Development and Aging

Action, the foundation for cognitive development

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It is argued that action constitutes the foundation for cognitive development. Action is a principal component of all aspects of cognitive development including social understanding. It reflects the motives of the child, the problems to be solved, the goals to be attained, and the constraints and possibilities of the child's body and sensory-motor system. Actions are directed into the future and their control is based on knowledge of what is going to happen next. The child's sensory-motor system is especially designed to facilitate the extraction of this knowledge. In addition, the infant is endowed with motives that ensure that these innate predispositions are transformed into a system of knowledge for guiding actions. By acting on the world, infants develop their cognition.

Key words: Perception-action, development, motivation, social cognition.

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The movements of biological organisms are organized as actions, that is, they are defined by goals and guided by prospective information. Earlier events and stimuli in the surroundings may provide information and motives for actions, but they do not just elicit the movements like reflexes do, not even in the newborn infant. Perception is needed both for planning actions and for guiding them toward their goals. Not only do actions rely on perception, but actions are also a necessary part of the perceptual process. For instance, active touch is required to haptically perceive the form of an object (Gibson, 1966). The hand must move over the object and feel its form, its bumps and its indentations. The clearest example of the necessity of action for functional perception is vision itself. Our visual field consists of a very small fovea surrounded by a large peripheral visual field over which acuity rapidly deteriorates with increasing angular eccentricity. Already at 10° off the fovea, the visual acuity has decreased 80%. In spite of this, we have the illusion that we see equally clearly over our whole field of vision. A simple experiment shows that this is wrong. If one firmly fixates a word in a text it is hardly possible to even read the neighboring words. The illusion of an equally clear visual field is created by the fact that we move the fovea to every single detail that we want to attend to, and by doing this we can inspect it with optimal resolution. The same principles hold for all modes of perceiving. Perception is always characterized by exploratory activities such as looking, listening, sniffing, tasting, and feeling (Gibson, 1966). It is equally true that all actions also have perceptual functions. Locomotion reveals the layout of the environment, manipulation reveals object properties, and social interaction is essential for person perception. One's movements also reveal information about the biomechanics of the body, the forces acting on it and how these change over the execution of a movement. Thus, by necessity, any action also involves perceptual actions.

Adaptive behavior has to deal with the fact that events precede the feedback signals about them. In biological systems, the delays in the control pathways may be substantial. The total delays for visuo-motor control, for instance, are at least 200 ms. Relying on feedback is therefore non-adaptive. The only way to overcome this problem is to anticipate what is going to happen next and use that information to control one's actions. Most events in the outside world do not wait for us to act. Interacting with them requires us to move to specific places at specific times while being prepared to do specific things. This entails foreseeing the ongoing stream of events in the world as well as the unfolding of our own actions. Time is irreversible and what has been accomplished is only of interest for the ability to control the next part of the action. The development of skill is both a question of building procedures for structuring actions far ahead in time and procedures for extracting the right kind of predictive information for the detailed monitoring of actions (Johnson, 2000).

Predictive control is possible because events in the world are governed by rules and regularities. The most general ones are the laws of nature. Inertia and gravity, for instance, apply to all mechanical motions and determine how they will evolve. Infants know these rules and use them to guide their actions from a very early age. They are part of what Spelke (2000) has called *core knowledge*. Other rules are more task specific and have to be learnt like those that enable us to ride a bike or play chess. Finally, there are rules that facilitate social behavior and enable us to communicate and exchange information with each other.

Information for predictive control of behavior is available through both perception and cognition. Perception provides direct information about the state of the body and the outside world and what is going to happen next. Knowledge of the rules and regularities of events enable us to predict what is going to happen over longer periods of time. Together the sensory based and the knowledge based modes of prospective control supplement each other in making smooth and skilful actions possible.

If mastery of actions relies on the perception and knowledge of upcoming events, then the development of actions has to do with acquiring systems for handling such information (von Hofsten, 1993, 2003, 2004, 2007). It has to do with anticipating one's own posture and movements as well as identifying objects and events in the world, and understanding other people's actions. For every mode of action that develops, new prospective problems of movement construction arise, and it takes time to acquire ways to solve them. The knowledge gathered through systematic exploration of a task is structured into a frame of reference for action that makes planning possible. This is the basis of skill. The importance of practice and repetition is not to stamp in patterns of movement or achieve an immutable program, but rather to encourage the functional organization of action systems (Reed, 1996).

THE ACTION SYSTEMS OF THE NEWBORN CHILD

Converging evidence shows that most neonatal behaviors are prospective and flexible goal-directed actions. This is not surprising. Sophisticated pre-structuring of perception and action is the rule rather than the exception in biological organisms. Perception is less sophisticated than later in life, but the information it provides is meaningful. For instance, the light reaching the retina is divided up into units with inner unity and outer borders that correspond to surfaces and objects in the world.

The behavior of neonates has traditionally been discussed in terms of reflexes rather than actions. According to Sherrington (1906) a reflex is a hardwired sensory-motor loop organized at a spinal or para-spinal level. Although reflexes serve important functions, they are stereotyped, elicited, and once launched run their predetermined course. In other words, they cannot be considered goal directed and they do not adjust to future states in a prospective way. This means, for instance, that reflexes are not subject to learning. Neither are they adjusted in order to meet other goals or attain other advantages than those for which they were originally designed.

Like adults, neonates have reflexes. For instance, a slight hit below the knee-cap elicits a stretch reflex. However, most of the so-called neonatal reflexes are not characterized by the properties described above. On the contrary, neonatal movements are functional, goal-directed, prospective, and flexible in the sense that they can be altered to gain advantages. The newborn child is clearly prepared to interact with the external world and adapt to it.

Rooting, for instance, is traditionally described as a typical neonatal reflex. It refers to the infant's search for the nipple of the breast. Mechanical stimulation in the area around the mouth makes the infant move his or her mouth toward the point of stimulation (Prechtl, 1958). However, rooting is more than a simple reflex. Wherever the face is touched, the head is turned in that precise direction indicating that the response is flexible and goal-directed rather than stereotyped. Odent (1979) also showed that rooting does not just involve movements of the head and mouth, but seems to include explorative movements of the whole body with all the senses involved. Furthermore, rooting is not elicited when the infant touches itself (Rochat & Hespos, 1997), but only when an external object is the source of stimulation. Finally, a newly fed infant is less likely to perform these movements. These facts speak in favor of a far more sophisticated organization of this behavior than suggested by the reflex notion.

Sucking is probably the most precocious newborn behavior. It is the only one for which the newborn child may be more skilled than the adult. Sucking relies on a complex interaction of muscle contractions that are prospective in nature. Within a day or so after birth the sucking system functions with amazing accuracy (Craig & Lee, 1999). Such smooth functioning relies on adjusting the change in sucking pressure to the flow of milk that is different from suck to suck. Thus, the infant has to sense the upcoming flow of milk and adjust the sucking pressure to it ahead of time. Apart from using sucking to acquire food, neonates are also able to use sucking to gain other advantages, for instance, as a means to get access to the mother's voice (DeCasper & Fifer, 1980) or to regulate a visual event (Kalnins & Bruner, 1973). DeCasper and Fifer found that, within a day from birth, neonates would alter their sucking rate in order to access their mother's voice. This shows that newborn infants can use behaviors as means rather than ends and they can flexibly apply them to a variety of problems.

Neonatal reaching: Although successful reaching does not appear until around 4 months of life, the link between eye and hand is already established in newborn infants. Van der Meer (1997) made a fronto-parallel, horizontal beam of light pass in front of newborn children in such a way that the light was not visible unless the child happened to put their hand into the beam. If this was the case, the hand became bright by the reflected light. It was found that after the first event of this kind, the children put their hand repeatedly into the beam. More importantly, when the beam was moved, the newborn children rapidly altered the position of their hand and thereby improved the chance of having it illuminated. When moving the hand(s) into the beam, they controlled the position, velocity and deceleration of their arms so as to keep them visible in the light beam.

Newborn infants also move their arm(s) toward attractive objects in front of them (von Hofsten, 1982, 1984). The immediate function of this reaching behavior cannot be to grasp and manipulate objects, because the infant does not yet control arm and hand movements independently (von Hofsten, 1984). However, newborn reaching has another very important function. When the hand moves toward the object of interest it enters into the visual field and its movements can then be visually perceived and become controlled by visual information. Another kind of goal directed arm and hand movements that neonates engage in is putting their fingers or thumbs into their mouth. When they do, they open the mouth in anticipation of the arrival of the thumb (Lew & Butterworth, 1995). Such behaviors have also been observed prenatally (Zoia, Blason, D'Ottavio *et al*., 2007).

The function of all these built-in skills, in addition to enabling the newborn child to act, I suggest, is to provide activity-dependent input to the sensory-motor and cognitive systems. This makes it possible for the newborn infant to begin exploring the relationship between commands and movements, between vision and proprioception, and discover the possibilities and constraints of their actions. It is important to note that the core abilities rarely appear as ready-made skills, but rather as something that facilitates the development of skills.

THE DEVELOPMENTAL PROCESS

Although perception and action are deeply rooted in phylogeny, they would be of little use if they did not develop. Development is the result of a process with two foci, one in the central nervous system and one in the subject's actions. The brain undoubtedly has its own dynamics that makes neurons proliferate, migrate and differentiate in certain ways and at certain times. However, the emerging action capabilities are also crucially shaped by the subject's interactions with the environment. Perception, cognition, and motivation develop at the interface between neural processes and actions. They are a function of both and arise from the dynamic interaction between the brain, the body, and the outside world. A further important developmental factor is the biomechanics of the body: perception, cognition and motivation are all embodied and subject to biomechanical constraints. Those constraints change dramatically with age, and they both affect and are affected by the developing brain and by the way actions are performed. The nervous system develops in a most dramatic way over the first few months of postnatal life. During this period, there is a massive increase in the connectivity of the cerebral cortex and the cerebellum. Once a critical mass of connections is established, a self-organizing process begins that results in new forms of perception, action and cognition. The emergence of new forms of action always relies on multiple developments. The onset of functional reaching depends, for instance, on differentiated control of the arm and hand, the emergence of improved postural control, precise perception of depth through binocular disparity, perception of motion, control of smooth eye tracking, the development of muscles strong enough to control reaching movements, and a motivation to reach.

MOTIVES DRIVE DEVELOPMENT

The development of an autonomic organism is crucially dependent on motives. They define the goals of actions and provide the energy for getting there. The two most important motives that drive actions and thus development are social and explorative. They both function from birth and provide the driving force for action throughout life.

There are at least two exploratory motives. The first one has to do with learning about one's own action capabilities. For example, before infants master reaching, they spend hours and hours trying to get the hand to an object in spite of the fact that they will fail, at least to begin with. For the same reason, children abandon established patterns of behavior in favor of new ones. For instance, infants stubbornly try to walk at an age when they can locomote much more efficiently by crawling. In these examples there is no obvious external reward. It is as if the infants knew that sometime in the future they would be much better off if they could master the new activities. The direct motives are, of course, different. Moving is probably just very pleasurable. According to Adolph and Berger (2006), infants who have recently started to walk take, on the average, over 9,000 steps during a day. Expanding one's action capabilities seems extremely rewarding. When new possibilities open up as a result of, for example, the establishment of new neuronal pathways, improved perception, or biomechanical changes, children are eager to explore them. At the same time, they are eager to explore what the objects and events in their surroundings afford in terms of their new modes of action (Gibson & Pick, 2000). The pleasure of moving makes children less focused on what is to be achieved and more on their movement possibilities. It makes children try many different procedures and introduces necessary variability into the learning process.

The second explorative motive has to do with finding out about the surrounding world. Infants are extremely curious and they rapidly learn about new objects and events that surround them. When the objects are known, they are much less interesting. This is such a profound characteristic of infant behavior that the most common way of investigating infant cognition is to show an object or event several times to the child. The children will look less on every new presentation, and when the looking time has decreased to a certain lower level, a change is introduced. If the children are sensitive to this contrast, they will then increase their looking again. This method has, for instance, been used to investigate infants' sense of numbers (Feigenson, Dehaene & Spelke, 2004). It is hard to imagine the full impact of this curiosity motive. In a recent study where 11- and 13-month-olds were video-recorded in their homes for one hour, Karasik, Tamis-LeMonda, and Adolph (2009) found that the infants made contact with about 40 objects during that time, corresponding to a new object every 1.5 minutes. The motive to explore objects is closely related to the social motive of the child. Not only do children explore objects and events for their own benefit, but they also want to share their newly acquired knowledge with other people. Karasik *et al*. (2009) found that in a large majority of the cases the infants in her study showed the objects to the parent who was present and they often carried the objects to them.

The social motive puts the infant in a broader context of other humans that provide information, comfort, and security. From other people, the subject can learn new skills, find out new things about the world, and exchange information through communication. The social motive is expressed from birth in the tendency to fixate social stimuli, imitate basic gestures, and engage in social interaction. The social motive is so important that it has even been suggested that without it a person will stop developing altogether.

ACTING ON OBJECTS AND EVENTS

Looking is one of the most basic of all actions and is present in newborns. They primarily look at other people and salient moving objects, but they cannot track events smoothly. This ability appears at around 2 months of age (von Hofsten & Rosander, 1997) when infants begin to be able to stabilize gaze on moving objects. The smooth pursuit is predictive in the sense that gaze stays on target irrespective of how the object moves. It requires prediction of the upcoming motion. At around 4 months, infants also keep track of moving objects over temporary occlusion by making a saccade to the reappearance point before the object reappears there (Rosander & von Hofsten, 2004; von Hofsten, Kochukhova & Rosander, 2006). The tracking is typically interrupted by the disappearance of the object and just before the object reappears, gaze moves to the reappearance position. This behavior is demonstrated over a large range of occlusion intervals, suggesting that the infants track the object behind the occluder in their "mind's eye".

At around 4 months of age, infants begin to successfully grasp objects within reach. When planning the reach, the direction and distance to the object are taken into account and the hand starts to close before the object is encountered (von Hofsten & Rönnqvist, 1988). The orientation of the hand is adjusted to the orientation of the object ahead of time (von Hofsten & Fazel-Sandy, 1984). A remarkable ability of infants to time their manual actions relative to an external event is demonstrated in early catching behavior (von Hofsten, 1980, 1983; von Hofsten, Vishton, Spelke, Feng & Rosander, 1998). Von Hofsten (1980) found that infants reached successfully for moving objects at the same age they began mastering reaching for stationary ones. Eighteen-week-old infants were found to catch an object that moved at 30 cm/s. The reaches were aimed towards the meeting point with the object and not towards the position where the object was seen at the beginning of the reach.

During the second year of life, children are fascinated by problems of how to relate objects to each other. They put objects into piles, put lids on pans, and insert objects into holes. Such manipulations of objects require an even more sophisticated representation of objects and events. The child must imagine the goal state of the manipulation and the procedures of how to get there. Örnkloo and von Hofsten (2007) studied how children come to master the fitting of objects into apertures. The task was to insert elongated objects with various cross-sections (circular, square, rectangular, elliptic, and triangular) into apertures in which they fitted snugly. It was found that although 14- to 18-month-old children understood the task of inserting the blocks into the apertures and tried very hard, they were not very successful. Most of the time, they did not even turn the elongated blocks on end, but just placed them on the aperture and tried to press them through. The 22-month-old children, however, systematically rose up the horizontally placed objects when transporting them to the aperture, and the 26-month-olds turned the objects before arriving at the aperture, in such a way that they approximately fit the aperture. The results show that the infants were only successful when they had prepared the insertion of the objects in this way. Failure to insert the object did not seem to help the child to make an appropriate correction, that is, a pure feedback strategy did not work. Preparing the proper orientation adjustments before inserting the object into the hole requires that the child mentally rotates the manipulated object into the fitting position ahead of time. The ability to imagine objects at different positions and in different orientations greatly improves the child's action capabilities. It enables them to plan actions on objects more efficiently, to relate objects to each other, and plan actions involving more than one object.

INTERACTING WITH OTHER PEOPLE

There is an important difference between social actions and those used for negotiating the physical world. The fact that one's own actions affect the behavior of the person towards whom they are directed creates a much more dynamic situation than when actions are directed towards objects. Socially important information is readily displayed by specific movements, gestures, and sounds that are important to perceive and control. Facial gestures convey information about emotions, intentions, and direction of attention. The development of social perception is facilitated by a set of innate attentional dispositions that create an optimal learning environment for understanding social interaction. Other people's faces attract newborn infants, and from an early age infants are able to perceive other people's emotions and direction of attention. Infants perceive other people's gaze direction from 5 months of age (Gredebäck, Theuring, Hauf & Kenward, 2008). Looking helps to maintain communication with other people and follow their communications. Mastery of social communication is not just a question of being able to observe and listen to a conversation; it is also of crucial importance to predict what is going to be said next and by whom. We asked when children begin to understand this process by shifting gaze from the present speaker to the next one before the switch takes place. The gaze movements were recorded with a cornea refection technique in 1-year-olds, 3-year-olds, and children with autism while they viewed a 90 s conversation on video. The 3-year-olds shifted their gaze to the next speaker ahead of time in a majority of the turns, but 1-year-olds and children with autism did not (von Hofsten, Uhlig, Adell & Kochukhova, 2009).

How do children become able to understand other people's actions including the intentions underlying them? One influential theory states that they do it by reasoning (theory of mind, TOM). An alternative idea that recently has gained much support states that we understand other people's actions by projecting them onto our own action programs. The underlying assumption is that the principles that govern their actions are the same as those that govern our own. Devoted mechanisms in the brain help the child to take this shortcut to social understanding (the mirror neuron system, MNS). A number of studies have found evidence that the neural circuits activated when performing actions are also activated when observing the same actions (Fadiga, Fogassi, Pavesi & Rizzolatti, 1995; Hari, Forss, Avikainen, Kirveskari, Salenius & Rizzolatti, 1998; Rizzolatti & Craighero, 2004). As sensory-motor abilities generally seem to develop ahead of reasoning, studies of young children should help to distinguish between these two perspectives. If children's social competence relies on reasoning, we would expect it to develop in parallel with other cognitive abilities. If, however, it relies on projecting other people's actions onto their own action programs, it is the ability to perform those actions that become the limiting case.

Research on TOM usually employs problems of "false belief", that is, situations where the experience of a third person (B) is different from the experience of the person to whom the problem is posed (A). For instance, a hidden object is moved while A is looking, but B is not. Thus A knows where the object is, but B has a false belief about its hiding place. Person A is then asked where he/she thinks that person B believes the object is. Children below 4 years of age tend to give a wrong answer to this question, because they do not, in their reasoning, take into account the different experience of person B. Thus, it is clear that subjects who solve these problems can logically take into account the experience of a third person. The question is whether the ability to do this second order reasoning is necessary for understanding other people's minds.

One problem has to do with the understanding of verbal instructions. Younger children may mistakenly believe that the question is about their understanding of the situation and not the third person's. When looking behavior has been employed as a measurement of children's understanding of false belief, much younger children solve the problems. For instance, Southgate, Senju and Csibra (2007) showed 2-year-old children a sequence of hiding events that also included a third person. The third person, however, was shown to turn away when the critical displacement of the object was performed. At the end of the event sequence, the third person was shown with the two hiding places in front of her with no indication of where she would search for the object. Seventeen out of twenty of the 2-year-old subjects made their first saccade towards the hiding place where the third person would believe that the object was hidden. Similar studies using habituation of looking have indicated such understanding in 14-month-olds (Onishi & Baillargeon, 2005; Song & Baillargeon, 2008).

Although these studies show that children understand other people's minds much earlier than previously believed, they still beg the question of when such understanding appears in development. The MNS hypothesis provides a conceivable mechanism for such early social understanding. We have investigated the possible onset of MNS in two ways.

First, we investigated the eye movements performed when infants and adults observed visually guided actions. In such tasks, task-specific proactive eye movements are crucial for planning and control (Johansson, Westling, Bäckström & Flanagan, 2001). Because the eyes are free to move when observing goal-directed actions, the MNS hypothesis predicts that subjects should produce eye movements similar to those produced when they perform the task. Flanagan and Johansson (2003) found that adult subjects moved their gaze proactively to the goal of such actions. Falck-Ytter, Gredebäck & von Hofsten (2006) measured how adults, 12-, and 6-month-olds observed displacement movements. They found that adults as well as 12-month-olds shifted gaze proactively to the goal of the observed actions. The 6-month-old infants, however, did not do that. On the contrary, their gaze movements were linked reactively to the course of events. In a control condition where everything was the same as in the original displacement condition, except that no hand producing the movement was visible, neither the adults nor the children tracked the object proactively. (Fig. 1).

Why did the younger infants fail to predict the goal of this action by their looking? As the mirror hypothesis states that observed actions are projected onto one's own motor programs, it is expected that movements not yet mastered by the child should not be mirrored. Six-month-old infants do not yet systematically move objects from a position to another. If they pick up an object and displace it, they almost always move it to the mouth. Kochukhova and Gredebäck (2009) measured how 6-month-old infants track observed movements to the mouth. They found that 6-month-old infants shift gaze very proactively to the mouth (lead 0.5 s). When the hand moving the food to the mouth was invisible, gaze arrived to the mouth after the spoon. These results suggest that the onset of a functional MNS is set by the motor experience of the child. Movements directed at the mouth are understood at an earlier age than movements directed at another point in action space.

The other way in which we studied the onset of a functional MNS was through EEG measurements. There is a specific frequency interval in the EEG spectrum, the mu-rhythm (9–13 Hz in adults and 5–9 Hz in infants), which is enhanced during rest and desynchronized during action performance. The same desynchronization appears during the observation of actions in adults (Hari *et al*., 1998). This has been taken as an indication that the desynchronization of the mu-rhythm reflects the activity of the MNS. If this is so, then the desynchronization of the mu-rhythm should be greater when subjects observe goal-directed movements than when they observe movements that do not have obvious goals. Recently, Nyström, Ljunghammar, Rosander and von Hofsten (2009) found that 8-month-old infants who observed live goal-directed reaching actions showed a greater desynchronization of the mu-rhythm than when they observed simple placing movements of the hand performed by the model. The reaching and the placing movements were similar in the sense that both transported the hand to a tabletop. The EEG analysis showed that it was primarily the electrodes over the

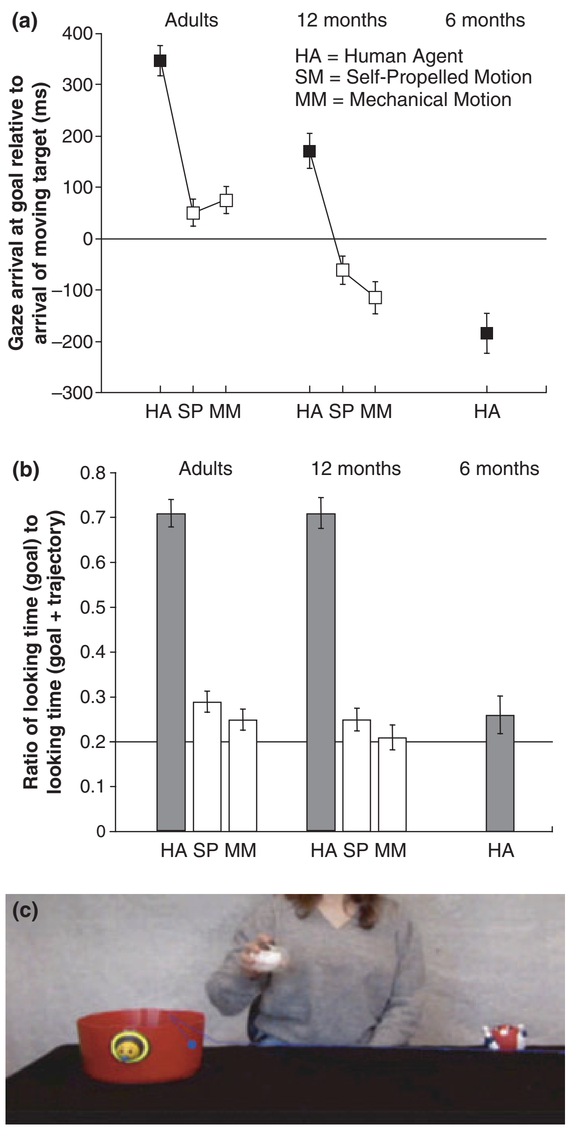

Fig. 1. The looking performance for the three age groups and the three conditions of Falck-Ytter, Gredebäck and von Hofsten (2006): (a) Timing (ms) of gaze arrival at the goal relative to the arrival of the moving target. Target arrival is represented by the horizontal line at 0 ms. Positive values correspond to early arrival of gaze at the goal area. (b) Ratios of looking time at the goal area to total looking time in both goal and trajectory areas during object movement. The horizontal line at 0.2 represents the ratio expected if subjects tracked the moving target. (c) The position of the hand when gaze arrived at the goal bucket on a typical HA trial. Note that the head of the agent was not shown to the subjects. The blue line and dot corresponds to the eye movement as measured by TOBII 1750.

premotor areas that showed this effect. This area is known to be of importance for the functioning of the MNS (Fig. 1). In summary, both the EEG studies and the studies of predictive eye movements suggest that the MNS related to manual actions becomes functional during the second half of the first year of life. As infants come to master their own manual actions, they also begin to understand such actions performed by other people. The studies support the hypothesis that this understanding is mediated by a devoted neural system anchored in the subject's own motor system.

CONCLUSIONS

Cognitive development cannot be understood in isolation. It has to be related to the motives of the child, the action problems to be solved, and the constraints and possibilities of the child's body and sensory-motor system. Action control relies on anticipation of what is going to happen next, and this has to be based on knowledge of the rules and regularities that govern events. Some of them are directly perceivable, while others rely on more indirect knowledge. It is not just a question of anticipating physical events, but also of relating one's own actions to the actions of other people. Recent research shows that specific areas in the brain encode our own and other people's actions alike, and that this forms a base for the understanding of how the actions of others are carried out as well as the goals and motives that drive them.

Piaget (1953, 1954) realized that there is an important ontogenetic connection between action and cognition, but he postulated that this connection fades away with the onset of rule based thinking. It is obvious that the link between action and cognition may seem less direct in older children and adults because they can simulate events and their outcomes in their minds. This does not mean, however, that the rules that govern these processes are different from those that govern actions more directly.

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