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Action in development

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Abstract

It is argued that cognitive development has to be understood in the functional perspective provided by actions. Actions reflect all aspects of cognitive development including the motives of the child, the problems to be solved, and the constraints and possibilities of the child's body and sensorimotor system. Actions are directed into the future and their control is based on knowledge of what is going to happen next. Such knowledge is available because events are governed by rules and regularities. The planning of actions also requires knowledge of the affordances of objects and events. An important aspect of cognitive development is about how the child acquires such knowledge.

Introduction

Cognition and action are mutually dependent. Together they form functional systems, driven by motives, around which adaptive behaviour develops (von Hofsten, 1993, 2003, 2004). From this perspective, the starting point of development is not a set of reflexes triggered by external stimuli, but a set of action systems activated by the infant. Thus, dynamic systems are formed in which the development of the nervous system and the development of action mutually influence each other through activity and experience. With development, the different action systems become increasingly future oriented and integrated with each other and ultimately each action will engage multiple coordinated action systems.

Adaptive behaviour has to deal with the fact that events precede the feedback signals about them. 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 behaviour. Furthermore, 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 surrounding world as well as the unfolding of our own actions. Such prospective control is possible because events 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 evolve. Other rules are more task specific, like those that enable a child to grasp an object or use a spoon. Finally, there are socially determined rules that we have agreed upon to facilitate social behaviour and to enable us to communicate and exchange information with each other. Knowledge of rules makes smooth and skilful actions possible. It is accessible to us through our sensory and cognitive systems.

The kind of knowledge needed to control actions depends on the problems to be solved and the goals to be attained. Therefore, motives are at the core of cognitive processes and actions are organized by goals and not by the trajectories they form. A reach, for instance, can be executed in an infinite number of ways. We still define it as the same action, however, if the goal remains the same. Not only do we categorize movements in terms of goals, but the same organizing principle is also valid for the way the nervous system represents movements (Bizzi & Mussa-Ivaldi, 1998; Poggio & Bizzi, 2004). When performing actions, subjects fixate goals and sub-goals of the movements before they are implemented, demonstrating that the goal state is already represented when actions are planned (Johansson, Westling, Bäckström & Flanagan, 2001).

The developmental primitives

An organism cannot develop without some built-in abilities. If all the abilities needed during the lifetime are built in, however, then it does not develop either. There is an optimal level for how much phylogeny should provide

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and how much should be acquired during the life time. Most of our early abilities have some kind of built-in base. It shows up in the morphology of the body, the design of the sensorimotor system, and in the basic abilities to perceive and conceive of the world. One of the greatest challenges of development is to find out what those core abilities are, what kind of knowledge about the self and the outside world they rely on, and how they interact with experience in developing action and cognition.

Some of the core abilities are present at birth. Although newborn infants have a rather restricted behavioural repertoire, converging evidence shows that behaviours performed by neonates are prospective and flexible goal-directed actions rather than primitive reflexes. For instance, the rooting response is not elicited if the infant touches him- or herself on the cheek or if they are not hungry (Rochat & Hespos, 1997). When sucking, neonates monitor the flow of milk prospectively (Craig & Lee, 1999). They can visually control their arm movements in space and aim them towards objects when fixating them (von Hofsten, 1982; van der Meer, 1997). Van der Meer (1997) showed that when a beam of light was positioned so that the light passed in front of the neonates without reflecting on their body, they controlled the position, velocity and deceleration of their arms so as to keep them visible in the light beam. 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 sensorimotor and cognitive systems. By closing the perception–action loop the infant can begin to explore 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.

Actions directed at the outside world require knowledge about space, objects, and people. For instance, we need some kind of mental map of the environment around us that enables us to move about and know where we are. We need to be able to parse the visual array into relatively independent units with inner unity and outer boundaries that can be handled and interacted with, i.e. objects, and we need to be able to distinguish the critical features of other people that makes it possible to recognize them and their expressions, communicate with them, and perceive the goal-directedness of their actions. Infants are endowed with such knowledge providing a foundation for cognitive development. Nevertheless, Spelke (2000) suggests that core knowledge systems are limited in a number of ways: they are *domain specific* (each system represents only a small subset of the things and events that infants perceive), *task specific* (each system functions to solve a limited set of problems), and *encapsulated* (each system operates with a fair degree of independence from other cognitive systems).

Motives

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

There are at least two exploratory motives. The first one has to do with finding out about the surrounding world. New and interesting objects (regularities) and events attract infants' attention, but after a few exposures they are not new any more, and the infants stop looking. This fact has given rise to a much used paradigm for the investigation of infant perception, the habituation method. The second exploratory motive has to do with finding out 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 behaviour in favour 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 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. It seems that expanding one's action capabilities is extremely rewarding in itself. 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 the child less focused on what is to be achieved and more on its movement possibilities. It makes the child try many different procedures and introduces necessary variability into the learning process.

Development of prospective control of action

Actions are organized around goals, directed into the future and rely on information about what is going to happen next. Such prospective control develops simultaneously with the emergence of all new forms of behaviour. Here I will discuss posture and locomotion, looking, manual actions, and social behaviour.

Posture and locomotion

Basic orientation is a prerequisite for any other functional activity (Gibson, 1966; Reed, 1996) and purposeful movements are not possible without it. This includes balancing the body relative to gravity and maintaining a stable orientation relative to the environment. Gravity is a potent force and when body equilibrium is disturbed, posture becomes quickly uncontrollable. Therefore, any reaction to a balance threat has to be very fast and automatic. Several reflexes have been identified that serve that purpose. Postural reflexes, however, are insufficient to maintain continuous control of balance during action. They typically interrupt action. Disturbances to balance are better handled in a prospective way, because if the disturbance can be foreseen there is no need for an emergency reaction and ongoing actions can continue. Infants develop such anticipations in parallel with their mastery of the different modes of postural control (Barela, Jeka & Clark, 1999; Witherington, von Hofsten, Rosander, Robinette, Woollacott & Bertenthal, 2002).

Looking

Although each perceptual system has its own privileged procedures for exploration, the visual system has the most specialized one. The whole purpose of movable eyes is to enable the visual system to explore the world more efficiently and to stabilize gaze on objects of interest. The development of oculomotor control is one of the earliest appearing skills and marks a profound improvement in the competence of the young infant. It is of crucial importance for the extraction of visual information about the world, for directing attention, and for the establishment of social communication. Gaze control involves both head and eye movements and is guided by at least three types of information: visual, vestibular, and proprioceptive. Two kinds of task need to be mastered, moving the eyes to significant visual targets and stabilizing gaze on these targets. Shifting gaze is done with high-speed saccadic eye movements and stabilizing them on points of interest is done with smooth pursuit eye adjustments. The latter task is, in fact, the more complicated one. To avoid slipping away from the target, the system is required to anticipate forthcoming events. When the subject is moving relative to the target, which is almost always the case, the smooth eye movements need to anticipate the upcoming movement in order to compensate for it correctly. When the fixated object moves, the eyes must anticipate its forthcoming motion.

Maintaining a stable gaze while moving is primarily controlled by the vestibular system. It already functions at an adult level a few weeks after birth. From at least 4 weeks of age, the compensatory eye movements anticipate the upcoming body movements (Rosander & von Hofsten, 2002; von Hofsten & Rosander, 1996). From about 6 weeks of age, the smooth part of the tracking improves rapidly. Von Hofsten and Rosander (1997) recorded eye and head movements in unrestrained 1- to 5-month-old infants as they tracked a happy face moving sinusoidally back and forth in front of them. They found that the improvement in smooth pursuit tracking was very rapid and consistent between individual subjects. Smooth pursuit starts to develop at around 6 weeks of age and reaches adult performance at around 14 weeks.

When attending to a moving object in the surroundings, the view of it gets frequently interrupted by other objects in the visual field. In order to maintain attention across such occlusions and continue to track the object when it reappears, the spatio-temporal continuity of the observed motion must somehow be represented over the occlusion interval. From about 4 months of age, infants show such ability (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 behaviour is demonstrated over a large range of occlusion intervals, suggesting that the infants track the object behind the occluder in their ‘mind’s eye’. This representation might not, however, have anything to do with the notion of a permanent object that exists over time or with infants’ conscious experience of where the occluded object is at a specific time behind the occluder. It could rather be expressed as a preparedness of when and where the object will reappear. In support of the hypothesis that infants represent the velocity of the occluded object are the findings that object velocity is represented in the frontal eye field (FEF) of rhesus monkeys during the occlusion of a moving object (Barborica & Ferrera, 2003).

Reaching and manipulation

In the act of reaching for an object there are several problems that need to be dealt with in advance, if the encounter with the object is going to be smooth and efficient. The reaching hand needs to adjust to the orientation, form, and size of the object. The securing of the target must be timed in such a way that the hand starts to close around the object in anticipation of and not as a reaction to the encounter. Such timing has to be planned and can only occur under visual control. Infants do this from the age they begin to successfully reach for objects around 4–5 months of age (von Hofsten & Rönnqvist, 1988).

From the age when infants start to reach for objects they have been found to adjust the orientation of the hand to the orientation of an elongated object reached for (Lockman, Ashmead & Bushnell, 1984; von Hofsten & Fazel-Zandy, 1984). When reaching for a rotating rod, infants prepare the grasping of it by aligning the orientation of the hand to a future orientation of the rod (von Hofsten & Johansson, 2006). Von Hofsten and Rönnqvist (1988) found that 9- and 13-month-old infants, but not 5-month-olds, adjusted the opening of the hand to the size of the object reached for. They also monitored the timing of the grasps. For each reach it was determined when the distance between thumb and index finger started to diminish and when the object was encountered. It was found that all the infants studied began to close the hand around the object before it was encountered. For the 5- and 9-month-old infants the hand first moved to the vicinity of the target and then started to close around it. For the 13-month-olds, however, the grasping action typically started during the approach, well before touch. In other words, at this age grasping started to become integrated with the reach to become one continuous reach-and-grasp act.

A remarkable ability of infants to time their manual actions relative to an external event is demonstrated in early catching behaviour (von Hofsten, 1980, 1983; von Hofsten, Vishton, Spelke, Feng & Rosander, 1998). Von Hofsten (1980) found that infants reached successfully for moving objects at the very age they began mastering reaching for stationary ones. Eighteen-week-old infants were found to catch an object that moved at 30 cm/sec. 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. In experiments by von Hofsten *et al.* (1998), 6-month-old infants were presented with an object that approached them on one of four trajectories. On two of them the trajectories were linear: the object began from a position above and to the left or right of the infant, it moved downward on a diagonal path through the centre of the display, and it entered the infant's reaching space on the side opposite to its starting point. The other two trajectories were nonlinear: the object moved to the centre as on the linear trials and then turned abruptly and moved into the infant's reaching space on the same side as its starting point. Because the object was out of reach until after it had crossed the central point where the paths intersected, infants could only reach for the object by aiming appropriately to the left or right side of their reaching space. Because the object moved rapidly, however, infants could only hope to attain it if they began their reach *before* the object arrived at the central intersection point. In this situation, 6-month-old infants reached predictively by extrapolating a linear path of object motion. On linear trials that began on the left, for example, infants began to reach for the object when it was still on the left side of the display, aiming their reach to a position on the right side of the reaching space and timing the reach so that their hand intersected the object as it arrived on that side of the reaching space. On nonlinear trials that began on the left, infants showed the same pattern of rightward reaching and aiming until about 200 ms after the object had turned leftward, and therefore they typically missed the object: a pattern that provides further evidence that the infants assumed that the object would continue to move on a linear path.

Manipulation

When manipulating objects, the subject needs to imagine the goal state of the manipulation and the procedures of how to get there. Örnkloo and von Hofsten (2006) studied how infants develop their ability to insert blocks 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. All objects had the same length and the difficulty was manipulated by using different cross-sections. The objects were presented both standing up and lying down. It was found that although infants 18 months and younger understood the task of inserting the blocks into the apertures and tried very hard, they had little idea how to do it. Most of the time, they did not even raise up elongated blocks, but just put them on the aperture and tried to press them in. 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. This achievement is the end-point of several important developments that includes motor competence, perception of the spatial relationship between the object and the aperture, mental rotation, anticipation of goal states, and an understanding of means–end relationships. The results indicate that a pure feedback strategy does not work for this task. The infants need to have an idea of how to reorient the objects to make them fit. Such an idea can only arise if the infants can mentally rotate the manipulated object into the fitting position. 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.

Development of social abilities

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 behaviour of the person towards whom they are directed creates a much more dynamic situation than when actions are directed towards objects. Intentions and emotions are readily displayed by elaborate and specific movements, gestures, and sounds which become important to perceive and control. Some of these abilities are already present in newborn infants and reflect their preparedness for social interaction. Neonates are very attracted by people, especially to the sounds, movements, and features of the human face (Johnson & Morton, 1991; Maurer, 1985). They also engage in social interaction and turn-taking that, among other things, is expressed in their imitation of facial gestures. Finally, they perceive and communicate emotions such as pain, hunger and disgust through their innate display systems (Wolff, 1987). These innate dispositions give social interaction a flying start and open up a window for the learning of the more intricate regularities of human social behaviour.

Important social information is provided by vision. Primarily, it has to do with perceiving the facial gestures of other people. Such gestures convey information about emotions, intentions, and direction of attention. Perceiving what another person is looking at is an important social skill. It facilitates referential communication. One can comment on objects and immediately be understood by other people, convey information about them, and communicate emotional attitudes towards them (see e.g. Corkum & Moore, 1998; D'Entremont, Hains & Muir, 1997; Striano & Tomasello, 2001). Most researchers agree that infants reliably follow gaze from 10–12 months of age (see e.g. Corkum & Moore, 1998; Deák, Flom & Pick, 2000; von Hofsten, Dahlström & Fredriksson, 2005). Gaze following, however, seems to be present much earlier. Farroni, Mansfield, Lai and Johnson (2003) showed that 4-month-olds moved gaze in the same direction as a model face shown in front of them.

The understanding of other people's actions seems to be accomplished by the same neural system by which we understand our own actions. A specific set of neurons, 'mirror neurons', are activated when perceiving as well as when performing an action (Rizzolatti & Craighero, 2004). They were first demonstrated in rhesus monkeys. These neurons are specific to the goals of actions. They fire equally when a monkey observes a hand reaching for a visible object or for an object hidden behind an occluder (Umiltá, Kohler, Gallese, Fogassi, Fadiga, Keysers & Rizzolatti, 2001). However, the same neurons did not fire when the hand mimed the reaching action, that is, the movement was the same but there was no object to be reached for. When humans perform an action, like moving an object from one position to another, they consistently shift gaze to the goals of these actions before the hand arrives there with the object (Johansson *et al.*, 2001, Land, Mennie & Rusted, 1999). When observing someone else perform the actions, adults (Flanagan & Johansson, 2003) move gaze predictively to the goal in the same manner as when they perform the actions themselves. Such predictive gaze behaviour is not present when moving objects are observed outside the context of an agent (Flanagan & Johansson, 2003).

The ability to predict other people's action goals by looking there ahead of time seems to develop during the first year of life. Falck-Ytter, Gredebäck and von Hofsten (2006) found that 12-month-old but not 6-month-old infants predict other people's manual actions in this way. Thus, infants, like adults, seem to understand others' actions by mapping them onto their motor representations of the same actions. The suggestion that cognition is anchored in action at an inter-individual level early in life has important implications for the development of such complex and diverse social competences as imitation, language and empathy.

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 sensorimotor system. Actions cannot be constructed ad hoc. They must be planned. From a functional perspective, cognitive development has to do with expanding the prospective control of actions. This is done by extracting more appropriate information about what is going to happen next, by getting to understand the rules that govern events, and by becoming able to represent events that are not directly available to our senses. Cognitive development, however, has to be understood in a still wider context. We need to relate our own actions to the actions of other people. Recent research shows that we spontaneously perceive the movements of other people as actions, that specific areas in the brain encode our own and other people's actions alike, and that this forms a basis for understanding how the actions of others are carried out as well as the goals and motives that drive them.

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