alexander, A. J. (2005). Picture perception in infants: do 9-month-olds attempt to grasp objects depicted in photographs? *Infancy, 8*(2), 147–166.
Ziemer, C. J., Plumert, J. M., & Pick, A. D. (2012). To grasp or not to grasp: infants' actions towards objects and pictures. *Infancy, 17*, 479–497.
Ziemer, C. J., & Snyder, M. (2016). A picture you can handle: infants treat touch-screen images more like photographs than objects. *Frontiers in Psychology, 7*.

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