Embodiment in early development

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‘Embodiment’ has come to represent the many ways in which the body influences the functioning of the brain and cognitive processing. This article on embodiment and early development reviews several examples of studies demonstrating embodiment in cognitive tasks. Our overall message is that what the body does during cognitive processing influences cognition in important ways. This might be especially true during early development, before actions are automatized. \textsuperscript{©} 2010 John Wiley & Sons, Ltd. WIREs Cogn Sci 2011 2 117–123 DOI: 10.1002/wcs.109

INTRODUCTION

Human intelligence is often described in terms of symbolic representations and data structures, and computations on these structures. Such language implies that our minds function like computers, like ‘physical symbol systems’ with the brain as neural hardware.\textsuperscript{1–3} Indeed, modern computers can solve complex problems such as chess (e.g., the computer Deep Blue’s defeat of chess master Kasparov). However, a crucial aspect of human intelligence is lost here: human intelligence is situated in a physical body and context. Human intelligence is embodied. Although computers excel in tasks that mainly require ‘brain power’, their performance is much less impressive in tasks that require complex interactions between brain and body. Even though computers can beat expert human chess players, computers are far from beating even a moderately skilled human in a game of pool.\textsuperscript{4}

A computer program can typically be moved from one computer to another and does not run substantially differently depending upon the hardware it runs on. In contrast, humans’ perceptual and cognitive processing are strongly influenced by a change in their physical features. For example, while wearing a heavy backpack humans judge hills to be steeper than without the additional weight on their body.\textsuperscript{5,6} Similarly, changes in temperature influence human’s social relationships, language use, and perception of relations.\textsuperscript{7} These examples show that human cognition is very much shaped by our bodies and our surroundings. From an embodied perspective, none of this is surprising. Our brains are not isolated calculators that function independently. Rather, they are embedded in and influenced by our bodies.

In recent years, the idea of embodiment has become more popular but the theory has a rich history. One of the most well-known proponents of this approach is certainly Jean Piaget. According to his theory, infants and children construct an understanding of the physical, three-dimensional world through their own actions upon and engagement with the world. Over time, young children become capable of representing objects, and these representations must be similarly constructed through the child’s physical interactions with the objects.

An alternate approach that also emphasizes the important role of the body’s actions is J. J. and E. J. Gibson’s ecological theory of perception.\textsuperscript{8–10} According to their theory, humans perceive in order to act and they act in order to perceive, thus casting perception and action as two processes inextricably bound. This connection is most evident in the concept of ‘affordances’ proposed by Gibson.\textsuperscript{10} Affordances are the action possibilities in the environment given our own abilities. Thus, they depend not only on the object we want to act on but also on our own motor capabilities—what our bodies are able to do with an object. How we perceive the environment changes with our own abilities. Maybe the most dramatic change in motor abilities occurs during early development. Thus, the theory of embodiment seems particularly relevant from a developmental perspective.

Purely cognitive perspectives on development tend to consider the body to be an impediment for...
assessing the child’s true cognitive ability. Accordingly, the body is not an interesting object of study, but rather a roadblock that prevents a child’s true competence from being revealed in their performance. This cognitive approach leaves the young child somewhat disembodied, as researchers strive to access the cognitive skills that the body tends to hide. Others, especially researchers studying motor development, advocate for an embodied approach to studying development. An embodied view tends to incorporate multiple interacting factors, including brain, body, context, prior learning, etc. From this perspective, the child’s overt behavior is extremely interesting, is multiply determined, and is the only concrete information available that allows us to assess the child’s ability.

In this article, we describe programs of research that have integrated body and mind in the study of early development. We focus on examples in which the young child’s cognitive skills are prominent and yet their actions play an important role, thereby demonstrating the tight connection between cognition and action. As we will see, influences of the body on cognition may already be present prenatally and in early development.

CLASSIC DEMONSTRATION OF THE EFFECTS OF EMBODIMENT

One of the first and probably the best-known demonstration of the role of the body in the development of perceptual-motor skills was the kitten carousel study published by Held and Hein in 1963. In this landmark study, kittens were raised in the dark. Their only visual experience came from episodes inside a carousel, during which they received either active or passive visual input. Pairs of kittens were placed in a carousel apparatus inside a normally lit room with stripes on the walls to provide patterned visual input. The active kittens were in a harness and were able to walk in a circle around the apparatus. The kittens in the passive group spent the same amount of time in the lit carousel chamber, but were placed in a sled that was connected to the harness of the kitten in the active group, making them a passive ‘passenger’. Subsequently kittens from both groups were placed (one at a time) on an apparatus known as the visual cliff: a Plexiglas surface composed of a shallow side (with the patterned material immediately underneath the Plexiglas) and a deep side (with the patterned material about a meter underneath the Plexiglas). Both the shallow and deep sides provided perfectly good support for walking, but the deep side seemed (visually) to present a dramatic drop off. Strikingly, the researchers observed that the active kittens, but not the passive kittens, avoided walking on the deep side of the visual cliff.12

This study and others like it show that it is not visual stimulation alone, but rather self-produced movement and the corresponding visual feedback that are necessary for the development of visually guided behaviors. Thus, learning and growth occur only with the active interaction of the agent with the environment. Such active exploration of our own bodies and motor abilities begins already prior to birth.

FETAL AND NEONATAL MOVEMENTS

The fetus is able to perform a variety of movements directed at her own body or other objects in the womb (e.g., the umbilical cord). Ultrasound studies show that general movements of the fetus emerge around 7 weeks gestational age (GA), isolated arm and leg movements around 9 weeks GA, and more complex movements (e.g., hand-to-face movements) around 10 weeks GA.13 When these movements are directed toward the fetus’s own body, it has been suggested that the fetus is able to predict and anticipate the outcome of the movement. For example, Myowa et al.14 report that fetuses as young as 19 weeks GA show anticipatory mouth opening when their own hands move toward their head. This behavior was evident in particular when the hand’s final position actually did make contact with the mouth and occurred significantly less often when contact with another part of the head was made. Supporting this interpretation, by 22 weeks GA the kinematics of hand-to-eye movements are significantly different from the kinematics of hand-to-mouth movements. Generally, fetuses show smooth arm trajectories by this age, but their hands approach their eyes much more quickly than they approach their mouths, suggesting that these movements are intentional with predicted outcomes.15 Finally, fetal movements that are directed toward the own body provide simultaneous experiences of touch from two body parts (e.g., the hand and the mouth, also referred to as ‘double touch’; see Ref 16) which enables the fetus to learn about the own body and self.

Thus, we see evidence for controlled, self-directed movements with anticipated outcomes prior to birth. These prenatal motor experiences likely promote the fetus’s learning about her own body and own abilities inside the womb. Moreover, in the absence of meaningful visual experience, learning inside the womb is entirely focused on the body, and it is entirely embodied. Self-produced actions remain
important for learning in early infancy, as studies on conjugate reinforcement demonstrate.

CONJUGATE REINFORCEMENT

In young infants, self-produced actions are important for learning and memory. For example, when a mobile hanging above the infant’s crib is attached to one of their feet with a ribbon, infants quickly learn about relation between their leg movements and those of the mobile and respond with increased activity of leg kicks in the presence of the mobile. This increase in activity is not reflexive, as infants show very specific memory for the trained mobile that is affected by the delay between training and test and the visual similarity between the training and test mobile. Using this paradigm, infants as young as 3 months of age can also learn more complex motor responses such as kicking their legs in tandem when the legs are loosely connected with an elastic band. Such learning of complex motor responses has even been shown in the rat fetus.

Thus, very young infants and even fetuses are able to adapt their motor behavior in response to environmental stimulation. Infants not only remember the stimulus they were trained with (e.g., the mobile) but also they remember the specific motor response they produced (e.g., a leg kick rather than an arm movement). After experiencing motor constraints (e.g., the elastic band between the legs), infants incorporate these in their response. This shows that the memory and representation of a situation or stimulus is not abstract and disconnected from the infant’s body, but instead is tied to the movements of the body in important ways. One might expect similar kinds of learning and behavioral flexibility to accompany the attainment of new motor milestones as well.

CHANGES ACCOMPANYING THE EXPERIENCE OF REACHING

The attainment of each new motor milestone brings with it new opportunities for learning and development. Development is a dynamic process, and therefore it is difficult to know whether certain changes occur specifically because of a change in motor abilities or would have happened anyway at this point in the child’s life even in the absence of changes in motor experience. To investigate this question, researchers have devised a way of providing prereaching infants with simulated reaching experience. Reaching was simulated via Velcro-palmed mittens worn by infants and used in conjunction with Velcro-edged toys. When infants bring their mittened hand close to a toy, it sticks to the mitten and infants can move it through their visual field. By introducing this experience to infants and comparing their behaviors to those of a group ofagematched infants who have not had this experience, we can determine which behavioral changes are brought about by the experience of reaching and which are not.

The results of these experiments have shown that the experience of reaching for objects brings about an increased interest in objects (as measured by increased looking at and mouthing objects), an earlier onset of independent reaching for objects, and an earlier ability to interpret other people’s reaches as goal-directed. This evidence shows that the experience of acting offers new opportunities for learning and development, not just in the motor domain (earlier independent reaching) but in the cognitive domain as well. It remains unclear whether the real impetus for independent reaching (in combination with the developing physical ability to do so) is an increased motivation to learn about objects, a realization that the arms and hands can be recruited for such actions, or some combination of these and other factors. Similar sets of changes in learning and cognition accompany other motor transitions as well (i.e., Refs 24 and 25). Such findings provide clear evidence for how learning and cognition are constrained and facilitated by the child’s changing motor repertoire. Certainly it is not the case that all learning is made possible by motor advances. Instead, it seems likely that certain kinds of knowledge might be best learned via one’s own experiences and sometimes these experiences await the development of requisite motor skills.

CHANGES BROUGHT ABOUT BY THE TRANSITION TO CRAWLING OR WALKING

Although it stands to reason that the development of new motor skills allows for new learning opportunities, tracking down precisely what is learned can be complicated. This fact is demonstrated in the research on the transition into self-produced locomotion.

One claim is that the onset of self-produced locomotion instigates a change from an egocentric to an allocentric representation of locations in space. According to this argument, prior to the onset of self-produced locomotion, infants are strictly limited in their spatial representation skills and are only able to represent object locations egocentrically or relative...
to their own body. In favor of this argument is evidence for dramatic improvements in infants’ spatial representational skills around the time that they begin to locomote on their own. 25–28 This suggests that the onset of self-produced locomotion is a direct catalyst to the development of infants’ ability to represent space via nonegocentric means. However, another possibility is that even prelocomoting infants are capable of forming allocentric representations of space, but do so less often. Perhaps egocentric representations are less demanding of cognitive resources than allocentric representations, and the scarcity of cognitive resources leads infants to create egocentric representations more often than allocentric representations. In favor of this latter explanation are findings by Rieser 29 and Kaufman and Needham, 30 among others, indicating that even prelocomotor infants are capable of forming allocentric spatial representations. Thus, self-produced locomotion may only facilitate but not begin the formation of nonegocentric representations of space. As infants move around independently and more often encounter situations that call for them to recalculate the location of an object, they may come to determine that allocentric representations are more durable and last over changes in their own location in a way that egocentric representations do not.

Another claim is that the onset of self-produced locomotion leads infants to develop a wariness of heights, possibly because of learning from their own falls. 31 However, research designed to investigate learning from falling suggests that children do not learn very efficiently from their own falls, 32 so it is not clear how quickly this information gets integrated into their behavioral repertoire. Further, Karen Adolph’s work 24,33 suggests that infants must learn through their own experiences how their body moves in various postures and on various surfaces. Infants’ learning about their own abilities is specific to each posture (e.g., sitting) and does not influence their behavior in a different posture (e.g., crawling). This work suggests that learning about the body’s movement is not a general cognitive realization brought on by abstract learning. Instead, it is an embodied enterprise that depends upon the child experiencing many details about how their body moves in each posture.

EMBODIMENT AND THE A-NOT-B ERROR

Theories of development take the influences of multiple domains of infant development into account (e.g., motor, cognitive, emotional) and often produce more satisfactory explanations for infant behavior than theories that focus on just one component. One example is explanations for the well-known A-not-B search task. In this task, a toy is hidden at one of two hiding locations (A) in full view of the infant. Following a brief delay, the infant is then allowed to search for and retrieve the toy. This sequence is repeated several times with the toy always being hidden at location A. Eventually, the toy is hidden at the other location (B)—again in full view of the infant—and the infant is allowed to search for the object. Originally devised by Piaget, 34 this simple object-hiding task leads to a surprising failure in 8- to 10-month-old infants. Following repeated searches at location A, 8- to 10-month-old infants show a preservation error and continue to search at location A despite witnessing the hiding of the object at location B. This response is known as the A-not-B error and has been replicated repeatedly with various alternations (for review see Ref. 35).

According to Piaget’s theory, 34 this error occurs due to an immature object representation system in infants of this age. However, three points argue against such an interpretation: (1) Using visually based violation of expectation paradigms, object permanence has been observed in 3- to 4-month-old infants. 36 Thus, there seems to be a decalage between what infants understand about the hiding events when tested in visually based paradigms and what they understand about the events when tested in manually based paradigms. (2) Certain seemingly unimportant aspects of the task strongly influence infants’ performance. Other than age, the delay duration and the preceding number of A trials predict the occurrence of the A-not-B error. 37,38 And (3), hiding an object is not required to elicit the effect. Simply drawing infants’ attention to an empty hiding place itself can also cause the behavior of the A-not-B error. 39,40

To explain these results, a dynamic field model has been proposed by Esther Thelen et al. 35 By explicitly taking motor plans and memory into account, this model predicts infants’ performance on the AB task very well: It predicts a U-shaped pattern of development with correct reaching responses in infants younger and older than 8–10 months. 41 Further, it accounts for the failure exhibited by 8- to 10-month-old infants and offers an explanation for the discrepancy between looking and reaching versions of the task. Finally, the model correctly predicts that changes affecting motor execution and planning should affect performance on the task. Indeed, changing infants’ position (from sitting to standing) or adding weights to their arms just prior to the switch trials removes the preservative A-not-B
error.40,42 Further, a case study with two infants suggest that there is a relation between infants’ development of stable reaching and the occurrence of the preservative A-not-B error.41 In summary, recent findings on the influence of motor abilities, experiences, and memories on performance in the AB task seem to argue for a multifaceted, embodied explanation of infants’ behavior in this task.

**ASSESSMENTS OF ABILITY DEPEND ON DEPENDENT MEASURE**

Over the past 20 years or so, researchers have uncovered many unexpected cognitive competencies in infants. Using paradigms that did not require motor actions but just measured infants’ looking behavior, studies documented more sophisticated cognitive skills than had been originally observed (e.g., by Piaget in his seminal work) using tasks requiring motor actions (e.g., manual search tasks). We now know that infants’ display of cognitive abilities depends on the way these abilities are assessed. The same holds for studies on toddlers and young children.

For example, in a series of studies by Rachel Keen et al. (e.g., Refs 43 and 44), young children’s ability to reason about the solidity of an object was assessed. Participants watched as a ball rolled down a ramp and was stopped by an obstacle on the ramp. In one condition, part of the ball’s path was hidden behind an opaque screen and in another it was visible through a Plexiglas screen. In either case, the obstacle protruded well above the top of the screen, and so participants should have been able to determine where to look for the ball based on where they saw the obstacle. They could look for the ball behind one of four doors located along the ramp at each of the spots where the obstacle might be placed. In a visual version of this task where the event is observed and then either followed by a possible outcome (the ball is where it should be) or an impossible outcome, both the infants and the toddlers succeed (i.e., both look longer at the impossible outcome following the event). In contrast, in a version requiring manual retrieval of the ball, only the older toddlers open the correct door. Younger toddlers and infants respond at chance levels. Thus, there seems to be a disconnection between what they ‘know’ when assessed via visual measures and what they ‘know’ when assessed via manual measures.

These differences provide evidence that children’s thinking is affected by their body’s involvement. It does not seem to be true that tasks access abstract, disembodied knowledge that is the same no matter how it is probed. Instead, the specific demands of the task make the young child look sophisticated or clueless, depending upon the motor demands of the task.

**MIRROR NEURONS—A NEURAL BASIS FOR EMBODIMENT?**

The discovery of ‘mirror neurons’ suggests that there could be a neural basis for an embodied cognition. Mirror neurons are neurons that become active during both action production and action observation and were originally discovered in the premotor cortex45 and parietal lobe (e.g., Ref 46) of macaque monkeys. Using behavioral and brain imaging techniques (e.g., positron emission tomography, functional magnetic resonance imaging), several studies have since provided behavioral and neurophysiological evidence for a similar mirroring system in humans (for review see Ref 47). More recently, evidence for individual neurons with mirror properties in the human brain has been reported as well.48

During observation of an action, the mirroring system matches the observed action onto our motor system and thus provides a ‘sense’ for actions.49,50 Further, the mirroring system is selectively activated by actions that are within our own motor repertoire and can be shaped by experience.51–53 It has been suggested that a rudimentary mirroring system may already be present at birth.54 However, direct evidence for a functional mirroring system using brain imaging has only been reported in 6- to 7-month-old infants.55,56 Together, these observations suggest that our action understanding abilities are embodied via mirror neurons and that this system is functional to some degree as early as 6 months of age. Therefore, a mirroring system may contribute to an embodied understanding of actions already in early infancy.

**CONCLUSIONS**

In this article, we have reviewed a collection of studies that make a strong case for the embodiment of cognition in early development. The studies reviewed here suggest that we have to view development from an embodied perspective. As the body grows and changes throughout prenatal development, infancy, and childhood, our learning and problem-solving skills are continually adjusting to these changes. This fact is most obvious when the body is undergoing rapid
changes in size and ability. But perhaps embodiment is no longer a factor once the body reaches maturity. Is adult cognition less embodied because the body has reached a stable state? Work by Barsalou (e.g., Refs 57 and 58) and others suggests that the body continues to put its mark on cognition even in adulthood. These effects may be subtler due to adults’ expertise in moving their bodies. Reaching, walking, and going up and down stairs are actions that we engage in without the need to think carefully about our actions. But before this expertise develops, moving the body may well require considerable cognitive effort. For adults, certain aspects of action may still require conscious thought, but most do not.59

The relevance of embodiment may become more compelling as researchers who have focused on disembodied cognition begin to think more about how cognition occurs in the world outside the lab. Out of necessity, these researchers will have to incorporate the body and its movement into their conceptual frameworks. This will be one of the challenging next frontiers for research in psychology.

REFERENCES


