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New perspectives on the effects of action on perceptual and cognitive development

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Over half a century ago, Piaget (1952, 1954) proposed that cognition grew out of the infant's, and then the child's, hands-on engagement with the world. Cognition, he suggested, take its form from the actions that give rise to it. In recent decades, this foundational insight has fallen out of the spotlight in many corners of the field. Developmental scientists have tended to treat action, on the one hand, and perception and cognition, on the other, as orthogonal and they have generally been studied separately, in different laboratories, by different communities of researchers. Indeed, when considered together, action has often been considered a “marker” for cognitive and perceptual development (Zelaznik, 1993) or as an indicator in the assessment of development milestones (Lockman & Thelen, 1993). And although a number of theorists have suggested that action is crucial for the development of primary mental representations (Adolph, 1997; Bushnell & Boudreau, 1993; Eppler, 1995; Gibson, 1988; Rochat, 1989; Ruff, Saltarelli, Capozzoli, & Dubiner, 1992), for many years the search for causal connections between infants’ actions and their perceptual and cognitive advances has been limited.

More recently, however, new evidence has led the field to reconsider the ways in which action structures perceptual and cognitive development. Several salient examples come from infancy research. For example, seminal work by Bertenthal, Campos and collaborators (Bertenthal, Campos, & Barrett, 1984; Bertenthal, Campos, & Kermoian, 1994; Campos et al., 2000) showed that infants’ self-produced locomotion affected their caution and reaction to the deep side of the visual cliff. That is, infants who had started to self-locomote by crawling, as well as non-crawlers who were randomly assigned to experience self-locomotion in a walker, were more likely to show an increase in heart rate and to avoid the deep side than infants without any self-locomotion experience.

A similar causal effect for the role of action on infants’ perceptual and cognitive development was indicated by a number of ingenious studies by Needham and colleagues (Needham, 2000, in press; Needham, Barrett, & Peterman, 2002). Needham (2000) found that individual variation in infants’ actions on objects predicted their ability to discern the boundaries between novel objects in a segmentation task. Further, Needham and colleagues found that motor interventions can have broad effects on infants’ exploration of and attention to novel objects (Needham et al., 2002; Needham, in press): They outfitted 3-month-old infants with Velcro covered “sticky mittens” which allowed infants to apprehend objects just by swiping at them. Infants learned to do this, becoming more systematic in their swipes with practice. Critically, this experience also led infants to increase attention to and exploration of novel objects even when they were not wearing the mittens.

Drawing from Needham's innovations, Sommerville and colleagues (Sommerville, Woodward & Needham, 2005) asked whether this kind of intervention would also alter

infants' understanding of the novel action itself. They gave 3-month-old infants the opportunity to act on a pair of objects via "stick mittens." After this experience, infants were tested in a habituation experiment in which they viewed an adult act on objects with a large mitten. Infants' visual responses indicated that engagement with sticky mittens led them to view the observed actions as goal-directed. Thus, infants' own actions provide information not only about the objects acted upon, but also about action itself.

These and other new lines of research , many of which appear in the following pages, indicate that there is a growing consensus that it is impossible to investigate perceptual and cognitive development without considering how it affected by, and intertwined with, infants' and children's action in the world. It is in this light that this Special Section was conceived. The articles included here represent novel, cutting-edge research that addresses the broad issues of if, when, and how the child's action in the world affects his or her perception and cognition.

Take-home messages

This Special Section was motivated by several goals, each stemming from the current renewed and wide-ranging interest in the effects of doing on knowing. First, a group of articles that address the same broad developmental issue can help to highlight a burgeoning interest on that issue and bring it to the forefront of emerging research. The Special Section thus serves as a showcase for the finest current work in this area, and at the same time it may engender new lines of research and new ways of thinking about development. It has the potential to lead to shift in thinking about development not as occurring simultaneously and in parallel across a number of areas but as a number of causally interacting areas, the complexities of which can be understood only by considering conjointly various mechanisms of change.

A second goal is to highlight this new direction in basic research for the broader community of researchers and practitioners. Research and theory on issues related to the facilitation or acceleration of the perceptual and cognitive abilities of infants and young children has obvious relevance for both early education and social policy. For example, a number of the papers included here could benefit caregivers and early educators because they show the importance during development of action interactive-rich environments. Complementarily, basic research on this issue can derive important insights from studies of real-world child-environment interactions and applied interventions.

A third goal is to facilitate the development of these new lines of research by setting them in a broader context. It is only by assembling a varied collection of research on the same topic that developmental scientists can discern the consistencies or themes that emerge from that research. The papers included here show that action facilitates advances in basic visual abilities such as perceptual completion. (Johnson et al., 2008), visual proprioception (Witherington et al., 2008), an understanding of animacy cues (Cicchino & Rakison, 2008), object function and tool use (Oakes et al., 2008), others' action goals (Sommerville, Hildebrandt, & Crane, 2008), and other's states of attention (Meltzoff & Brookes, 2008). Further, these papers suggest that the role of action in cognitive development persists beyond infancy. Children's exploratory actions, and their sensitivity to information in gesture are linked to the cognitive achievements of early childhood, including the induction for causal properties (Schulz, Standing, & Bonawitz, 2008), and conservation of quantity (Ping & Goldin-Meadow, 2008). The detection of regularities across such diverse lines of developmental research is vital to the evolution of coherent theories that can account for early behavior. We outline below three of these key themes.

Action affects perception and cognition at many points in developmental time

Piaget's theory posited profound, formative effects of action on thought during infancy. Consistent with this view, many of the articles in this Special Section relied on infants as participants. The infants vary considerably in age, from as young as 2½ months of age (Johnson, Davidow, Hall-Haro, & Frank, 2008) to barely locomoting 5- to 8-month-olds (Cicchino & Rakison, 2008; Oakes et al., 2008; Witherington et al., 2008), to more motorically expert 10-month-olds (Sommerville, Hildebrand, & Crane, 2008), to toddlers (Meltzoff & Brookes, 2008). The articles included here also suggest, consistent with Piaget's view, that the effect of action on cognition continues well beyond infancy. Schulz and her colleagues (Shultz et al., 2008), for example, find that children's exploratory actions vary systematically as a function of the inductive problem posed by novel causal properties, suggesting that these actions are contribute to children's learning in this context. Ping and Goldin-Meadow (2008) report that gestures - even in the absence of relevant objects - convey information for young children who are grappling with conservation tasks. These findings, and others like them, suggest that action can become a representational medium that learners can draw on when engaged in cognitive challenges.

Perhaps it is not surprising that older individual's action in the world, and their observation of others' action, is causally related to cognitive development. Anyone who has learned to play a musical instrument, for example, can understand the necessity of playing practice and not just the study of musical theory as a means of improving their understanding of how certain chords naturally work together. Nonetheless, in our view the importance of action in older children and adults' learning has been critically understated and understudied in the literature. This Special Section of *Developmental Psychology* illustrates that this connection exists and suggests that future research could incorporate this idea in the study of learning.

The relation between action and perception and cognition can be examined in a multitude of ways

Broadly speaking, the most direct method for demonstrating that action causally facilitates perception and cognition is through an experiment in which one group of randomly assigned participants engages in an action of some kind and a different randomly assigned group does not and then both groups are given the same test condition. This approach, which was implemented in previous studies on this issue (Bertenthal et al., 1994; Campos et al., 2000; Sommerville et al., 2005), was adopted in a number of the articles in the Special Section. For example, Witherington et al. (2008) showed that infants who were randomly assigned to received experience from a powered-mobility-device responded differently to peripheral and global optic flow – both in postural compensation and emotional expression – relative to infants who did not received such experience. Similarly, Meltzoff and Brookes (2008) demonstrated that 12-month-olds who were randomly assigned to a condition in which they wore an opaque blindfold were subsequently less likely to follow the gaze of a blindfolded adult relative to infants who experienced a blindfold with a window or saw a blindfold lying on a table.

Other researchers, however, implemented a somewhat different approach by either matching for age but not other pre-determined factors and then assessing behavior differences on one task, or by studying individual differences in relations across a number of variables. For instance, Cicchino and Rakison (2008) showed that age-matched but differently locomoting infants – crawling and non-crawling - responded in distinct ways to animacy-related motion in the visual habituation procedure, and Johnson et al. (2008) revealed that individual

differences in perceptual completion performance are strongly correlated with scanning patterns but unrelated to motion. These kinds of design do not allow for such definitive conclusions about the causal relation between action and perception and cognition. As Cicchino and Rakison (2008) point out, their results may reflect that crawling is just one factor, in addition to others that are linked to age, which leads to advances in the ability to perceive and understand animate motion. And as many (though unfortunately not all) first year psychology students know, the kind of correlational design adopted by Johnson et al. (2008) does not allow for any conclusions about causation. Nonetheless, these alternative designs are sufficiently powerful to generate data that make plausible the possibility that there is a causal link between an individual's action and their perceptual and cognitive abilities. Furthermore, they provide important evidence for the ecological validity of this hypothesis; that is, real-world actions - such as crawling - can be shown to be correlated with laboratory measures of cognition and perception.

Finally, one standout feature of the Special Section is that it demonstrates that broad arrays of methodologies are useful in exploring the relation between action and perception and cognition. These include eye-tracking (Johnson et al., 2008), visual habituation (Cicchino & Rakison, 2008: Oakes, Ross-Sheehy, Perone, Madole, & Carey, 2008; Sommerville et al., 2008), gaze-following (Meltzoff & Brookes, 2008), a moving room procedure (Witherington et al., 2008), Piagetian conservation tasks (Ping & Goldin-Meadow, 2008), and exploratory play (Schulz et al., , 2008).

The causal mechanisms between action and perception and cognition remain unknown

The contributions to this special section highlight the, still largely open, question of **how** action renders its effects on cognition and perception. According to Piaget, knowledge is slowly constructed through the internalization of motor actions, and consequently mental representations do not emerge until around 18 months of age. Following the classic work of Spelke, Baillargeon, Meltzoff, and other (e.g., Baillargeon, 1998; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Meltzoff & Moore, 1999), few developmental scientists adhere to this position today. What, then, are the mechanisms by which action alters infants' perceptual and cognitive abilities? In all likelihood, as a number of the articles here suggest, there is a bi-directional link between action, on the one hand, and perception and cognition, on the other; action affects what is represented about the world and in turn these representations affect what is acted upon. But, as the Special Section illustrates, there are probably many means by which action has its developmental effects. We outline here a number of the more prominent of these accounts.

One possibility is that motor action - whether it be reaching, crawling, or spontaneous play - causes the child to employ new attentional strategies that in turn affect what kinds of information are encoded. At the essence of this perspective, first outlined by Gibson (1979) who called it the "education of attention", is the notion that infants and children deploy their attention where it is needed to acquire information that will help them complete specific goals or tasks. This perspective is most strongly endorsed by Campos and colleagues (Campos et al., 2000; Campos, Kermoian, Witherington, Chen, & Dong, 1997; Witherington et al., 2008; see also Cicchino & Rakison, 2008) who have used it to explain, among other things, why the onset of crawling co-occurs with improvements in infants' social comprehension and interactions; that is, crawling leads to more varied social interactions and causes infants to attend more to social beings.

Another plausible explanation for how action affects perception and cognition is that proprioceptive input from action acts as a supplementary form of perceptual input (Meltzoff

& Brookes, 2008; Sommerville et al., 2008). This view is in concert with the idea that infants represent the proprioception of their own and others' actions in the same amodal format (Meltzoff & Moore, 1977, 1983). That is, when infants see an individual perform an action they consider what their own internal states are when they perform those actions, or as Meltzoff and Brookes (2008, p.XXX) describe it "Others are seen as 'Like-Me,' and the infants' own first-person experience enriches their interpretation of 'like behavior' in others".

Related to this last possibility, a third possible mechanism by which action could influence perception and cognition is that it results from an action production-observation matching system (Decety & Grezes, 1999). There is now considerable, though controversial (Dinstein, Thomas, Behrmann, & Heeger, 2008), evidence that adults, primates, and children represent their own and observed actions in neurally similar ways (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Lepage & Theoret, 2006; Rizzolatti, Fogassi, & Gallese, 2001). There is evidence that the same system is in place during infancy although it may still undergo considerable change during and after this period (Bertenthal & Longo, 2007; Lepage & Theoret, 2006; Sommerville & Decety, 2006). The early existence of shared systems for acting and perceiving actions opens the possibility that action development could directly influence aspects of social perception or social understanding (see Falck-Ytter, Gredeback, & von Hofsten, 2006; Gerson & Woodward, in press; Meltzoff, 2007).

All of these accounts show promise and are worthy of attention as research on this issue continues to grow. Even so, it is entirely possible that other, as yet unknown, mechanisms operate to allow an individual's action to enhance their perceptual and cognitive abilities. Our hope is that the articles in this Special Section will stimulate researchers to develop new ideas about how motor behavior can produce changes in other areas of development.

Concluding remarks

The articles in this Special Section reflect a growing interest among developmentalists to examine, through new lenses, the classic, yet often ignored insight that development is driven by the actions of children. Just as a complete understanding of the biology of the human heart must incorporate chemistry and physics, so the work reported here demonstrates that a coherent theory of development must incorporate the multifaceted interaction between behavior in the world and representational change. This is not to say that all knowledge is affected by or constructed through action in the world. Modern developmentalists entertain the possibility that some aspects of conceptual structure arise independent of particular motor experiences (e.g., Spelke et al., 1992). Neither does this view assume, like Piaget, that a single mechanistic account will describe all of the ways in which action affects cognition and perception. The novel view of the developing mind adopted in the articles in this Special Section poses complex challenges for the researchers who pursue it. Nonetheless, this approach has the potential to make a substantial impact on developmental science in that it can lead to rapid progress about our understanding of development.

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