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12 Early Ontogeny of Action Perception and Control

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Abstract. Perception and interpretation of goal-directed behaviour is one of the crucial social-cognitive skills in the field of human cognition. At a very early age, infants start to be able to perceive and interpret a human action as goal-directed. This early ability is often viewed as an important precursor for intentional understanding and, even more importantly, for later Theory of Mind development. A question which is discussed controversially is how infants' abilities to perceive and understand goal-directed human actions are interrelated with their competence to perform the same behaviour. There is ample evidence that in adults, perception and production of an action share a common representational ground where planned actions are represented in the same format as perceived events [e.g. Common Coding Principle, 1, 2]. However, studies on the development of this interrelation have yielded contradictory results. The present chapter integrates various findings from different studies investigating perception, production, and imitation of goal-directed actions and discusses them in the light of existing hypotheses and theories on the development of action perception and production.

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12.1 Introduction

Research in developmental psychology has repeatedly shown that infants from early age on have an amazing knowledge about their surrounding environment [3, 4]. Infants as young as 2.5 month old are able to represent the continued existence of a hidden object and understand that this object continues to exist after it disappeared [3, 5-7]. At around the same age human infants are able to understand that objects are solid and cannot move through another [3, 8, 9]. Spelke [4] concludes from these and other studies that young infants have systematic knowledge about three principles in the domain of physics: continuity (objects move on connected, unobstructed paths), cohesion (objects move as connected, bounded units), and contact (objects affect one another's motion if and only if they touch). Spelke introduced the term *Core Knowledge* as according to her, this initial

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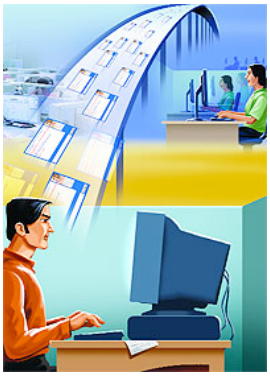

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knowledge is innate. This early representation of the physical world is important as by its biological nature, human perceptual-motor skills are the result of a long evolutionary history, which always was and still is constraint by the laws of physics.

However, the environment, in which a human infant grows up, is not only physical but also social. From the very first day of life, and even before, infants act and interact in a social world. Thus, as it is important to learn that objects continue to exist even if they are no longer visible, it is even more important to learn how to control own actions and to come to understand and interpret actions performed by others. The present chapter shall give an overview of the ontogeny of action understanding in the first years of life and how this development might be related to the development of action control.

12.1.1 What constitutes an action?

To study action understanding and control, a clear definition is required of what constitutes an action – as opposed, for example, to a simple body movement. Actions differ from body movements in their intentional character, that is, actions are directed towards an intended goal. As a consequence, it is important for both theoretical considerations and practical experimental planning to distinguish the two constituents of an action: the movement and the goal. Infants start at about 18 weeks of age to perform simple goal directed actions like reaching and grasping for stationary or even slowly moving objects [10]. And, as in adults, infants' reaching movements are predictive. Arm and hand movements are initiated before the target is within reaching distance, and the reaching movement is geared ahead of the object's momentary position toward a future interception position [11-13]. Thus, very early, infants are already able to dissociate movement and goal in their action. This distinction becomes even more apparent in tasks, in which infants have to differentiate between means and ends. Infants begin to pass simple versions of a means-end task (e.g. pull a cloth to receive a toy) around the age of 6 months [14, 15]. The competence to produce means-end behaviour becomes increasingly systematic over the next months, with infants aged 9 to 12 months being able to produce spontaneous means-end behaviour [16-19]. Interestingly, at the same age other important skills like motor competence, locomotion, and social cognition develop [20].

12.1.2 History of research on human action

The study of human actions has a long history in adult research, which can be traced back to the 19th century. The ideomotor theory, which can be seen as the first cognitive approach to action control, assumes that goal representations, which are in the view of this approach functional anticipations of action effects, play a crucial role in action control [21-24]. Intentional action requires a goal, which is seen as an anticipatory representation of the expected action effects. This idea has recently been picked up by Prinz and colleagues in the Common Coding approach [1, 2, 25]. The primary assumption of this Common Coding approach is that action perception and action control share a common representational ground where planned actions are represented in the same format as perceived events. Whereas separate coding accounts need to postulate transformations to explain how

coordination between the action system and the perceptual system is achieved, the Common Coding account tells a much simpler story. Event representations that are common to perception and action make transformations between perceptual and motor information unnecessary. Empirical support for such an approach comes from different domains, for example, from studies on the timing of movements [e.g., 26], on stimulus-response compatibility [e.g., 27], on bimanual coordination [28], and on action perception [29]. This evidence shows that the Common Coding approach offers a powerful framework for the interpretation of action production as well as action perception [30, for a related assumption of common representations see 31].

12.1.3 Perception of goal-directed action

During the last years, the perception and understanding of goal-directed action has been more and more identified to be one of the most crucial social-cognitive skills in cognitive development [32-34] and in the field human cognition per se [25].

Already at the age of 5 to 6 months, infants start to be able to perceive and interpret actions as goal-directed [35-40]. In Woodward's [36] seminal studies, infants were habituated to a grasping action towards one of two objects. In the testing phase, in which the positions of the two objects were switched, 6-month-old infants demonstrated a stronger novelty response to the hand grasping a new object but performing the old motion path than for the hand grasping the same object at a new position. To be interpreted as goal-directed by 6-month-olds, the action has to be performed by a human agent [36, 39, 41, 42], for an exception see [38]. Moreover, the action has to be either familiar to the infants [e.g., a grasping action, 40] or it has to result in a salient action effect [i.e., a salient change in the object's state, 39, 41-43]. Infants at this age are even able to encode the goal of an uncompleted action, that is, if the action is presented without the actual achievement of the goal [35]. Thus, by the age of 6 months, infants differentiate in their reasoning between human action and object motion, and they can encode goal-directed actions of others.

A few months later, at 9 months of age, infants' abilities to understand others' actions are extended to the understanding of computer-animated displays, e.g., a ball performing rational vs. non-rational movement patterns [44, 45]. According to Gergely and colleagues infants apply a non-mentalistic action interpretation system, the 'teleological stance', which also takes into account the context of the external goal and the situational constraints in order to interpret and understand actions [46, 47]. Interestingly, the same action pattern can be interpreted already by 6-month-olds if the action is not performed by an inanimate object but by a human [48]. At the age of 9 to 11 months, infants are able to parse observed sequences of continuous everyday actions along intention boundaries [49, 50]. Such action analysis is central to inferring intentions, and at natural breakpoints the links between action and intention are especially strong [51]. At the end of the first year, infants are able to infer goals from a variety of cues like gaze direction, emotional expression, and pointing [52-55] and they have a broad notion of what counts as an agent. At this age, infants' ability to detect agents can no longer be reduced to perceive humans, objects that are perceptually similar to humans, or objects that display self-propulsion but it is now based on the detection of goal-directedness [56].

These early competencies of action perception are further improved during the second year of life. In this period, infants or toddlers develop a more sophisticated understanding of other persons' actions and their corresponding mental states. They begin to understand other persons as intentional. That is, they not only know that others pursue goals persistently, which is the case for 9-month-olds [57], but they also understand that others choose specific means to obtain goals [58, 59]. And infants start to infer goals of other persons from their actions in varying situations. In his seminal study, Meltzoff [60] showed that 18-month-olds could infer and imitate an adult's intended act even by watching attempts, in which the adult model failed in achieving the end of the intended action. Subsequent studies demonstrated that also 15-month-olds are able to infer the goals of actions performed by a stuffed orang-utan operated by a puppeteer [61]. In a replication of the Meltzoff [60] study, 12-month-olds did not frequently imitate goal-directed actions, which were unsuccessful [62]. Thus by the age of around 15 months, children are able to complete an observed intended action instead of just copying the surface features of failed attempts. Similarly, at the age of 14 months infants reproduce an action done on purpose but not an action done by accident [63] and infants understand that identical actions may have different goals depending on the context [32].

These early abilities of perception, understanding and imitation of various kinds of intentional actions can be considered as an important precursor for the understanding of others' intentions more importantly, for a later development of a Theory of Mind [64-66]. Theory of Mind (ToM) is the ability to interpret other people as having beliefs, desires and intentions that are different from one's own. This is an essential basis for humans to communicate with each other in a meaningful way [67, 68]. The presence of a ToM (as assessed by a standard, verbal *false belief* task) was long considered to be present not before 4 years of age [69]. However, in recent studies using looking paradigms, Southgate, Senju, and Csibra [70] showed that already 25-month-old infants showed some extend of ToM when they were tested in a nonverbal implementation of the false belief task using and Onishi and Baillargeon [71] found such understanding even in infants as young as 15 months.

Evidence from recent longitudinal studies suggests a close link between early social-cognitive skills like action understanding and later social cognition [72-74]. In 14-month-olds for example, decrement of attention during habituation to human intentional action was significantly correlated to ToM abilities and predicted later preschool mentalistic construal of persons [73]. A similar relation has been shown between 6-month-olds' habituation to a goal-directed action and their later performance in false belief tasks [74]. And infants' intentional understanding in an imitation task at 14 and 18 months was related to the use of internal state language at 32 months, which predicted their concept of intention tested at the age of four years [75, 76].

12.2 Interrelation of action perception and action control in development

What we have learned so far in the previous section is that infants at a very early age show a sophisticated level of understanding of their social world. However, a

question that remains open is how perception and understanding of actions are related to the infants own competence to perform the same action.

In adults, the interplay of action perception and production is extensively described in the theoretical framework of the Common Coding Principle [1, 2] mentioned above. This account assumes a bidirectional influence of action and perception, which has found support in adult research with many different paradigms. On the one hand, perceived events can have an impact on planned and executed actions if perceived events and planned actions share common features as has been shown, for example, using imitation paradigms [77, 78]. Brass and colleagues [77] conducted a task, in which participants had to initiate, as fast as possible, a particular finger gesture while watching either the same or a different gesture performed by a hand on a computer screen. Participants initiated the required gesture much faster when the same gesture was shown on the screen compared to a different gesture. On the other hand, planned or executed action can also have an impact on the perception of events if they share common features [79, e.g., 80, 81, 82]. Hamilton and colleagues [80], for example found that actively lifting a box altered the perceptual judgment. An observed box was judged to be heavier when subjects were lifting a light box, and it was judged to be lighter when they were lifting a heavy box.

These findings of a common representation have received support from research on the neural basis of these shared representations, the mirror neuron system. Mirror neurons are neurons that fire both when an action is perceived and when it is performed. They have first been discovered in the premotor area (F5) of the macaque brain [83, 84]. Research on brain imaging in humans has shown similar evidence for common brain regions subserving perception and production of actions [85, 86], empathy [87], language acquisition [88], and Theory of Mind [89].

In the field of developmental psychology, however, there is disagreement whether a mirror neuron system and, thus, a possible interrelation of action perception and control is already in place at birth or in early infancy [for a detailed overview, see 90] and about the developmental direction of this interrelation. An important issue discussed in the literature is whether in infants the understanding of oneself as an agent precedes the understanding of others as agents or vice versa [see, e.g., 91]. There are two main hypotheses on how the interrelation between action perception and action production develops. The first hypothesis (action first) states that infants come to understand others' actions based on an understanding of their own actions and a competence to produce own actions [92, 93]. The second hypothesis (perception first) suggests that infants' understanding of their own actions is based on the understanding of other people's actions [e.g. in imitation, 94] and that infants are able to understand actions, which they are not yet able to produce themselves. There is empirical evidence in support of both hypotheses. These findings and implications will be discussed in the following sections.

12.2.1 Action first: perception grounded in action

Evidence for the action first hypothesis first came from constructivist theories based on the work of Jean Piaget [95]. In the sensorimotor stage during the first two years of life, infants and toddlers construct a representation of the world

through self-motivated action in and interaction with the surrounding world [96-98]. The hypothesis received support from different directions. First, from findings on the development of infants' manual skills, in which infants increased their attention to auditory and visual properties of objects as this information becomes useful for guiding new actions [99]. Second, support for the action first hypothesis came from the famous neonatal imitation studies by Meltzoff and Moore [100]. They discovered that newborns can imitate facial acts and concluded "that imitation, and the neural machinery that underlies it, begets an understanding of other minds" [92, p. 56]. And third, it has been proposed that the motor system is used to emulate observed actions. Via covert imitation, the motor system maps the perceived actions of others' actions onto one's own action repertoire. This emulation of others' actions helps to generate predictions about future events and thus, to understand underlying goals [101-103].

Empirical evidence comes from several studies on infants' understanding of goal-directed actions. Using a means-end task with 8- and 12-month-old infants, Schlesinger and Langer [104] demonstrated that already 8-month-old infants were able to respond to the causal structure of a means-end sequence in their action, however, only at the age of 12 months this causal structure influences infants' expectations about the perceived means-end event. The results of two recent studies show that 6- to 9-month-old infants only seem to be able to understand actions, which they are able to perform themselves [105, 106]. Longo and Bertenthal [106] looked at perseverative search errors of 9-month-olds in a task comparing covert imitation of ipsilateral and contralateral reaches. Infants at this age tend to use the ipsilateral hand when reaching for an object [ipsilateral bias in reaching during early development, 107]. In the imitation task, infants imitated an action more often if this action was already in the infants' action repertoire (ipsilateral reach) than if the action was not yet in the infants' action repertoire (contralateral reach). This general view is supported by findings indicating that prior action experience can alter and facilitate following action perception [108, 109].

12.2.2 Perception first: action grounded in perception

The perception first hypothesis, which received supporting evidence from neonativist accounts [3, 110], assumes that infants' cognition is first expressed in their perceptions and that, therefore, infants' understanding of their own actions is based on the understanding of other people's action. Empirical support for this assumption comes, for example, from studies on infants' search behaviour [e.g., 17, 111, 112]. Studies testing 8-month-old infants have shown that when an object is hidden in a location A and then in location B, infants tend to search in the wrong location A (A-not-B error). Baillargeon and Graber [111] used a looking-time paradigm to examine 8-month-olds' ability to remember the location of a hidden object. In this paradigm, infants looked longer when an actors hand retrieved a toy from an inconsistent position than when the actor retrieved the toy from a consistent position, where the toy was actually hidden. These results indicate that the ability of 8-month-old infants to remember the location of a hidden object is far better than their performance in the A-not-B-Error search task. More evidence comes from a similar set of studies investigating infants' and toddlers' knowledge about solidity [3, 113]. Three-month-old infants were presented with a rolling ball,

which disappeared behind an occluder. On test trials, an obstacle was placed on the track behind the occluder, showing above the occluder. When the occluder was removed and the children were presented either a consistent event, in which the ball was resting in front of the obstacle or an inconsistent event, where the ball seemed to have passed the obstacle and violated the rules of solidity infants looked reliably longer at the inconsistent event than at the consistent event [3]. Thus, already at the age of 3 months, infants seem to detect incongruences with physical laws. However, if children at the age of 2 to 3 years have to actively search for a ball rolled behind an occluder, most of the 2- and 2.5-year-olds did not perform above chance [113]. The ability to visually differentiate between consistent and inconsistent events is not lost in toddlers: if tested in a looking time paradigm, the same toddlers succeed in detecting impossible outcomes of an person or puppet searching an object, but failed in an active search task [114, 115]. Again, here is a dissociation between the rather sophisticated knowledge about solidity and continuity of infants and the rather poor performance in toddlers.

Recent evidence from our own research with 6- and 9-month old infants further supports this hypothesis. In a study on the understanding of goal-directed but uncompleted actions, infants were able to encode the goal of an action only when they perceived the action from an allocentric perspective (as performed by another person) but not from an egocentric perspective, similar to the perspective from which they perceive their own manual actions [35]. This study also exhibited no difference between infants' ability to encode ipsilateral or contralateral reaching movements. The ability to perform contralateral reaching movements, however, seems to develop at a later age [107]. Furthermore, already 6-month-olds are able to encode the goal of a grasping action towards objects of different sizes from the aperture size of the actor's hand during the grasp [116]. This ability seems to be independent from infants' ability to anticipatorily adjust the aperture size of their own hands to the size of a target object, which starts only at the age of 9 months [117]. In a recent study, 6-month-olds abilities to perceive and perform a simple means-end task were tested in both an action perception and an action production task [14]. In an action perception version, a preferential looking paradigm was used, in which infants were shown an actor performing support pulling behaviour with an expected and an unexpected outcome. In an action production version, infants had to pull a cloth to receive a toy. Results showed that in the perception task, infants discriminated between expected and unexpected outcomes of the pulling action. This perceptual ability was independent of their actual competence to perform means-end behaviour in the action production task.

Finally, in a study examining infants understanding of tool-use actions it was shown 9-month-old infants are able to interpret an action performed by a mechanical device (a claw) as goal-directed, if the infants were shown that the device was operated by a human hand [33]. Infants at this age are not yet able to intentionally use a claw as a tool but they were shown to be able to interpret an action performed with the claw. Similar results were reported by Bertenthal and Longo [118] showing the same effect in an A-not-B-Error task.

In sum, these findings suggest a close link between action perception and action production, however, they do not support the common sense view that infants' understanding of their own actions is a precondition for the understanding of other people's actions.

12.3 Conclusion

To sum up, the research reviewed in this chapter has shown that infants start at a very early age to successfully interpret other's goal-directed actions. This early understanding of others' actions provides fundamental basis for the understanding others' mental states. It was furthermore shown that perception and control of an action are mechanisms which are from very early on deeply intertwined similar to adults. The underlying neural mechanisms of this early understanding of the surrounding social world seems not to be fundamentally different from adults' as research on the interrelation of action perception and control shows both, an earlier development of action control compared to action perception and vice versa. From the research reported, one can conclude, that cognitive development does not only seem to be depend on experience with own actions but also on shared experiences with other persons. Due to an early presence of a mirror neuron system or a common representation of perception and action as described earlier in adults might allow the causal influence of action perception and control to be bidirectional. A strong and bidirectional interrelation already in very early infancy may serve as an extremely powerful engine in the development of social understanding [65, 119, 120]. Not to be reduced for either direction of influence extends the possibilities to acquire knowledge about the surrounding physical and social world. This hypothesis of a parallel development of action perception and control received recent support by a study conducted by Sommerville and Woodward [121], in which infants aged 10 months either succeeded in both the perception and the action version of a means-end support task or failed in both tasks. For a larger overview of a possible theoretical background of the parallel development of action perception and control, see Aschersleben [122].

To sum up, as human beings, we need to coordinate our actions with others, and we need to understand other people's actions to interact with them. It is thus of great relevance to learn how to control own actions and to come to understand and interpret actions performed by others. In the present chapter we showed that this intersubjectivity is deeply rooted already very early in infancy.

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