Learning about goals : development of action perception and action control

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Chapter 9: Summary and conclusions

Summary and Epilogue

The aim of the current thesis was to answer some of the questions which current developmental (neuro-) cognitive theories pose with regard to how infants learn to perceive, and perform goal-directed action. There is consensus among scholars that during the first year of life infants become sensitive to the goals of observed actions (e.g., Woodward, 1998), to the means by which they are achieved (e.g., Gergely et al. 1995) and use this information to predict future events and guide their own action (e.g., Elsner & Aschersleben, 2003). Nevertheless, the cognitive mechanisms that subserve these abilities are still under debate. Before discussing in more detail the (preliminary) answers the current empirical work offers, the main findings of the empirical chapters of the thesis will be summarized. Lastly, the implications for further research and my current *opinion* on what theoretical view best captures the current findings in the field will be presented.

Summary

Chapter 2 presents a study that investigated the relative importance of outcome-selection information vs. means-selection information. Many studies that use Woodward's (1998) VoE paradigm show that outcome-selection information (information presented by the choice an actor makes between potential outcomes) is important for infants' goal perception. On the other hand, a significant number of studies in the tradition of Gergely et al. (1995) show that means-selection information (information presented by the efficiency of the action toward the outcome in regard of the situational constraints) is important for infants' goal perception. Until now the relative importance of these two types of information has not been directly compared, partially due to the conceptually different paradigms used to investigate them. In this study these two types of paradigms were combined. It was found that when outcome selection information was presented, but the means were inefficient toward the goal, 7- and 9-month-old infants did not attribute a goal to an observed action. This finding suggests that means selection information displays primacy over outcome selection information not only for adults but also for infants. The early presence of this bias sheds light on the nature of the notion of goal in action understanding. Furthermore, the central claim of the “theory of rational action” - that infants *only* attribute a goal to an action if the action can be evaluated as an efficient action toward the end-state in the given situation - has so far only been supported by relatively indirect evidence. The experimental paradigm that had been used to investigate this theory tested infants’ predictions about the means, and not the goal, of the action. However, the finding that infants do not generate a specific expectation about the new means if the initial action is non-efficient only suggests, but does not prove, that infants do not in the meantime attribute a goal to the initial action. Infants may have given up on predicting the means, but could in principle have relied on the end-state of the action to infer it as the goal. The current paradigm enabled testing the expectations about the goal of the action by providing two possible end-states. The finding thus confirms that if the action, the end-state, and the situational constraints do not form a relation that satisfies the principle of efficient action, then infants do not commit themselves to a specific goal. In sum, this study showed that infants' early understanding of goal-directed actions is similar to that of adults as far as the relationship between means selection and outcome selection information is concerned. The early presence of the preferential bias for means selection information may suggests that this bias is not an acquired, but rather a core property of the cognitive mechanisms of goal attribution and thus it sheds light on the nature of the notion of goal.

Chapter 3 utilizes a similar paradigm to chapter 2, integrating the Woodward- (1998) and Gergely et al.- (1995) type paradigms to further investigate how means-selection information relates to outcome-selection information. It is possible that infants appeal to one goal-like notion (e.g., 'preference') in situations that provide outcome selection information, and to another one (e.g., 'planning') when they receive evidence on means selection. Alternatively, a unitary concept of goal explains the results of both kinds of studies, which takes input from either type of information. In the latter case, one would expect transfer of goal attribution from situations with one type of information to situations in which the other type of information is available. Thus the central question in this chapter is if infants can transfer goal attribution from a situation in which only means information is presented toward one goal, to a situation in which there two possible outcomes. In other words, does observing an actor efficiently adjusting his action to situational constraints, lead infants to expect that the actor will continue to approach the same goal after another potential outcome is presented in the scene? Such transfer would indicate that both the Woodward- (1998) and Gergely et al.-(1995) type paradigms tap into the same unitary concept of goal that can rely on both outcome- and means- information. It was found that 12-month-olds who had attributed a goal based on the causal efficiency of a means-end action, generated expectations about the actor's action in another scenario in which the actor could choose between alternative outcomes. This finding thus suggests that, by 12 months, infants possess a unitary concept of goal.

The fourth chapter explores the question how experience with a certain movement can influence goal attribution. More specifically, the hypothesis was investigated that, linking a novel first-person and/or third-person action to a salient action effect, is critical for infants to interpret a novel third-person action as goal-directed. The findings suggest that 12- but not 9-month-olds, provided they have previously associated the novel action with a salient visible outcome in another context, can assign a goal to the action even in the absence its outcome. On the other hand, the control condition suggests that prior experience with the action, but without the salient effect, does not lead to goal-directed interpretation of the novel action. The finding thus demonstrates the essential role action effects play in the developing ability of infants' goal-directed understanding of novel actions.

To further validate ideomotor theory as a cognitive developmental theory, chapter five replicates previous findings (Eenshuistra et al., 2004; Kray et al., 2006) that indicate that 4-year-old children can form bidirectional action-effect associations and compares their performance to adults. The secondary aim of the study, was to investigated whether action-effect associations are also acquired under explicit-learning conditions, and whether familiar action-effect relations (such as between a trumpet and a trumpet sound) are learned the same way as novel, arbitrary relations are. Findings suggest that explicit learning produces the same bidirectional action-effect associations as implicit learning does, that non-arbitrary relations improve performance without affecting learning per se, and adults and young children show equivalent performance—apart from the common observation that children have greater difficulty to withstand stimulus-induced action tendencies.

The next two chapters represent the first attempts to provide direct evidence for the spontaneous acquisition of bidirectional action-effect associations in infancy. In chapter six a highly simplified version of the Elsner and Hommel paradigm (2001) was applied. First evidence for the spontaneous acquisition of bidirectional action-effect associations in 9- 12- and 18-month-olds was found, suggesting that the mechanism underlying action-effect integration is in place at the latest around 9-months-old.

Chapter seven is methodologically more advanced adaptation of the Elsner and Hommel paradigm (2001). The paradigm was made suitable for all age groups ranging from 7-month-old infants to adults, and employed a novel pupillometric and oculomotor paradigm to study developmental changes in the role of action-effects in the acquisition of voluntary action across the lifespan. The findings suggest that both 7- and 12-months olds (and adults) can use acquired action-effect bindings to predict action outcomes but only 12-months-olds (and adults) showed evidence for employing action-effects to select actions. This dissociation supports the idea that infants acquire action-effect knowledge before they have developed the cognitive machinery necessary to make use of that knowledge to perform intentional actions.

The last empirical chapter of the thesis used the newly developed methodology from chapter seven to investigate, how infants represent sequential action from an ideomotor point of view. The aim was to contrast chaining-, concurrent- and integrated models of sequential-action representation. Nine- and 12- month-olds were taught action sequences consisting of two elementary actions. Thereafter the secondary action was selectively activated to assess any interactions with the primary action. Results suggest that concurrent models best capture the representations formed.

Chapter 9

Discussion

Chapter 2, 3 and 4 were concerned with the question how infants learn to perceive others' actions. In general, the first three chapters of this thesis provide evidence that third-person action perception processing relies on several different sources of information. Chapter 2- and 3 show that the efficiency of an action is an important source of information for goal perception. Chapter 2 further suggests that it is more important than ends-selection information. Chapter 4 goes on to provide evidence for the notion that action-effect knowledge plays an important role in action perception.

Taken together the first three studies show that during the first year of life infants acquire a unitary concept of goal. Chapter 2 shows that at least by 7-months of age previously obtained means-selection information can transfer to predictions in situations involving two potential outcomes, and at least by 12-months of age, action-effect knowledge can transfer to predictions in situations involving two potential outcomes (Sommerville et al. (2005) provide evidence for similar transfer at 3.5-months of age). These transfers suggests that at the latest by age one, all three types of information feed into a unitary generalized concept of goal. Such a unitary concept of goal suggests a more sophisticated higher order interpretation of the current findings regarding infant goal attribution than just preference- efficiency- or action-effect detection. It suggests infants to recognize a "common denominator" in different aspects of human behavior, namely planning, action-effect relations and the expression of preference.

Nevertheless, in the current thesis both types of transfer: (1) from means selection information to situations that involve ends-selection information, and (2) from action effect knowledge to situations that involve ends-selection information, have only been shown in one direction. In principle, to truly show that these types of information are processed in reference to a unitary goal concept, transfer should also be possible in the opposite direction. Showing transfer in the opposite direction of (1) should be impossible. On the other hand, showing transfer in the opposite direction of (2) is harder to test since the selection of an end is to a certain extent the same thing as an action effect. Additionally, transfer from means selection information to situations where action effects are presented (3) and its reverse, should in theory also be possible. How would one go about to test these hypothesis, or is there evidence corroborating these hypothesis?

To test the first assumption (transfer in the opposite direction of (1)) one would need to design a new VoE paradigm. In the familiarization phase infants should see an actor repeatedly touching one of two toys. Where after, in the test phase infants should be shown the actor reaching efficiently or non-efficiently for the same toy (the other toy is not presented in the test phase). If transfer has occurred infants should expect an efficient approach to the toy and therefore should look longer at an inefficient action. On the other hand, if no transfer occurred they should not have a specific expectation as to the efficiency of the action shown. As a control condition infants should be shown efficient and inefficient reaches toward the new toy (the old toy is not presented). Since no goal attribution took place for this toy infants should not differentiate between the two test events. Further research should investigate this hypothesis.

The second proposed reversal of transfer (2) is already tested indirectly in 8-month-olds using EEG by Paulus et al. (2013). In their study they showed that the effects of actions that they had seen their parents do, elicited greater motor activation in infants than effects that were not associated with actions. This evidence indicates that infants can acquire action effect associations by observing others' actions.

The third type of transfer (3) (transfer from means selection information to situations where action effects are presented) is again testable. One would need to adapt the Gergely et al. (1995) paradigm in the following way. The familiarization should be conceptually the same as in the original paradigm; a small ball repeatedly approaches a big ball. In one group of infants the small ball adjusts its approach to changing situational constraints with the only addition that the small ball starts in the middle. In the other group the ball approaches the big ball inefficiently, again starting from the middle. In the test phase the big ball is located on the opposite side as compared to the familiarization phase. The test phase should have two potential outcomes; one wherein the small ball approaches the big ball in a straight line and another wherein the small ball moves away from the big ball in a straight line. If transfer occurred, infants should expect the same outcome (or action effect) again (the big ball touching the small ball) even though it moves in the opposite direction as in the familiarization phase. Furthermore, this effect should only occur for the group of infants that were familiarized to the efficient approach. The opposite direction of the proposed transfer can also be tested. In the familiarization phase a small ball starting from the middle moves towards a big ball. In the test events the small ball moves toward the big ball which is now on the other side and adjusts its path to efficiently jump over an obstacle or the ball efficiently moves away from the bigger ball, efficiently jumping over an obstacle. If transfer took place, infants should look longer at the efficient jump away from the big ball.

Providing additional evidence for the reverse transfer of (1) and (2), and providing evidence for (3) and its reverse, would further strengthen the notion of an overarching unified concept of goal. As mentioned earlier such a unified concept would indicate a rather advanced goal perception. Furthermore, the developmental pathway of the integration of these types of information into a unified concept is of great interest to elucidate the ontology of the concept of goal, and should be investigated further.

The second part of the thesis was concerned with how actions are learned by experience. There is ample corroborating evidence suggesting (just as chapter 3 does) that infants use action-effect associations for third-person action perception (for a review, see: Hauf, 2007; Kiraly et al., 2003), imitation (for a review, see: Elsner 2007; Meltzoff, 2007) and exploration behavior (Elsner & Aschersleben, 2003). However, these studies do not provide direct evidence for the crucial bidirectional quality of action-effect associations as proposed by ideomotor theory. Many researchers nonetheless assume that learning new goals (learning new bidirectional action-effect associations) should be supported by the same mechanism as that found in adults (Elsner & Hommel, 2001). Thus the first aim of the second section of the thesis was to generate direct evidence for bidirectional action-effect uptake. The secondary aim was discover the developmental pathway the uptake of bidirectional action-effect associations follows.

After we succeeded in replicating the findings of Eenshuistra et al. (2004) and Kray et al. (2006) that indicate that 4-year-old children can form bidirectional action-effect associations similarly to adults, we went on to search for the same mechanism in infants. In chapter 6 and 7, we present first direct evidence for the uptake and use of bidirectional action-effect associations in infancy and therefore achieved our primary aim.

Furthermore, combining the findings of chapter 6 and 7, our findings suggests a major change in action-effect learning from just action monitoring to action selection, just before the ninth month of age. In chapter 6 we found evidence indicating that learned action-effects influence action control starting at 9 months of age and do so progressively more at 18 months of age. In chapter 7 we showed that although infants at 7 months of age do take up action-effect knowledge, they do not use it (under the conditions of the experiment) for action control. The dissociation we obtained in 7-month-olds suggests a developmental precedence of action monitoring over intentional action selection. Additionally we showed that 12-month-olds and adults showed employed action-effects to select actions in a similar fashion indicating that the same mechanism found in adults is already in place during infancy. Taken together the studies suggest a major change in action-effect learning from just action monitoring to action selection, just before the ninth month of age.

In chapter 8 our findings demonstrate that young infants are able to construct action plans comprising of more than one element and that they do so in a manner that puts the available elements into the right order. Even though we consider the findings as a first step towards the understanding of sequential-action representation in infants, the details of the suggested scenario are not entirely clear yet. We nonetheless present first evidence that infants are able to represent first-person sequential actions. Furthermore our finding is in agreement with the concurrent activation approach to sequential action (Estes, 1972) but not with integrative and chaining theories. It seems essential to develop a more comprehensive theory of (the development of) sequential action representation, which would need to address how novel components are integrated into a sequential plan, how the sequencing is generated, and whether this requires hierarchical representations. We are confident that the paradigm presented in chapter 8 can be helpful in answering some of these questions, especially by introducing further modifications of the task.

Due to the setup of our particular paradigm in chapter 3, we could not differentiate whether the action-effect knowledge that enabled goal perception came from prior first-person experience or whether prior observance of others' action effects was sufficient. Sommerville's et al. (2008) findings seem to suggest that self-experience is primary to observed action-effect perception. However, taken together with the findings of Sommerville et al. (2005) who used a conceptually close paradigm to ours, and a significant number of studies that used other methods (a review, see: Hauf, 2007; Elsner 2007; Melzoff, 2007), our finding suggests an important role for action-effect knowledge in third-person action perception. Furthermore, Paulus et al. (2012, 2013) showed that action-effects of observed actions elicit similar motor activity in the brain of 9-month-old infants as those of those of self-produced actions (in 8-month-old infants). This finding suggests that infants represent first-person- and third-person- action-effect knowledge in the same way. Thus these results are also compatible with theories, such as the Theory of Event Coding (Hommel et al., 2001), embodied cognition as a whole, and simulation theories (e.g., Meltzoff, 2007) that propose sensorimotor processes play an important role in the perception of third-person actions.

If one takes into account the functional and representational equivalence of self-performed and perceived actions as suggested by Theory of Event Coding (Hommel et al., 2001), this pattern fits with data suggesting that at 6 months of age infants can understand goal directed action (e.g. Woodward, 1998), or more accurately, experience violation-of-expectation to a change of goal, but are unable to perform true intentional action (distinguishing means from ends) until around 8 to 9 months of age (Goubet et al., 2006; Hauf, 2007; Piaget, 1936). Our findings also fit with results from studies on action perception, showing that infants at 9- but not 7-months of age can use observed action-effect relations to guide behavior (Hauf & Aschersleben, 2008). Additionally, our data suggest that motor resonance when listening to previously self-produced sounds in 8-months-olds, as found by Paulus et al. (2012), might indeed reflect the existence of knowledge about action-effect relations; and yet, we do not necessarily expect this knowledge to result in overt behavior, at least not at 7-months of age. Similar evidence for action-knowledge activation during action observation has been obtained in infants as young as 6 months (Nyström, 2008). Some authors have argued that it is lacking representational equivalence between self-produced actions and observed actions that prohibits infants younger than nine months from imitation (Hauf, 2007). Our data, together with those of Paulus et al. (2012, 2013), Verschoor et al. (2010), Nyström (2008), and Sommerville et al. (2005), suggest that it is not representational equivalence that is reached by 9 months of age, but the ability to successfully use bidirectional action-effect associations, learned either by observation or experience, for voluntary action.

Indeed, action-effect associations could even be a basis for simulation itself. One of the main problems of simulation theories is the problem of how “supra modal codes”, as Meltzoff (2007) calls them, can emerge. Supra modal codes refer to action representations that unite first- and third-person into a common representational framework. Such representations allow infants to see the behaviors of others as commensurate with their own. Based on a ‘like me’ perception of others, infants could use these codes to interpret third-person behavior (Meltzoff, 2007). Meltzoff suggest that this supra modal encoding space is with us from birth based on findings showing early imitation of facial gestures in newborn infants (Meltzoff & Moore, 1977, 1997). However other theorists would predict the emergence of this supramodal space thru experience (e.g., Hommel, 2003). Hommel (2003) hypothesizes that action-effects themselves bridge the gap between first- and third person action representation (as chapter 3 suggests). This would work something like this: if an infant performs a certain action this produces perceivable effects, if another person produces similar perceivable effects these effect trigger the infant's motor representation of their own action. This simple mechanism thus generates a certain perceptual equivalence in action representation of first- and third- person action (e.g., Paulus et al. 2012- 2013). Furthermore, unlike theories that propose that perception is translated automatically into supramodal codes, this theory can account for simulation of non-human actions.

Lastly, a finding from chapter 2 requires further discussion, the finding that by 7-months of age infants will *only* attribute a goal to an action if it is efficient, regardless to whether outcome selection information could disambiguate the action. In the discussion of chapter 2 the early presence of the preferential bias for means selection information is taken to suggest that the principle of rational action is a "core property" of the cognitive mechanisms for goal attribution. Although, Csibra and Gergely (1998) state that the principle of rational action is the initial state of the infants' naïve psychological theory, this "core property" does not necessarily have to be innate or come online via a process of maturation. It *could* also be learned. If one takes the perspective of embodied cognition and TEC seriously, one could go on to theorize in the following way. Infants, who have limited amounts of energy, are actors themselves. Therefore they should quickly learn, by evaluating action-effect contingencies, that acting efficiently toward a desired end state saves time and effort. If one further assumes that cognition emerges from sensory-motor processing, like embodied cognition does, one could assume that infants first internalize the principle of rational action themselves, and then generalize this principle to other agents.

Chapter 9

Final Conclusion

By using innovative paradigms, the present thesis provides convincing evidence that action-effect learning, and sensorimotor processes in general play a crucial role in the development of action-perception and production in infancy. This finding was further generalized to sequential action. Furthermore the thesis suggests that means-selection-, ends-selection information, and action-effect knowledge together feed into a unitary concept of goal. Both these findings have the potential to generate interesting new research question