Seeing by Doing:
The impact of short-term experience on action understanding

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Summary

When observing other people acting upon their environment, we are very proficient in understanding what they are doing, although we do not have direct access to their internal intentions. But still, we are able to infer their action goals and intentions, just from observing their body movements in a specific context. According to recent research, action understanding is guaranteed by a direct matching process which states that in observing others' actions, people take advantage of the same action knowledge that enables them to perform the same actions.

One possibility to investigate action understanding in the observer is to assess anticipatory eye movements. Anticipatory eye movements have previously been shown to occur during both action execution and action observation, and to be directly linked to the observer's corresponding action plans. Hence, they can be taken as indicators of activated action knowledge during the observation of others' actions. Another possibility to investigate action understanding is to measure pupil size changes following the observation of unexpected actions. Previous research has demonstrated that participants' pupils dilated as a result of unexpected events. Hence, pupil size changes indicate the violation of expectations about action outcomes.

In order to be able to predict others' actions or to perceive an action outcome as unexpected, people need to possess action knowledge. According to the ideomotor theory, action knowledge is defined as an association between a body movement and its caused effects, established when individuals act upon objects in the environment. Hence, a connection between own action experience and the ability to understand others' actions can be assumed. However, most studies investigating the impact of experience on action understanding concentrated on motor experts like athletes and musicians, whereas only few studies investigated whether action plans can be activated by short-term experience.

Within this dissertation, we aimed to fill this gap by investigating the influence of a brief period of experience on the ability to understand others'

actions in adults and children. To this end, we conducted three studies in which we employed a block stacking task in a pre-post eye tracking design. During pre- and posttest, participants watched short video clips showing an actor performing the block stacking task. Intermediately, participants either performed the same block stacking task or one of two control tasks (puzzles or pursuit rotor task). We assumed that short-term experience with the block stacking task should activate task-specific action plans supporting a direct matching process during the observation of posttest trials. Further, puzzles were applied as a first control task with the purpose to activate similar action plans comparable to those of the block stacking task, as both the block stacking task and puzzles shared several features. In the study with adults, a second control task – a pursuit rotor task – was employed, which required participants to follow a moving red dot on a circular track with their index finger. We assumed that experience with the pursuit rotor task would activate action plans different from those activated by the block stacking task and puzzles, hence, not having an influence on action understanding during the observation of posttest trials.

Specifically, in the first and in the third study we questioned whether short-term experience with the block stacking task would have a task-specific influence on the ability to predict the action goals of the same block stacking task during observation. Results of these two studies indeed indicated that participants who had performed the block stacking task directed their gaze significantly earlier towards the action goals of the block stacking task during post-test trials. However, this effect could only be found in participants older than 10 years of age. In accordance with the direct matching hypothesis, these two studies provide evidence that short-term experience with the block stacking task activates task-specific action knowledge which enhances an improved prediction of the action goals during observation.

Within the second study, we aimed to investigate whether short-term experience would also have a task-specific influence on the extent of surprise when participants observed unexpected action outcomes indicated

by pupil dilation. Results of this study revealed that participants' expectations were violated when they observed unexpected action outcomes, indicated by a pronounced prediction error in form of pupil dilation after unexpected events. However, no influence of short-term experience on pupil dilation could be found. Hence, this study provides evidence that although action understanding can be investigated via pupil size changes, they rather reflect an evaluation process than a direct matching process.

In sum, we were able to demonstrate that different measures of action understanding deliver specific types of information about action understanding. Moreover, we could show that own experience with an action only impacts predictive gaze behavior during the observation of the same action. Crucially, this effect emerges around the age of 11 years, indicating a developmental change during childhood.

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This dissertation contains text passages, figures and tables of scientific papers of which I am the first author. These parts are not explicitly highlighted in the manuscript.

The dissertation is partly based on the following publication:

Möller, C., Zimmer, H. D., & Aschersleben, G. (2015). Effects of short-term experience on anticipatory eye movements during action observation. *Experimental Brain Research*, *233*(1), 69–77. http://doi.org/10.1007/s00221-014-4091-x

"I hear and I forget. I see and I remember. I do and I understand."
Confucius – Chinese Philosopher

Introduction

Imagine you are driving your car when you suddenly notice a person standing at the roadside next to a damaged car waving her hands in your direction. By watching this gesture within this context, you will immediately know that this person most likely had an accident and asks for your help. In other words, you *understand* the action of this person. Understanding others' actions is a crucial human ability which ensures an adequate interaction with other individuals. If we would not be able to understand the intentions or goals of other people in our environment, we would constantly be dependent on asking our counterparts what they are doing and for what purpose. This is difficult to imagine, since we are used to a convenient, fluent and apparently automatic interaction with other people. But how is action understanding enabled and what are influential factors on the ability to understand others' actions?

Prediction. In order to understand others' actions correctly and to initialize appropriate reactions, the prediction of future aspects of others' actions is essential. Only, if we are able to anticipate what a person will do in the next moment, we can reliably plan according reactions. In the example above, you would probably immediately predict that the person is in need for help and as a result you would most likely stop by, offer your help and give an emergency call. However, it might become obvious from the example that the prediction of others' actions can be more or less deficient from time to time. In this example, it could also be possible that the person next to the damaged car is setting up a crime and trying to lure a victim. Admittedly, the second possibility is rather unlikely and reminds of a bad horror movie, but still this scenario illustrates well that the prediction of actions is influenced by prior knowledge and expectations of the observer, and can therefore end up in a *prediction error* when expectations are violated (as it would be the case in the crime scenario).

Moreover, in order to reliably anticipate the intention of someone when observing his/her actions, it is necessary that new information is integrated in the prediction process. For instance, in our example you could notice that the person next to the car does not wave at you but instead at a fireman who is already approaching the person. In this case, you would understand that the gesture was not meant for you but for another person and that help is already at place. This would mean that you probably would not stop by, thus, your reactions towards the observed gesture would change due to updated information. Basically, this means, that contextual information as well as new aspects of the observed action itself need to be integrated in the prediction process in order to unambiguously understand others' action goals.

Experience. As already mentioned above, the observer usually possesses prior knowledge about observed actions. This implies that the observer must have been confronted with the same action before and this implies that the ability to predict others' action goals is strongly dependent on one's own experience with an action.

我听见我忘记.我看见我记住.我做我了解.
(I hear and I forget. I see and I remember. I do and I understand.)

This proverb stated by the Chinese philosopher Confucius (551 - 479 BC) illustrates intuitively that it is not sufficient enough to just listen to a description of an action or to passively observe someone else performing an action but that it is rather essential to have active experience with an action in order to gain a deep understanding. These principles are easily illustrated when you imagine that you would be asked to handwrite the proverb above in Chinese letters (presumed that you have no experience with Chinese language). By never having written Chinese letters it would be very difficult for you to do so by merely listening to someone describing the letters to you or by just observing someone else writing the letters once and you are asked to remember them by heart. But by having written the letters on your own before, your performance in writing this proverb will be most likely much better. Yet, given this example it is not clear how much and what type of experience you need to recognize the letters or to predict which letter will be written next by another person. Thus, this raises the question which amount of experience is required to understand others' actions. To date we know that experts have an improved ability to understand actions of their trained domain, but much less is known about non-experts, or how sparse experience changes action understanding.

Development. In order to investigate the influence of experience on action understanding, it is reasonable to start with individuals that do not possess manifold experience in a broad variety of domains – children. Since the development from childhood to adulthood is associated with a continuous gain of experience, adults are more likely able to draw on their prior knowledge to understand others' actions, whereas children probably have problems to understand several observed actions. Moreover, to date it is well established in this research area that action understanding is guaranteed by neural structures that respond to both when an action is executed and when an action is observed. But how does this interface develop and when is its function comparable to adults? And moreover, can this connection be influenced by experience?

The present thesis aims to enlighten the interface between action execution and action understanding with regard to the influence of experience. We intend to investigate whether a relatively short amount of experience improves action understanding in both adults and children. Moreover, we plan to determine whether children are equally likely to benefit from experience as adults or if there are fundamental differences between children and adults.

In the first chapter of this thesis, a summary of traditional and contemporary theoretical accounts describing the relationship between action and perception will be given first, followed by the description of two methods how action understanding is measured within this thesis. Subsequently, empirical findings about the interface of action and perception as well as influential factors on action understanding and its development throughout childhood are reviewed.

In the following three chapters, three studies conducted within this research project will be described and discussed. The first study deals with the influence of short-term experience on action understanding in adult participants measured via predictive eye movements. In the second study, we present how pupil dilation is related to action understanding and whether it can be influenced by action experience. In the third study we report how short-term experience influences action understanding (measured via predictive gaze) in children of different age-groups.

In chapter 5 and 6, we summarize and discuss our findings in the light of previous research findings and propose suggestions for further research.

Chapter 1: Theoretical Background

In this chapter, a general definition of the concepts of action and (action) perception is initially given, followed by a summary of traditional and contemporary theoretical accounts describing the relationship between action and perception. Traditionally, both concepts were considered to be independent and incommensurate, hence, a distinct definition of both concepts is suitable in order to highlight specific features of action and perception. However, contemporary theoretical accounts emphasize the interface between action execution and action perception and throughout this chapter, it will become obvious that action and action perception are strongly interrelated and cannot be considered independently of each other, especially in terms of action understanding.

After the description of central theoretical accounts, we shed light on how action understanding is measured within this thesis and report recent empirical evidence concerning the interface of action and perception as well as influential factors on action understanding and its development throughout childhood.

1 Definition of Action and Perception

In order to specify the relationship between action and perception in the next section, the terms *action* and *perception* will be disentangled separately first.

1.1 Action

While awake, people are usually engaged in doing something, e.g., answering an e-mail, drinking tea or reading a book. All of these activities have in common that a person makes use of certain body movements in order to accomplish a final state (e.g., grasping a cup in order to drink tea). Thus, an volitional *action* in its simplest form consists of two main components – a movement and a goal (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 1997). However, actions are often more complex and require more than one movement to reach a certain goal (e.g., typing various letters on a keyboard in order to finish an e-mail). Hence, an action can be defined as the number of movements of an activity which converge in a common goal (Prinz, 2014).

The aforementioned definition implicitly indicates that an agent has to plan and execute appropriate movements prospectively in order to accomplish his goal. This is ensured on the basis of internal mental representations, so called ‘motor programs’ (Keele, 1968; Morris, Summers, Matyas, & Iansek, 1994) or ‘action plans’ (Flanagan & Johansson, 2003; Rotman, 2006) that include information about the action goal besides information about the movement (Hommel et al., 2001). Thus, executing an action involves the prospective internal anticipation of the action goal, in order to initiate appropriate movements.

Furthermore, people do often engage in several activities at a time (e.g., drinking a cup of tea while reading the newspaper), illustrating that actions are frequently executed more or less simultaneously. Moreover, actions can comprise both goals that lie in the far future (e.g., doing sports in order to stay healthy in the future) and immediate goals (e.g., lifting a weight at the gym). From this example it becomes obvious that goals are organized in a hierarchical manner – from overarching goals, that usually last for a long time period, to sub-goals which can be achieved easily by simple motor acts in a short time period. Typically, overarching goals are abstract and complex (e.g., being a good person), whereas sub-goals are concrete and well-defined (Prinz, 2014a).

1.2 Perception

Generally, *perception* can be defined as ‘the process by which we organize and interpret information about the world that has been collected by our sensory receptors’ (Pomerantz, 2003). When interacting with the physical environment, people are confronted with external stimuli (e.g., light or sound) stimulating their sensory receptors. During the process of perception, these basic sensations are integrated and transformed into coherent mental representations resulting in a meaningful perception of external stimuli (Schacter, Gilbert, & Wegner, 2009).

For the present work, the general definition of perception has to be adapted to the special case of action perception. In contrast to perception in the sense of basic physiological processes, the term *action perception* already suggests that it encompasses more than just the mere perception of observed sensations. It rather implies an understanding of the intentions underlying observed actions, sometimes referred to as 'grasping the sense of an observed action' (Gallese, 2006). According to Keitel (2013, p.5), action perception is "the observation of actions performed by others and the obtainment of a mental representation of this action including the action goal." Hence, an observer *perceives* an action performed by another person by integrating observed sensations of the action (e.g., single movements of the agent, objects, action effects) into a meaningful mental representation of this action.

Moreover, the term *action understanding* is often used synonymously to action perception, intuitively illustrating that an observer *understands* the intentions and goals of an agent (Gallese, 2009).

For the present work, the terms action perception and action understanding are used synonymously, following the operational definition by Keitel (2013).

2 Theoretical Accounts of the Relationship between Action and Perception

When observing others' we are most of the time able to understand what they are doing, although we do not have direct access to their internal intentions. But still, we are able to infer action goals and intentions from observing others' body movements in a specific context. There are a number of theoretical accounts that address the foundation of action understanding. In this chapter, the most prominent approaches about the relationship between action and perception and their explanation of action understanding will be described.

2.1 Traditional Accounts

Traditional accounts of action and perception considered both concepts to be independent domains in human cognition (cf. Hommel & Nattkemper, 2011). Descartes' (1664) assumed that information of external stimuli (afferent signals) was transferred to the brain which in return transmitted signals to the muscles (efferent signals). At this point, action and perception were considered to be independent and incommensurate, hence, not influencing each other. Rather, actions were considered to be the result of perception only, meaning that actions occur as a reaction towards the perception of a certain event (cf. Prinz, 2014). This so-called *sensorimotor* approach became an influential conception throughout the following centuries of research on action and perception.

About 200 years later, Donders (1868) described this process further by dividing the processing between afferent and efferent signals into twelve separate steps (starting with a certain stimulus input and resulting in a certain motor output) with the first six steps concerning perceptive operations and the latter six steps concerning motor operations. The intention behind this idea was to determine the amount of time each single processing step requires in order to measure and describe the processing chain of human cognition. This view was highly influential for later behavioral scientists and cognitive psychologists who typically adapted Donders' approach by studying simple stimulus-reaction associations and explaining human behavior as being a consequence of an external stimulus (cf. Hommel & Nattkemper, 2011). Importantly, these researchers still emphasized the incommensurability between afferent and efferent signals which led to a framework often referred to as *separate coding*. Separate coding might be best illustrated by a simple reaction time experiment in which participants should press one of two keys with either the left or the right hand in response to a low or high pitched sound. In this case, the afferent codes represent the two different sounds and the efferent codes represent the two different hands. In order to allow the participant to press the key with the correct hand according to the presented sound the afferent codes need to be translated into efferent codes – metaphorically, sounds have to be translated into hands. Hence, separate coding fulfills the purpose to explain how afferent and efferent signals can “talk” to each other in spite of their incommensurability. By proposing a *translation* mechanism (Welford, 1960) the two separate codes (efferent and afferent signals) are enabled to communicate, and by doing so, the gap between perception and action is overcome (cf. Prinz, 1990, 1997).

2.2 Ideomotor Theory

In the middle of the 19th century, traditional behavioral and cognitive theories of action and perception were challenged from time to time by studies demonstrating an interface between action and perception (see Stock & Stock, 2004 for a review). For example, Laycock (1845) described the influence of perception and imagination on the behavior of patients infected with rabies. Within his observational studies he demonstrated that typical behavioral symptoms, like convulsions of the face, trunk or limbs did occur when the patient was visually confronted with a cup of water or even by the mere imagination of water or drinking. As a consequence, he reasoned that perceived or imagined situations somehow directly elicit the action associated with these situations.

In the following, further theoretical consideration emerged, which were based on the question why people are able to perform voluntary, goal-directed actions but at the same time do nothing know about *how* they perform these actions – a phenomenon referred to as *executive ignorance* (Lotze, 1852). For instance, when asking people how they perform a certain action (e.g., opening a bottle) they would typically start to imagine themselves performing this action and subsequently describe what they ‘perceived’ (cf. Hommel & Nattkemper, 2011).

These considerations finally converged into the *ideomotor theory*, proposed by Lotze (1852) and James (1890), who stated that “every mental representation of a movement awakens to some degree the actual movement which is its object”. In contrast to traditional accounts, this approach argues that external events are caused by actions, not vice versa, and even more important, that actions are exclusively represented in terms of their sensory effects (Prinz, 1990), referred to as action knowledge.

According to the ideomotor theory, *action knowledge* is the crucial aspect which allows the agent to either predict the effects of his actions, or to select an appropriate movement in order to achieve an intended goal. Action knowledge is considered to be based on associative learning between movements and their caused effects (cf. Prinz, 2014). For example, if a child is confronted with a new toy with a button which elicits a sound when pressed and starts to explore its functions, it will at some point touch the button which will elicit the sound. Crucially, this action causes three types of sensory effects: *side* effects (a specific hand position in order to press the button), *near* effects (the button moves downwards) and *far* effects (the sound), which will be consistently associated with the execution of this specific action (cf. Prinz, 2014). As a result an associative network which contains representations of the specific body movements and their caused near and far effects will be established.

Once this associative network is constituted it can be used by the agent in two ways – as a forward model which allows the prediction of action effects caused by specific body movements, and as an inverse model which allows the planning of body movements in order to realize intended effects (cf. Prinz, 2014). Further information about the acquisition and function of these associative networks can be found at Elsner and Hommel (2001).

2.3 Common Coding Approach

Based on the assumptions of the ideomotor theory, the *common coding approach* (Hommel et al., 2001; Prinz, 1990, 1997) intents to explain the interface between action and perception. Basically, this approach supposes that planned actions and perceived events share the same format, referred to as the "*common code*" (see **Figure 1**).

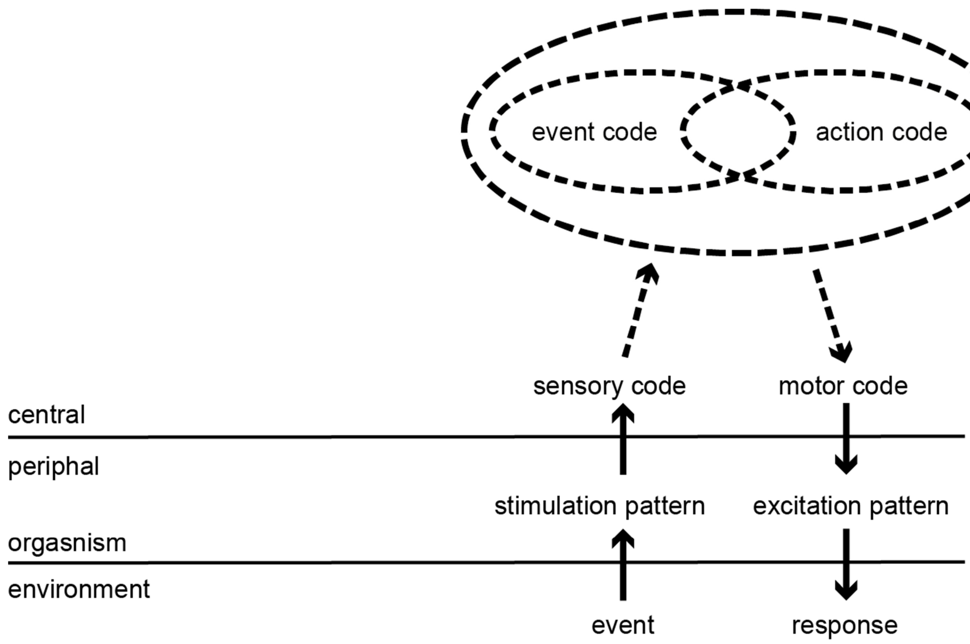

Figure 1. Relationship between action and perception according to the common coding approach. Broken lines in the top part indicate common representational medium of action and perception. Adapted from "Perception and action planning" by Prinz, 1997. European Journal of Cognitive Psychology, 9(2), p. 130.

This common code is neither perception-specific nor action-specific – rather, representations of action and of perception are stored and processed within a high-level representational medium (Prinz, 1997). Due to this shared representational medium, a direct exchange of information is enabled, thus, action and perception being commensurate. Hence, a bidirectional influence between action and perception should be enabled, indicating that action perception should at some point facilitate or interfere with action execution and vice versa, depending on their similarity. Several behavioral studies employing induction or interference paradigms have indeed supported this assumption by showing that action execution can influence action perception and vice versa (Brass, Bekkering, & Prinz, 2001; Brass, Bekkering, Wohlschläger, & Prinz, 2000; Craighero, Bello, Fadiga, & Rizzolatti, 2002; Kilner, Paulignan, & Blakemore, 2003; Müsseler & Hommel, 1997; Schubö, Prinz, & Aschersleben, 2004).

For example, Müsseler and Hommel (1997) investigated whether the perception of a stimulus had an impact on a simultaneously performed task. In this experiment, participants were initially shown an arrow directed either to the left or the right. The task required that participants should first double-press a certain key and subsequently either press a left or a right key according to the direction of the arrow. The moment participants performed the double-press action, a masked arrow occurred and the participants' task was to identify its direction by a corresponding key press. Critically, the masked arrow occurred exactly at that moment when the response to the first arrow was being prepared. Assuming that common codes are recruited for current perception and ongoing action planning, the authors hypothesized that the identification accuracy of the masked arrow should be lower when its direction was corresponding to the direction of the first arrow. The results indeed showed this pattern, which was interpreted as evidence that the ongoing planned action already recruited the same codes which were also required by (but not available for) the perception of the masked arrow, hence, resulting in a lower identification accuracy.

Concerning action understanding the common coding approach proposes that due to the shared representational format it is guaranteed that observers are able to identify the agent's intended actions goals. This is ensured by an internal simulation process which activates the perceived action within the observer (Prinz, 1990). Hence, the observer is able to predict the action goals and intentions of the observed action and therefore, obtains action understanding.

However, while both the ideomotor theory and the common coding approach are theoretical frameworks that include specific predictions about the relationship between action and perception in a variety of experiments, the exact nature of their shared representational codes is unknown (cf. Keitel, 2013).

2.4 Direct Matching Principle

An approach about how action execution and action perception are linked in the brain is the *direct matching principle* (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Gallese, 2009; Jeannerod, 1994, 2001; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996; Rizzolatti & Craighero, 2004), which supposes that an observed or imagined action is mapped onto the same motor representations, which are activated when the same action is executed. This mapping process allows the observer to run internal real-time simulations of the agent's movements, goals and intentions (Gallese, 2009) and as a consequence, the observer is able to understand the meaning of the agent's action (Gallese, Keysers, & Rizzolatti, 2004). Thus, action understanding is guaranteed by the mere motor simulation of an observed action, without the necessity of overt movement from the observer (Cross, Hamilton, & Grafton, 2006; Jeannerod, 2001a). Moreover, the simulation process is initiated at the moment the observed action starts, and therefore, enables the observer to predict the future course of the observed action (Cattaneo, Maule, Barchiesi, & Rizzolatti, 2013; Sebanz & Knoblich, 2009).

Crucially, according to the direct matching principle, action understanding strongly relies on the ability to perform the observed actions (Gallese & Goldman, 1998). Several studies supported this assumption by emphasizing the importance of own experience in order to understand the intentions and goals of others' actions (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005; Casile & Giese, 2006; Mulligan & Hodges, 2013). Nevertheless, it is not entirely clear whether the ability to perform actions or the ability to understand others' actions develops first in infancy. To date, there is some evidence that infants are usually able to understand others' actions about the same time when they can perform the same actions themselves (e.g., Jovanovic et al., 2007; Király, Jovanovic, Prinz, Aschersleben, & Gergely, 2003), whereas other authors clearly state that own experience with actions is a presumption in order to understand others' actions (e.g., Gredebäck & Kochukhova, 2010; Loucks & Sommerville, 2012).

Mirror neurons have been discussed to be the neural substrate underlying the direct matching principle (Buccino, Binkofski, & Riggio, 2004; Gallese et al., 1996; Kilner, Friston, & Frith, 2007; Rizzolatti, Fogassi, & Gallese, 2001) and the prediction of other people's behavior during social interactions (Bonini & Ferrari, 2011). Mirror neurons were first discovered in the premotor cortex of macaque monkeys and have been demonstrated to fire both when the monkey executed a specific action and when it observed another individual executing the same action (Gallese et al., 1996; Rizzolatti et al., 1996).

Subsequent research provided growing evidence that a *mirror neuron system*, similar to that found in monkeys, also existed in humans (Molnar-Szakacs, Kaplan, Greenfield, & Iacoboni, 2006; Mukamel, Ekstrom, Kaplan, Iacoboni, & Fried, 2010; Urgesi, Candidi, Fabbro, Romani, & Aglioti, 2006). To date, areas in the premotor, primary motor and parietal cortices have been identified to contribute to a direct matching process (Dushanova & Donoghue, 2010; Fogassi et al., 2005; Gallese et al., 1996; Nelissen, Luppino, Vanduffel, Rizzolatti, & Orban, 2005). Studies investigating what aspects of others' actions were 'mirrored' in the observer's motor system reported that movements as well as the goals of these movements are coded within the MNS (Alaerts, Heremans, Swinnen, & Wenderoth, 2009; Cattaneo et al., 2013; Engel, Burke, Fiehler, Bien, & Rösler, 2008; Lago & Fernandez-del-Olmo, 2011; Urgesi et al., 2006).

2.5 Predictive Coding Framework

The *predictive coding framework* (Kilner et al., 2007; Neal & Kilner, 2010) addresses the functional role of the MNS and its predictive nature in action understanding. The foundation of this approach is the assumption that actions can be described at four levels: (1) the intention level, which defines the long-term goal of an action, (2) the goal level, which contains short-term goals that are required to achieve the long-term goal, (3) the kinematic level, which describes specific body movements, and (4) the muscle level, which describes the pattern of muscular activity (Hamilton & Grafton, 2007). In order to understand an action the observer must be able to represent the intention or goal level, although he has only access to the kinematic level via visual information. Whereas the direct matching approach merely assumes that the same neurons of the MNS are activated during both action execution and action observation the predictive coding framework intends to explain how visual information is transformed along the MNS and finally results in action understanding in the observer. For this purpose, it is assumed that the MNS is functionally organized in a hierarchical manner corresponding to the different levels of actions[1] (Kilner et al., 2007). Thus, visual information of an action is transformed along the MNS by forward connections up to the intention level which allows action understanding. This assumption is supported by studies showing consecutive patterns of activation in the human MNS during action observation (Nishitani & Hari, 2000, 2002).

However, the problem of a mere feedforward model is that it is entirely based on bottom-up processes – thus, congruent visual information of two distinct actions (e.g., waving arm as a greeting vs. waving arm for hailing a taxi) could not be understood unambiguously. Hence, the predictive coding framework proposes reciprocal connections between anatomical structures of the MNS which guarantee top-down processes to have an influence on action understanding, and which ensure predictions on all hierarchal action levels.

For instance, when observing an action, the observer forms expectations about the intentions or goals of that action deriving from contextual or situational constraints. This predicted intention leads to a simulation process in the observer's own motor system in order to generate a prediction of how he would perform the same action (Neal & Kilner, 2010). By doing so, the observer predicts specific body movements which should be elicited by the agent in order to achieve his intention. Critically, the predicted movements are compared with the actual observed movements, and as a consequence a prediction error can emerge, with its size depending on the discrepancy between the observed and the predicted movements. By updating the predictions on all hierarchal levels according to the prediction error, it can be minimized, and as a consequence the observer is able to infer the most likely intention of that action, hence, action understanding is realized.

[1] Three cortical areas are considered to constitute the MNS and have been shown to be reciprocally connected: area F5 of the premotor cortex, the inferior parietal lobule and the superior temporal sulcus (see Keysers & Perrett, 2004 for further information).

2.6 Teleological Stance Theory

A further approach of action understanding is described within the *teleological stance theory* (e.g., Gergely, Nádasdy, Csibra, & Bíró, 1995; Gergely, 2003; Gergely & Csibra, 2003). This approach was originally developed to explain why infants can understand some observed actions without having motor experience with those actions and without inferring intentions from the agent.

Basically, the teleological stance theory describes that in cases where no prior motor experience exists action understanding is guaranteed by the fact that the observer expects the agent to act rationally and efficiently. This idea is based on the *principle of rationality* which describes that every action always serves to achieve a certain goal (Csibra & Gergely, 2007). Hence, observers expect other people to act goal-directed and in a rational manner (Eshuis, Coventry, & Vulchanova, 2009).

A process referred to as *teleological reasoning* enables the observer to interpret an action as goal-directed and rational – meaning that an agent should approach a goal in an efficient way in the given situation (Csibra & Gergely, 2007). For example, teleological reasoning in 12-months-old infants was demonstrated in a prominent study by Gergely and colleagues (1995) who presented infants with a computer-animated task: infants should observe a small circle jumping over a barrier in order to reach a large circle. After several habituation trials, test trials were presented in which the barrier was removed and the small circle either performed the same jumping action (irrational) or a straight path movement (rational) towards the large circle. The results demonstrated that infants showed significantly more dishabituation behavior when confronted with the irrational jumping action compared to the rational straight path movement during test trials, meaning that infants were able to infer the most rational movement the circle would perform to achieve its goal. Hence, children were able to identify the circle as an agent and moreover, inferred that its behavior would follow rational principles.

Teleological reasoning was mostly investigated in infants and it could be repeatedly shown that they are able to evaluate the rationality of actions performed by human agents (Sodian, Schoeppner, & Metz, 2004), robots (e.g., Kamewari, Kato, Kanda, Ishiguro, & Hiraki, 2005) or even objects with ambiguous agency (e.g., Csibra, Gergely, Bíró, Koos, & Brockbank, 1999). Moreover, recent findings emphasize the occurrence of teleological reasoning in adults as well as in infants, especially in cases where motor simulation or direct matching processes are insufficient, like in unusual or novel situations (Brass, Schmitt, Spengler, & Gergely, 2007; Gredebäck & Melinder, 2010, 2011).

2.7 Interim Conclusion

Taken together, the modern approaches outlined above emphasize the interface between action and perception and its role in action understanding. However, each approach differs in some ways from the others by explaining action understanding slightly different or by concentrating on different aspects of action understanding. Nevertheless, the aim of this thesis is not to verify or falsify the distinct accounts. Rather, the accounts are considered to be the conceptual framework for the present thesis, and moreover, they consistently provide two key aspects that are relevant for the present work: (1) that action and perception are directly linked, and (2) that anticipatory processes are involved in action understanding.

These two premises allow us to investigate the influence of experience with an action on action understanding during the observation of the same action. In the following section we will elaborate on how action understanding is measured within the present work.

3 Measures of Action Understanding

For the present work, we will focus on two indicators of action understanding: *anticipatory eye movements* and *pupil size changes*. In the following two subsections we provide definitions for both measures and review important research findings about the relation between these measures and action understanding.

3.1 Anticipatory Eye Movements

As outlined in Chapter 2, one crucial part of action execution and action perception is anticipatory processing (Csibra & Gergely, 2007; Kilner et al., 2007; Prinz, 1997). This means on the one hand that the agent has to be able to plan his actions in advance in order to execute them, and on the other hand that the observer must be able to predict future goals of ongoing perceived actions in order to understand the agent's intentions. One possibility how these anticipatory processes can be measured in the agent or in the observer is by means of *anticipatory eye movements*.

Anticipatory eye movements are often referred to as "look-ahead fixations" (Morgante, Haddad, & Keen, 2008) or "goal-directed gaze shifts" (Henrichs, Elsner, Elsner, & Gredebäck, 2012; Henrichs, Elsner, Elsner, Wilkinson, & Gredebäck, 2014) – terms which intuitively illustrate that these eye movements are directed towards a specific object or sub-goal of an action prior to its manipulation or accomplishment (Land & Furneaux, 1997). For example, when an agent intends to drink, his gaze will be directed towards the cup prior to the arrival of his hand. Anticipatory eye movements have been shown for agents during the performance of everyday actions like tea-making (Land & Hayhoe, 2001; Land, Mennie, & Rusted, 1999) and in experimental contexts (Johansson, Westling, Bäckström, & Flanagan, 2001). Taken together, these studies have argued that eye movements are predictive in order to plan and monitor the execution of an ongoing action (Johansson et al., 2001), thus, emphasizing their function in anticipatory processing during action execution.

Within their seminal study, Flanagan and Johansson (2003) were able to demonstrate that not only agents, but also observers show anticipatory gaze when they observe others' actions. Within that study the authors applied a block stacking task which was alternately performed or observed by two persons in an eye-tracking design. The presumption of the study was that eye movements are an inherent part of an action program, thus, whenever an agent is engaged in an action, corresponding eye movements guiding that action would occur. Following this assumption, the authors proposed that in case a direct matching process would occur during action observation, eye movements should be similar for the agent as well as the observer. Indeed, eye movements were found to be highly similar for agents and observers, and this was taken as evidence that action understanding is based on a direct matching process and moreover, that eye movements can be taken as indicators of action understanding during observation. Consecutively, several studies have shown that adults (Ambrosini, Costantini, & Sinigaglia, 2011; Costantini, Ambrosini, & Sinigaglia, 2012; Gesierich, Bruzzo, Ottoboni, & Finos, 2008) as well as infants (Falck-Ytter, Gredebäck, & von Hofsten, 2006; Gredebäck, Stasiewicz, Falck-Ytter, von Hofsten, & Rosander, 2009; Kochukhova & Gredebäck, 2010) elicit predictive gaze behavior when observing ongoing actions.

A recent study using transcranial magnetic stimulation (TMS) and eye tracking provides further support for the assumption that anticipatory eye movements depend on the recruitment of corresponding action plans in the observer's motor system. While participants observed point-light grasping actions, TMS pulses were either delivered to the hand area or the leg area in half of the trials. When the TMS pulse occurred over the hand area, anticipatory eye movements were delayed compared to no TMS. The results provide strong evidence that the ability to predict observed actions is realized by a direct matching process located in the observer's mirror neuron system (Elsner, D'Ausilio, Gredebäck, Falck-Ytter, & Fadiga, 2013). In line with this, the ability to perceive and anticipate action goals has been shown for both adults and children to be strongly dependent on their own extent of motor experience with the same action (Kochukhova & Gredebäck, 2010; Rosalie & Müller, 2014) underpinning the assumption that anticipatory eye movements are causally related to the observer's motor system.

According to these findings, we assume that anticipatory eye movements can be taken as indicators of action understanding in the observer. Moreover, for the present thesis it is of particular relevance that own (motor) experience with an action was found to facilitate the prediction during the observation of the same action. Accordingly, we propose that short-term experience with an action should have a direct impact on anticipatory eye movements during the observation of the same action. Therefore, we aim to investigate whether a systematic manipulation of own experience will cause specific changes in gaze latencies during the observation of an action.

3.2 Pupil Size Changes

In contrast to anticipatory eye movements, pupil size changes are typically applied as a post-hoc measure providing information about the individuals' expectations in a certain situation, specifically when expectations are violated. Traditionally, pupillary responses to light have been studied extensively for many years, but about 50 years ago, pupil size changes have been demonstrated to not only occur in response to a varying amount of light reaching the retina (the so called papillary light reflex) but moreover also as a consequence of arousal (Hess & Polt, 1960) or cognitive effort (Hess & Polt, 1964; Kahneman & Beatty, 1966). Importantly, changes in pupil size in response to cognitive activity have been reported to be rarely greater than half a millimeter (Beatty & Lucero-Wagoner, 2000) which is slightly moderate compared to changes in pupil size caused by illumination (MacLachlan & Howland, 2002; Wyatt, 1995). Nevertheless, since the discovery that pupillary changes occur dependent on mental activity, several studies have reported and replicated the finding that changes in pupil diameter can be described as a function of the level of cognitive effort – with higher cognitive activity leading to an increased pupil diameter being found (Ahern & Beatty, 1979; Hess & Polt, 1964; Hyönä, Tommola, & Alaja, 1995). A well accepted explanation for this correlation is that cognitive effort or mental activity in general lead to an increased arousal in the individual, which becomes openly apparent in pupil size changes. This view is supported by robust findings of several neuropsychological studies (Koss, 1986; Rajkowski, Kubiak, & Aston-Jones, 1993), demonstrating that pupillary responses are directly linked to an activation of the noradrenergic system, specifically the locus coeruleus (LC), which is considered as the main cortical structure regulating the neuro-transmitter norepinephrine (Aston-Jones & Cohen, 2005), and which is activated by stress (Sterpenich et al., 2006). Hence, a higher arousal in the individual caused by higher cognitive effort leads to an increased activation of the LC, and as a result to an increased pupil diameter.

For the present thesis, studies investigating the violations of expectations ('prediction errors') on pupil size changes are of particular relevance. Several recent studies have addressed this issue by using a broad variety of methods. Results mainly indicated that violations of expectations indeed result in increased pupil diameters (Gredebäck & Melinder, 2010; Morita et al., 2012; Preuschoff, 't Hart, & Einhäuser, 2011; Raisig, Welke, Hagendorf, & van der Meer, 2010; Scheepers, Mohr, Fischer, & Roberts, 2013). For instance, one study questioned whether pupil dilation would occur in response to prediction errors in an auditory gambling task. The presumption of this study was on the one hand that the activation of the noradrenergic system is directly linked to pupillary responses, and on the other hand that the activation of the noradrenergic system might signal surprise in the participant. Hence, the authors assumed that prediction errors in a gambling task should result in a form of surprise in the participant which should be assessable via pupil dilation. Results effectively showed that pupil dilation was strongly correlated with prediction errors, indicating that pupil size changes can indeed signal surprise in an individual (Preuschoff et al., 2011).

Regarding the perception of body movements, a further study reported that adults, but not nine to 12 months old infants, showed an increased pupil size when watching animations of impossible human body movements (e.g. arms bending backwards) compared to possible body movements (e.g. arms bending upwards). The authors discussed this finding in the sense that adults possessed expectations about possible human body movements which were violated by the demonstration of biomechanically impossible body movements and therefore led to a higher arousal in the observers. This interpretation was supported by participants' self-reports stating that impossible human body movements prompted unpleasantness and discomfort (Morita et al., 2012).

Concerning the perception of social interactions, a study conducted by Gredebäck and Melinder (2010) used pupil size measures to investigate infants' responses to unusual social interactions. In this study, six and 12 months old infants were presented with rational (a spoon was moved to the interaction partner's mouth) and irrational (a spoon was moved to interaction partner's hand) feeding actions. Both age groups dilated their pupils when observing the irrational feeding actions compared to rational feeding actions. This finding was discussed in such ways that infants expect agents to act rationally and efficiently. When being confronted with an irrational action in which the agents violated this expectation, infants became surprised which caused a higher arousal, and therefore resulted in an increase in pupil size.

Taken together, these findings indicate that the violation of existing expectations leads to a state of surprise in an individual which is measurable via pupil dilation. For the present work this implies that the observation of unexpected action outcomes should lead to an increase in pupil diameter in the observer. However, the influence of own experience on pupillary responses in association with unexpected action outcomes is still unknown. To date, pupillary responses are considered to occur spontaneously, and not being able to be influenced voluntarily (Loewenfeld & Lowestein, 1993). Nevertheless, experience with an action might have an impact on the latency or amplitude of pupil dilation since own experience might modify or even improve predictions about action outcomes. Hence, a modified prediction error assessable via pupil size changes could be the result. In the present thesis, we aim to investigate whether a systematic manipulation of own experience might result in specific changes in pupillary response measures.

3.3 Dissociation between Online and Post-Hoc Measures

Anticipatory eye movements and pupil dilation can both be used as indicators of action understanding. However, both measures differ in such ways that anticipatory gaze is measured *online* while the observed action is ongoing, whereas pupil dilation is usually applied as a *post-hoc* measure in response to a completed action (Daum, Attig, Gunawan, Prinz, & Gredebäck, 2012).

In principal, both online measures and post-hoc measures provide information about the observer's expectations. However, online measures (such as anticipatory eye movements) indicate expectations about upcoming events in the ongoing action, whereas post-hoc measures (such as pupil dilation) provide information about the evaluation of the observer's expectations after the action is completed. Thus, these two measures mainly differ in the amount of information available for the observer at the time of data collection – when measuring post-hoc, the observer already possesses the full information about the observed action, hence, what we measure is the observer's expectations being compared to the actual action outcome. In contrast, when measuring online, the observer only possesses part of the information about an action available, thus, we measure expectations about upcoming events in the observed action (Daum et al., 2012).

To analyze how online and post-hoc measures (in this case predictive gaze and looking times, respectively) are related to each other, and whether they reflect different processes underlying action understanding, a study with nine-months-old infants conducted by Daum et al. (2012) addressed these issues by applying a habituation task: During familiarization trials an animated agent (fish) repeatedly moved toward one of two objects. During the test phase, the locations of the two objects were switched, and two scenarios were randomly presented to the infants: The agent either took the same path as before, but reached a new object (old path/new object), or the agent took a new path in order to reach the old object (new path/old object). Moreover, in order to trigger predictive gaze behavior, the agent disappeared behind an occluder that was added in the center of the screen and reappeared at either the left or right side, corresponding to the object intended to reach (see **Figure 2**). Infants' action expectations were measured via looking times (post-hoc) and via predictive gaze (online). The results showed that infants looked longer at trials in which the agent moved toward a new object (via the old path) compared to trials in which the agent moved toward the old object (via the new path), indicating that infants did not expect the agent to approach a new object (see Woodward 1998 for further information on this paradigm). Thus, at the age of nine months post-hoc measures such as looking time most likely indicate expectations about the identity of an object rather than about the location the agent might approach. Concerning predictive gaze, nine-months-old infants directed their gaze significantly more often toward the old location, irrespective of the object at this location, which indicates that infants expected the agent to continuously take the same path.

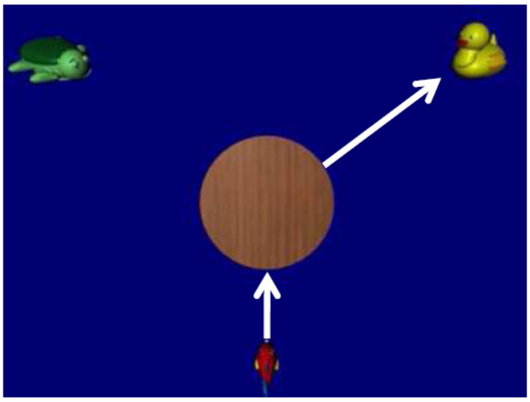

Figure 2. Example of stimulus presentation. Graphic from "Actions seen through babies' eyes: A dissociation between looking time an predictive gaze," by Daum et al., 2012, *Frontiers in Psychology, 3,* p.3, http://journal.frontiersin.org/article/10.3389/fpsyg.2012.00370, published under Creative Commons, Attribution 3.0 Unported (CC BY 3.0), https://creativecommons.org/licenses/by/3.0/.

Hence, online measures such as predictive gaze most likely reflect expectations about the location the agent might approach. In a second experiment, the authors investigated whether this dissociation would persist throughout the first years of life up to adulthood, and found this dissociation to disappear after the age of three years. From this age on children's expectations about object identity could also be measured online (Daum et al., 2012), meaning that children directed their gaze toward the old object instead of the old location.

The authors discussed these findings in terms of two different explanations: First, they supposed that a temporally successive processing chain might be responsible for the dissociation between online and post-hoc measures, meaning that the expectation about a location is processed relatively early during action observation (e.g., indicated by predictive gaze behavior), followed by the processing of identity-related expectations (e.g., indicated by looking time). A second possible explanation the authors discuss is that there might be different mechanisms involved in the processing of expectations about an object's location and its identity. This assumption finds support in neuropsychological studies reporting two visual pathways (Goodale & Milner, 1992), which are supposed to be responsible for a distinct processing of object identity and location. However, from an age of three years on, children seem to be able to integrate both processes since identity-related expectations are measurable via online measures, whereas young infants seem to rely on expectations about the location first (indicated by online measures), and only with sufficient information about an action they are able to build expectations about the identity of objects (indicated by post-hoc measures). Taken together, both interpretations can explain why younger infants distinctly process expectations about object identity and location. However, it cannot be ruled out from this study which one is actually true or if an interaction of both interpretations is underlying the aforementioned findings.

For the present work, we intend to measure observers' expectations about an ongoing action via online measures (predictive gaze), and further, we will apply post-hoc measures (pupil dilation) in order to investigate the violation of observers' expectations about the action outcome. Specifically, we aim to investigate the influence of own experience on both online and post-hoc measures. According to the two possible interpretations outlined above, both online and post-hoc measures should be integrated in adults and children older than three years of age. This leads to the assumption that own experience might have an equally strong influence on both measures. However, we need to be careful in assuming this, since our study differs in several aspects from the study conducted by Daum and colleagues (2012). First, we only assess participants' expectations about the location of objects, whereas the identity of objects never changes, and second, we will apply different types of stimuli when measuring action understanding online and post-hoc. Hence, a dissociation of both measures might occur only because of different stimulus material. Therefore, in the present thesis, we cannot entirely disentangle whether both measures are fully integrated in adults or remain partly independent, at least not in the same way as described in the study by Daum et al. (2012). Nevertheless, we intend to disentangle the influence of own experience on online and post-hoc measures and will be able to add some valuable information about the dissociation between different measures of action understanding from this perspective.

4 Empirical Evidence for Action Understanding in Adults

In the following section, empirical findings concerning the relationship between action execution and action perception and the impact of experience on action understanding will be outlined.

4.1 Relationship between Action Execution & Action Perception

As already outlined in Section 2, contemporary theoretical accounts propose a tight link between action execution and action perception. To date, a large body of evidence supports these accounts by demonstrating that action execution can influence action perception and vice versa (e.g., Brass et al., 2001; Hamilton, Wolpert, & Frith, 2004; Kilner, Paulignan, & Blakemore, 2003; Schütz-Bosbach & Prinz, 2007).

4.1.1 The Influence of Action Perception on Action Execution

It has previously been shown that the perception of an event can automatically trigger a related action in the perceiver, a phenomenon referred to as *ideomotor action* (cf. Herwig, 2014). Importantly, two types of ideomotor actions can occur when perceiving an external event – *perceptually induced* actions and *intentionally induced* actions. The following example will help to illustrate these two types of ideomotor action: A person observes someone on a ladder who bends backwards and is about to fall off the ladder. As a consequence, the observer might automatically elicit an ideomotor action, which could either be to bend slightly backwards (perceptually induced) or to bend slightly forward (intentionally induced). Hence, the perceptually induced action occurs in accordance with the observed movements (to bend backwards) whereas the intentionally induced action occurs in relation to the intended goal of the observed person (in this case to bend forwards to not fall off the ladder). Ideomotor actions were systematically investigated in a study conducted by Knuf et al. (2001). Participants were asked to observe a ball approaching a target stimulus, which it was about to miss narrowly. In order to let the ball hit the target stimulus, participants were allowed to intervene and could either influence the trajectory of the ball or adjust the position of the target stimulus by using a joystick. Crucially, the function of the joystick was disabled after a while and from that moment on, ideomotor actions (even of body parts that did not play a role in guiding the ball, like the head) could be observed. Importantly, the hands predominantly showed intentionally induced actions (in accordance with the intended direction toward the target stimulus), whereas the head also showed perceptually induced actions (in accordance with the perceived direction of the moving ball). This result indicates that the perception of an external event can automatically induce related actions in the observer, thus, provides again evidence for the commensurability between action and perception.

In order to investigate the influence of perceived body movements on the initiation of compatible or incompatible body movements, Brass and colleagues (2001) conducted a study in which participants were asked to perform simple finger movements in response to video stimuli which showed similar finger movements. In one block, participants were instructed to lift the index finger and in the other block, participants were instructed to tap on the table with the index finger. During both blocks, participants watched short video clips in which the index finger moved randomly either up or down. Hence, in one block, the lifting of the index finger was compatible with the video clip which showed the upward movement, and in the other block the tapping on the table was compatible with the downwards movement of the finger in the video clip. The results showed that the participants' response (lifting or tapping) was significantly faster in compatible trials compared to incompatible trials. Hence, the perception of an action compatible with the own planned action led to a quicker initiation of the same. In subsequent experiments within this study, it could be demonstrated, that the reaction time advantage disappeared when the degree of similarity between the observed and executed actions decreased (Brass et al., 2001). These findings are again in line with the idea that perceived actions and executed actions draw back on shared representations. But does action execution also influence how we perceive certain events?

4.1.2 The Influence of Action Execution on Action Perception

Illustrative examples of how action can influence perception are described within several classical experiments conducted by Helmholtz (1866) and Stratton (1896, 1897) – within these experiments, a person wore glasses bearing prisms that displaced or inverted the visual field. Hence, the person perceived the actual environment displaced or upside down. Importantly, when the person intended to interact with the environment, he/she failed to perform goal-directed actions on objects because the person guided his/her hands to the perceived location of the object. However, after several days of wearing the prism glasses and interacting with the environment, the person was able to adapt and to coordinate his/her movements according to the 'new' perception. Thus, he/she was again able to reliably grasp objects and to confidently move through his/her environment. Moreover, Stratton (1896) reported that his perception of a displaced or inverted environment disappeared after five days of wearing the prism glasses, indicating that after several days of exploring and interacting with the environment, an adapted association between the perceived location of an object and the actual location where the object could be manipulated was formed (see Redding & Wallace, 2006 for more details). Interestingly, similar experiments have been conducted with subjects being seated in a wheelchair and passively moved around in an environment. Although these subjects had a comparable visual experience to other subjects who walked themselves, no adaptation to the prism glasses occurred (Held & Freedman, 1963). Taken together, these experiments illustrate well how action can influence the perception of an environment.

In more recent studies, the influence of action on perception was further investigated and it was again demonstrated that the execution of actions can modulate what a person perceives (see Schütz-Bosbach & Prinz, 2007 for a review). For example, Repp and Knoblich (2007) presented pianists pairs of tones in a tritone interval. Some listeners perceive this tone sequence as an ascending melody while others perceive a descending melody. The pianists were asked to produce left-to-right or right-to-left key presses on a piano while listening to the tritone pairs. When producing left-to-right key presses (which cause an ascending melody on the piano), the pianists perceived significantly more often an ascending tritone interval, whereas right-to-left key presses caused the perception of a descending tritone interval. Hence, the auditory perception of tones could be influenced by concurrent executed actions.

Furthermore, effects of action on perception could also be found in the domain of visual perception (Blaesi & Wilson, 2010; Hamilton et al., 2004; Miall et al., 2006; Müsseler & Hommel, 1997; Schubö et al., 2004). For example, Hamilton et al. (2004) asked participants to lift a box of varying weight (heavy to light) while they simultaneously watched a video in which a person lifted an identical-looking box with varying weight (heavy to light). Subsequently, participants were asked to estimate the weight of the box lifted in the video. The results indicated that participants tended to overestimate the weight of the box lifted in the video when they simultaneously had lifted a light box, whereas they underestimated the weight of the box lifted in the video when they themselves had lifted a heavy box. Thus, again the execution of an action affects the perception of concurrently perceived similar actions.

A further study conducted by Miall et al. (2006) demonstrated how action execution can improve *or* impair the perception of incongruent or congruent hand actions, respectively. To this end, the authors presented participants a sequence of hand images while they were asked to produce specific hand movements. The participants' task was to identify an oddball image that differed from the other pictures in the sequence. The oddball image was identified faster when the participants produced hand movements that were congruent to those shown in the remaining images of the sequence. This result seems rather unexpected in the first place, since we would expect that specific actions should facilitate the perception of identical actions. However, it has been repeatedly shown in further studies that planned and/or executed actions can impair or improve the perception of similar actions (Hamilton et al., 2004; Müsseler & Hommel, 1997; Zwickel, Grosjean, & Prinz, 2010), referred to as assimilation or contrast effects.

4.1.3 Assimilation and Contrast Effects

Influential effects of action and perception have been systematically studied in experiments implementing dual tasks. Traditionally, the performance costs of either two (or more) simultaneously executed action tasks or perception tasks have been investigated, and it was consistently reported that the performance in such dual tasks was significantly impaired compared to separately executed actions or perception tasks (see Müsseler, 1999 for an overview). In order to investigate whether action and perception are also influencing each other in dual tasks, paradigms consisting of an action task and a perception task were designed (Hamilton et al., 2004; Miall et al., 2006; Müsseler & Hommel, 1997; Schubö et al., 2004; Wykowska, Schubö, & Hommel, 2009). Typically, two effects can be found in such dual task paradigms – on the one hand that action and perception inhibit each other, referred to as *contrast effects*. On the other hand, that action and perception enhance each other, referred to as *assimilation effects.* Contrast effects are considered to emerge when the time interval between the perceptual processing and action execution is minimized, hence both simultaneously compete for their shared representations, whereas assimilation effects typically occur when the time interval between the perceptual processing and action production is increased (Schubö et al., 2004; Schütz-Bosbach & Prinz, 2007). Crucially, both contrast and assimilation effects occur more likely the higher the similarity between the executed and the perceived action is (e.g., Springer et al., 2011). Moreover, the interaction of action and perception is bi-directional, meaning that contrast and assimilation effects should occur both either when an action influences perception or vice versa (Schütz-Bosbach & Prinz, 2007). Thus, contrast effects as well as assimilation effects seem to emerge as a consequence of the tight relationship between action execution and action perception.

The above described phenomena and findings indicate that action and perception are tightly linked. Thus, they provide evidence for modern theoretical approaches that suppose shared underlying representations for action and perception.

4.2 Action Understanding

As already discussed in Section 1.2 the term action understanding goes beyond the mere perception of simple stimuli (cf. Keitel, 2013). Rather, it describes the understanding of the intention or goal of an observed action. However, the linkage between action execution and action perception is considered to be the fundamental basis underlying the ability to understand others' goals and intentions. It is now widely accepted that this link is realized by the mirror neuron system which allows a direct mapping of observed actions onto own motor programs (Buccino et al., 2004; Hari et al., 1998; Hickok, 2013; Rizzolatti et al., 1996; Rizzolatti & Craighero, 2004). Hence, whenever a person observes another person performing an action, specific motor programs of the observer are activated and simulate the observed action. As a consequence, the observer is enabled to understand what the other person is doing (Chaminade, Meary, Orliaguet, & Decety, 2001; Jeannerod, 2001).

When investigating action understanding, participants are typically presented with live or video demonstrations of fully or partly executed actions or action sequences. The task of the participants is mostly to passively observe (e.g., Ambrosini et al., 2011) the action (sequences) or to judge the outcome of a specific action sequence (e.g., Mulligan & Hodges, 2013). To date, various methods (neurophysiologic and neuroimaging methods like EEG or fMRI, eye tracking, behavioral measures) are applied in order to measure action understanding in the observer. Behavioral measures of action understanding typically comprise judgement tasks requiring participants to indicate how an action outcome will be. This method is often used in the domain of sports science, especially when groups with different degrees of expertise are studied (e.g., Cañal-Bruland, van der Kamp, & van Kesteren, 2010; Moore & Müller, 2013). According studies using behavioral measures will be reported in Section 4.3 when the relationship between experience with an action and action understanding will be disentangled. Here, we will concentrate on studies applying neurophysiological and neuroimaging methods due to their crucial role in investigating the human mirror neuron system, followed by studies applying eye tracking methods that are of particular relevance for the present thesis.

4.2.1 Empirical Evidence from Studies applying Neurophysiological and Neuroimaging Methods

Since the discovery of mirror neurons in the premotor cortex of macaque monkeys (Gallese et al., 1996; Rizzolatti et al., 1996), an increasing number of studies implemented neurophysiological and neuroimaging methods with the purpose to identify a similar mirror neuron system in humans.

First evidence for a neural connection between action execution and action perception was provided already in the early 1950s within EEG studies that demonstrated a desynchronization of the so-called μ-rhythm (8-13 Hz) over central electrodes when participants performed actions and when they observed others' actions (e.g., Gastaut & Bert, 1954). These findings were validated by several further EEG studies repeatedly demonstrating μ-rhythm desynchronization over premotor areas during action execution and action observation (Braadbaart et al., 2013; Cochin, Barthelemy, Lejeune, Roux, & Martineau, 1998; Cochin, Barthelemy, Roux, & Martineau, 1999; Pineda, 2005). Further studies investigating functional aspects of the μ-rhythm indicated that μ-oscillations specifically respond to object-related actions (Muthukumaraswamy, Johnson, & McNair, 2004) and to animate stimuli (Altschuler, Vankov, Wang, Ramachandran, & Pineda, 1997). To date, various studies draw back on μ-oscillations when investigating action understanding in infants (see Marshall & Meltzoff, 2011 for a review) or in individuals with autism spectrum disorders who seem to be affected by a dysfunctional mirror neuron system (e.g., Oberman et al., 2005).

Studies using functional magnetic resonance imaging (fMRI) have been conducted in order to determine more precisely which brain areas are involved when observing others' actions (e.g., Buccino et al., 2001; Calvo-Merino et al., 2005; Shmuelof & Zohary, 2006; Vingerhoets et al., 2012). For example, Buccino et al. (2001) intended to determine brain areas that were activated during the observation of videos of object-directed and non-object-directed actions executed by different parts of the body (mouth, hand, foot), e.g., biting an apple vs. chewing, or kicking a ball and mimicking to do so. Results indicated an activation of the premotor cortex in a somatotopically manner for both conditions, which the authors interpreted as a mirror process that matched the observed action onto own motor representations. Moreover, when observing object-directed actions an additional activation of the posterior parietal lobe was found and interpreted as an object-related analysis.

Studies comparing typical cortical activity (measured by fMRI) during action observation and desynchronization of the µ-rhythm (measured by EEG) while observing others' actions reported a correspondence between both measures (Braadbaart et al., 2013; Perry & Bentin, 2009). For example, Braadbaart et al. (2013) sequentially recorded EEG and fMRI measures in a within-subject design in which participants were asked to imitate or observe manual actions. Results indicated that µ-suppression was correlated with BOLD responses in brain areas that are involved in action perception and action planning. Hence, both measures have been demonstrated to be sensitive to the observation of others' actions.

Taken together, studies applying neurophysiological and neuroimaging methods (including MEG and TMS) provide evidence for a human mirror neuron system which enables a direct matching process of observed actions on own motor programs and thus, seems to play a crucial role in action understanding.

4.2.2 Empirical Evidence from Studies applying Eye Tracking Methods

When acting upon objects in everyday actions, people show goal-directed saccadic eye movements (Land & Hayhoe, 2001; Land, 2009; Land et al., 1999), which have been demonstrated to be predictive in order to plan and monitor the execution of an ongoing action (Johansson et al., 2001) and to acquire information about objects for future manipulation (Mennie, Hayhoe, & Sullivan, 2007). For example, Land et al. (1999) recorded participants' eye movements while making tea in a natural environment. By analyzing scene and gaze data frame-by-frame the authors were able to precisely describe participants' gaze behavior. The results indicated that participants predominantly fixated on objects that were relevant for the task (e.g., the cup) and moreover, that participants predictively directed their gaze to objects being manipulated in the next step of the action sequence. The authors concluded that even in highly automatic actions the gaze guides and monitors the ongoing action by predictively fixating on objects that are crucial for upcoming action steps.

Interestingly, people also produce highly similar, predictive eye movements when observing, rather than performing, manual actions (Flanagan & Johansson, 2003; Gesierich et al., 2008; Rotman, 2006). As already described in detail in Section 3.1, anticipatory eye movements have been demonstrated to be indicators of a direct matching process (Flanagan & Johansson, 2003). Flanagan and Johansson (2003) assumed, in accordance with the direct matching hypothesis (see Section 2.4 for further details), that eye movements should be highly similar during both action execution and action observation. By applying a block stacking task in an eye tracking design, the authors were able to show that participants' eye movements during observation were predictive and indeed highly similar to those during action execution. These results provide evidence that action understanding is based on a direct matching process and that eye movements can be taken as indicators of activated action knowledge. In a recent study applying transcranial magnetic stimulation (TMS) and eye tracking this finding was further supported by demonstrating that predictive eye movements indeed depend on the action-specific activation of the mirror neuron system (Elsner, D'Ausilio, Gredebäck, Falck-Ytter, & Fadiga, 2013) .

Since the study of Flanagan and Johansson (2003), predictive, goal-directed eye movements have been measured in various studies that intended to disentangle the relationship between human gaze behavior and action understanding in adults as well as children (Causer, McCormick, & Holmes, 2013; Falck-Ytter et al., 2006; Gesierich et al., 2008; Kochukhova & Gredebäck, 2010). For example, Gesierich et al. (2008) replicated the findings of Flanagan and Johansson (2003) by applying an animated block stacking task. Participants either performed a block stacking task on a computer screen by using a mouse, or they passively observed different conditions of the construction of a block stacking task on the screen. Crucially, by applying an animated version of the block stacking task, no direct interaction of the hand and the blocks was visible which might have affected the occurrence of anticipatory saccades due to the artificial context. However, the overall results of this study were congruent with those found by Flanagan and Johansson (2003), with the only difference that participants in this study showed individual differences in their gaze behavior during action observation. More precisely, about half of the participants elicited predictive saccades comparable to those produced when constructing the block stacking task themselves, whereas the other half rather tracked the ongoing action by closely following the blocks with their eyes. This finding was explained due to the artificial context in which the block stacking task was observed, which is in line with similar findings obtained by Falck-Ytter and colleagues (2006).

More recent studies aimed to further investigate anticipatory eye movements during action understanding and determined contextual, spatial or action-related constraints that affect anticipatory eye movements (Ambrosini, Pezzulo, & Costantini, 2015; Ambrosini et al., 2011; Costantini et al., 2012). For example, Costantini et al. (2012) recorded eye movements while participants observed video stimuli in which an agent tried to grasp either a small (strawberry) or a big (apple) object with a pre-shaped hand movement. A control group of participants observed similar actions with the difference that the agent did not produce pre-shaped hand movements but only touched the object with an open hand. Moreover, the objects in both conditions were located either within or outside the reach of the agent. Results showed that participants produced significantly more predictive gaze shifts toward the target object in the pre-shape condition compared to the control condition, indicating that people take pre-shape-cues into account when anticipating goal-directed actions. Furthermore, predictive gaze shifts were significantly affected when the target objects were out of the agent’s reach. The authors discussed this finding in such ways that the observer possesses a representation about his/her own interpersonal body space. When observing someone else performing an action, the reaching space of this person is automatically mapped onto the observer’s own body space representation, and as a result enables the observer to predict whether a target is reachable or not. Hence, in the case, that the target is within the reach of the agent, the action is considered to be goal-directed and as a consequence, predictive saccades toward the target are elicited.

In a further study, Ambrosini et al. (2015) investigated the impact of several sources of information (agent’s gaze, pre-shape, arm trajectory, uncertain timing) on anticipatory gaze shifts. The authors intended to determine how every type of cue affects the participants’ gaze behavior during the observation of grasping actions. The results indicate that participants’ predictions were affected by the agent’s gaze direction as long as no pre-shape cue was available. Thus, pre-shaping the hand was again found to be a strong cue that affects people’s predictions about target objects in grasping actions. Moreover, participants relied increasingly on the trajectory of the arm when the action progressed over time. These findings indicate that people make use of and integrate several cues to predict the outcome of an observed action.

Overall, according to previous research, anticipatory eye movements seem to be a reliable measure to investigate action understanding during the observation of others’ actions.

A second possibility to investigate action understanding via eye tracking is to measure pupil dilation. As already outlined in further detail in Section 3.2, pupil size changes predominantly occur when expectations about action outcomes are violated. Hence, studies applying this method usually intend to determine whether individuals identify surprising or uncommon action outcomes (e.g., Gredebäck & Melinder, 2011). In a recent study, pupil dilation has been demonstrated to predict goal-directed eye movements (Mathôt, Siebold, Donk, & Vitu, 2015). The authors explained this finding in terms of mental effort that is necessary to guide the eyes toward relevant objects in a visual scene. Hence, pupil dilation does not only reflect surprise or prediction errors when applied as a post-hoc measure, but rather it can also be implemented as an online measure to investigate goal-directed behavior.

Taken together, neurophysiological, neuroimaging and eye-tracking measures provide different possibilities to measure action understanding. Recently, a number of studies dedicated their interest to the influence of own experience on action understanding. In the following section, according studies are described in further detail.

4.3 Influence of Experience on Action Understanding

A relation between one's own experience with an action and the ability to predict action goals of the same action during observation has been proposed in several studies (Aglioti, Cesari, Romani, & Urgesi, 2008; Calvo-Merino et al., 2005; Wöllner & Cañal-Bruland, 2010). The main assumption in this research area is that the extent to which an action can be understood is positively related to an individual's experience with that action. Typically, this approach has been investigated by comparing groups of individuals who have varying degrees of task-relevant experience with specific actions. Results of these studies indicate that strong effects of expertise on prediction are especially obvious in motor experts such as athletes (Abernethy, Schorer, Jackson, & Hagemann, 2012; Aglioti et al., 2008; Moore & Müller, 2013; Tomasino, Guatto, Rumiati, & Fabbro, 2012; Williams, Ward, Knowles, & Smeeton, 2002) or musicians (Wöllner & Cañal-Bruland, 2010). For example, Abernethy, Zawi and Jackson (2008) investigated expert and non-expert badminton players' ability to predict the depth of opponents' badminton strokes by presenting them temporally and/or spatially occluded video stimuli or point light figure displays. As expected, the ability to anticipate opponents' stroke depth was superior for expert players over non-experts in such ways that experts were more able to use kinematic information from the opponent's body movements to predict future states in both video stimuli and point light figure displays.

However, when taking studies investigating experts and non-experts into account it remains unclear whether experts' advantages in understanding specific actions can be explained due to their motor experience, visual experience or an interaction between both. According to the literature, two accounts have been proposed how experience affects action understanding: On the one hand, a *motor experience* account was supposed which states that the observer's pre-existing own motor repertoire allows the understanding of observed actions (e.g., Sebanz & Shiffrar, 2009). On the other hand, a *perceptual experience* account has been suggested which states that visual familiarity with others' actions facilitates the recognition of observed actions (Jackson, Warren, & Abernethy, 2006). Yet, the particular influence of both types of experiences cannot be distinguished within experiments not manipulating the degree of visual and motor experience. To overcome this issue, a few studies (Aglioti et al., 2008; Calvo-Merino et al., 2005; Calvo-Merino, Grèzes, Glaser, Passingham, & Haggard, 2006; Cañal-Bruland, van der Kamp, & van Kesteren, 2010) intended to disentangle this dissociation by investigating visuo-motor experts (e.g., athletes) on the one hand and visual experts without motor expertise (e.g., journalists or coaches) on the other. One prominent study in this field was conducted by Aglioti and colleagues (2008) who asked professional basketball players, expert watchers (journalists and coaches) and novices to judge whether free basket shots (video recorded) would score or miss the basket. Crucially, the professional basketball players were able to predict the outcome of free shots earlier and more accurately than visual experts and novices. Moreover, visual experts and novices seemed to rather predict the outcome of the shot from the trajectory of the ball in contrast to motor experts who mainly relied on the player's body kinematics. These results can be interpreted in such ways that own motor experience with basketball led to an improved ability to perceive and predict actions from this discipline.

The influence of own motor experience on action understanding could also be demonstrated in an fMRI study conducted by Calvo-Merino et al. (2006). Here, it was questioned whether the activation of the mirror neuron system during action observation changes as a function of own motor experience with that specific action. To this end, the authors compared the brain activity of male and female expert ballet dancers during the observation of gender-specific ballet moves. It was assumed that female dancers exclusively possess motor experience with typical female dance figures whereas they solely have visual experience with male dance figures. For male dancers the opposite pattern was supposed. Results have shown that activation of the mirror neuron system was higher when observing dance movements of the own motor repertoire (performed by a dancer of the same gender) compared to observing visually familiar movements (performed by a dancer of the opposite gender). Hence, the response of the mirror neuron system seems to be not so much dependent on prior visual experience with the action but rather appears to be influenced by previous motor experience when performing the same action.

Some studies, however, emphasize that both motor and visual experience have an impact on action understanding. For instance, Cañal-Bruland et al. (2010) showed that expert handball field players and expert goal keepers were equally able to interpret deceptive behavior of penalty-takers (true vs. fake shots), although having different degrees of motor experience with performing penalty shots. Moreover, both expert groups outperformed novices indicating that experience in general contributes to the successful perception of observed actions, although this study could not clearly distinguish between the impact of visual and motor experience.

In order to clearly disentangle the role of motor and visual experience in action understanding, experimental studies manipulating the degree of visual and motor experience are required. To our knowledge, less than a handful of studies have recently dealt with this issue (e.g., Cannon et al., 2014; Mulligan & Hodges, 2013). For example, Mulligan and Hodges (2013) manipulated the amount of visual experience in a training study, in which participants were trained to throw darts towards specific areas of a dartboard. Before and after the training, participants should predict landing positions of dart throws on temporally-occluded video stimuli. Participants in the motor training condition were trained in two groups – either blindfolded or with vision. Furthermore, two passive groups did not receive a motor training, but one group was able to observe someone else throwing a dart (visual training) whereas one group did not receive any training at all (passive control group). Results have shown that both motor training groups significantly improved to predict the landing position of dart throws during the post-test with no difference between them, whereas the visual training group and the passive control group did not improve at all, indicating that visual experience had no impact on the ability to predict the goal positions of the dart throws.

A second training study conducted by Cannon et al. (2014) hypothesized that the magnitude of μ-rhythm desynchronization should be dependent on prior motor experience with an action during observation. To this end, one group of participants was trained to pick up a toy using a claw-like tool in order to implement motor experience with this relatively novel action. A second group consisted of trained video coders who had a high amount of visual experience with the specific action but no motor experience, and a third group did not have any visual or motor experience with the action. Subsequently, EEG data was collected and results revealed that participants in the active training group showed the greatest μ-rhythm desynchronization compared to the two other groups, indicating that the mirror neuron system was mostly activated for participants who had own motor experience with the observed action. Taken together, the two studies outlined above were able to show that active motor experience has a superior impact on action understanding during observation whereas visual experience did not affect the perception of actions.

Besides this finding, which has already been reported for motor experts (e.g., Aglioti, 2008), it is important to emphasize that even short amounts of experience affected behavioral and neurophysiological measures of action understanding. This result is of particular relevance for our study since we indented to investigate whether a brief period of experience would have an impact on action understanding. Only a small number of studies with non-experts indicate that short-term experience indeed affects the ability to recognize and predict actions during observation (Casile & Giese, 2006; Marshall, Bouquet, Shipley, & Young, 2009; Quandt, Marshall, Bouquet, Young, & Shipley, 2011; Taya, Windridge, & Osman, 2013).

For example, Casile and Giese (2006) trained blindfolded participants to perform novel and unusual upper-body movements by verbal and haptic feedback only. Prior to the training, all participants engaged in a visual discrimination task in which point light figures were presented. Specifically, three types of point light figures were used as prototype stimuli – one with a normal human gait pattern, which is characterized by a phase difference of 180° between the two opposite arms and legs, and two further ones with manipulated phase differences of 225° and 270°. During the visual discrimination task, participants were repeatedly presented with two point light figures – one of the prototype stimuli (180°, 225°, or 270°), and a second point light figure which was either the identical prototype figure in 50% of trials or a similar point light figure with a slightly different phase difference in 50% of trials. Participants' task was to report whether the two presented point light figures were identical or not. During training, participants were blindfolded and learned to perform the arm movements corresponding to the point light figure with a phase difference of 270°. Subsequently, participants were asked to perform the same visual discrimination task as initially applied. The results indicated that participants showed improved recognition of those actions learned during the training (270° phase difference). Furthermore, the recognition performance was strongly correlated with the performance accuracy of the learned movements. These results demonstrate that novel acquired action knowledge has a direct and highly selective impact on visual action perception, independent of visual feedback during the learning period.

In a further study, Marshall et al. (2009) investigated whether brief experience with novel drawing actions would have an influence on µ-rhythm desynchronization during observation of the same actions. To this end, participants were presented with videos showing unfamiliar drawing actions, half of which have been imitated by participants. Results indeed showed a desynchronization in the upper alpha band (11 – 13 Hz) at mid-frontal regions during action observation for imitated drawing actions only. Additionally, higher accuracy in imitation was significantly correlated with stronger bilateral desynchronization of the lower µ band (8-10 Hz). In a similar study, Quandt et al. (2011) replicated these findings, showing stronger frontal µ-rhythm desynchronization for trained drawing actions compared to novel drawing actions. Furthermore, participants' imitation performance was better for trained movements compared to novel movements.

Taken together, these results indicate that even a brief period of training, and therefore only sparse experience, affects the perception of actions and underlying neurophysiological processes. Since we intend to measure action understanding via predictive eye movements, studies investigating the impact of short-term experience on eye movements would be of particular relevance. However, little is known so far whether brief motor experience has an impact on gaze behavior during action observation. One study which sheds some light on this question was conducted by Taya and colleagues (2013). Here, it was investigated whether the degree of experience in tennis would modulate anticipatory gaze behavior when passively observing video-recorded tennis scenes. To this end, participants answered a questionnaire about their knowledge and experience with tennis and their scores were correlated with several measures of gaze behavior. It was found that participants with a higher experience score showed more accurate anticipatory eye-movements during the observation of tennis scenes, especially in uncertain situations. This indicates that own experience with an action can modulate gaze behavior during the observation of the specific action. However, although participants in this study have not been experts in the field of tennis, they still might have had an extensive amount of experience with playing tennis. Hence, it still remains unclear whether even brief periods of own experience would also affect anticipatory gaze behavior during action observation.

In conclusion, studies investigating the relationship between own experience with an action and the ability to understand this action during observation indicate that the degree of experience is positively related to the ability to predict the outcome of the same action when it is being observed. To date, the question how visual and motor experience exactly contribute to this relationship still remains unclear, although numerous studies argue that active motor experience has a more beneficial impact on action understanding than visual experience. This is in line with modern accounts of action perception that mostly suppose that actions are understood in terms of their activated motor programs or by motor simulation processes (see Chapter 2). However, in most studies, visual experience and motor experience have been confounded and within this work we do not intend to dissociate between these two types of experience.

For the present study it is rather important that even a brief period of experience affects the ability to understand actions during observation. Moreover, there is evidence that predictive gaze behavior can be influenced by own experience, although, to our knowledge, no study has systematically investigated the impact of short-term experience on anticipatory eye movements so far.

5 Empirical Evidence for Action Understanding in Children

In the previous sections, we mainly presented empirical evidence for action understanding in adults. However, in the last decades a growing number of researchers dedicated their interest to the investigation of action understanding in children. The main research questions in this area are from which age on children are able to understand others' actions, how the mirror neuron system contributes to action understanding in childhood, and whether action understanding is enabled and/or improved due to own experience.

Whereas most studies in this field concentrate on infants and toddlers, only a handful studies take preschoolers, school children or adolescents into account. Thus, most studies reviewed in the following section will report empirical evidence of action understanding in infancy. As in studies with adults, various methods measuring action understanding are implemented in studies with infants as well. Classically, studies applying behavioral measures (especially looking times in habituation paradigms) have been conducted to determine whether an infant understands goal-directed actions and is surprised by an unexpected action outcome or an irrational action (e.g., Gergely et al., 1995; Woodward, 1998). More recent studies increasingly draw back on eye tracking and neurophysiological methods with the purpose to identify whether direct matching processes comparable to those in adults are already present in infancy (e.g., Falck-Ytter et al., 2006; Marshall, Young, & Meltzoff, 2011).

In this section, we will first review empirical findings for the development of action understanding in infancy, followed by evidence for an action-perception matching process already present in infants, and finally we intend to shed some light on the importance of infants' own motor experience for the ability to understand observed actions.

5.1 The Development of Action Understanding in Infancy

Studies have shown that infants as young as five to six months are able to understand others' actions as goal-directed (e.g., Luo & Baillargeon, 2005; Woodward, 1998, 1999). For example, in a study conducted by Woodward (1998) infants observed how an agent repeatedly grasped one of two toys. Following this habituation phase, the positions of the toys were switched and the agent now either grasped the old toy at the new position or the new toy at the old position. The crucial idea behind this paradigm was that if infants were able to represent the observed grasping movement as goal-directed they should understand that the agent intended to grasp one specific toy. Hence, infants should be more surprised in test trials in which the agent grasped the new toy compared to test events in which the agent grasped the old toy. Thus, infants should look longer at new-toy/old-location trials compared to old-toy/new-location trials. The results indeed showed this pattern – infants were more surprised when the agent grasped the new toy and as a result they looked longer at these trials. This indicates that infants as young as six months were able to represent the observed actions as goal-directed rather than just having a representation about the position of the agent's arm. In a second control experiment, the impact of a non-human agent was investigated and results indicated that infants did not discriminate between the two types of test events when a mechanical claw performed the grasping actions. This indicates that human agency might play a crucial role in infants' action understanding.

In a further study, Woodward (1999) investigated purposeful and non-purposeful actions in a similar habituation paradigm. Here, infants either observed an agent grasping one of two toys or touching the toy with the back of the hand. Results indicated that 5-months-old and 9-month-old infants only looked significantly longer to new-toy/old-location trials in the grasping condition, whereas their looking times were comparable for both test events in the back-of-hand condition. This indicates that infants as young as five months are also able to interpret an action as purposeful and non-purposeful.

Subsequent experiments applying modified versions of the classical Woodward paradigm (1998) further investigated influential factors on infants' interpretation of goal-directed actions. Results indicated for example that infants were able to consider the agent's intentions to interpret actions as meaningful (Luo & Baillargeon, 2007), that salient action effects facilitated their interpretation of goal-directed actions (e.g., Jovanovic et al., 2007; Király, Jovanovic, Prinz, Aschersleben, & Gergely, 2003), and moreover that infants as young as six months were able to interpret actions with salient action effects as goal-directed, even when they were presented on a video-screen (Hofer, Hauf, & Aschersleben, 2007).

One aspect that is controversially discussed in the literature is infants' interpretation of goal-directed actions performed by non-human agents. Whereas some researchers emphasize the importance of a human agent for infants' action understanding (e.g., Kanakogi & Itakura, 2011; Meltzoff, 1995; Woodward, 1998), others state that even young infants are able to interpret actions of non-human agents as goal-directed (e.g., Gergely et al., 1995; Kamewari et al., 2005; Luo & Baillargeon, 2005). According to the first view, infants' ability to interpret others' actions as goal-directed is assumed to develop as a result of their early interaction with human agents. Hence, infants are supposed to first attribute goals to human agents, and then gradually extend to other agents. In contrast, the latter view supposes that infants attribute goals to both human and non-human agents whenever they identify them as agents. In accordance with this idea, crucial features (e.g., self-propulsion) have been determined that seem to indicate agency, and which enable infants to identify even simple physical shapes (e.g., a circle) as agents (Gergely & Csibra, 2003). A study conducted by Luo and Baillargeon (2005) intended to shed light on this issue by investigating 5-months-old infants with a modified version of the Woodward paradigm (1998). Here, the agent was a box that moved across the floor of an apparatus in a self-propelled manner (agency cue) prior to habituation trials. During habituation trials, a cylinder and a cone were placed on the left and right sides of the apparatus and the box repeatedly moved towards the cone. During test trials the positions of the cylinder and cone were switched and the box moved either toward the cylinder (new goal) or to the cone (old goal). Results indicated that infants looked significantly longer when the box approached the cylinder, suggesting that they were able to identify the box as a non-human agent that acted in a goal-directed manner. Hence, by providing sufficient agency cues, infants as young as five months are able to attribute goal-directedness to both human and non-human agents.

Throughout the first year of life, infants' action understanding rapidly improves in such ways that nine- to 11-months-old infants are able to subdivide action sequences into meaningful action steps (D. A. Baldwin, Baird, Saylor, & Clark, 2001), indicating that they are able to represent action structures of increasing complexity. Moreover, by the end of the first year of life, infants take social cues (e.g., gaze or pointing) into account in order to interpret others' intentions (Phillips, Wellman, & Spelke, 2002; Tomasello, Carpenter, & Liszkowski, 2007). Even more strikingly, infants as young as 12-months have been demonstrated to show an early mentalistic understanding of others' actions in an imitation study. Although observing the agent failing to reach the intended goal during the presentation phase, infants were able to correctly infer the agent's intentions and imitated the action in a successful manner (Nielsen, 2009). This is in line with an earlier imitation study conducted by Carpenter, Akhtar and Tomasello (1998) demonstrating that infants between 12 and 15 months are able to discriminate between actions that were intentionally or accidentally executed (indicated by verbal cues of confidence ("There!) or surprise ("Whoops!")). Moreover, by the age of 14 months infants selectively imitate actions dependent on the perceived rationality during presentation (Gergely et al., 2002). Thus, infants in the second year of life are able to integrate information about the agent (e.g., human vs. non-human), social cues (e.g., gaze) and the rationality of actions in order to infer others' actions goals.

Nevertheless, although it is evident, that infants are able to understand the intentional and goal-directed structure of actions early in life, it is still more or less unclear how this ability emerges and what the origins of this ability are. To date, attempts to answer these questions range from nativist positions that suppose an inherent ability to understand others' goal-directed actions (e.g., György Gergely & Csibra, 2003; Király et al., 2003) to positions that emphasize the role of own experience for the ability to understand others' actions (e.g., Gerson & Woodward, 2010; Meltzoff, 2005). Since studies in favor of these views are rarely longitudinal it is almost impossible to disentangle developmental changes, which makes it difficult to determine whether the ability to understand others' actions is inhered or caused by own experience. However, analogous to findings in adults (e.g., Aglioti et al., 2008), own experience with an action is considered to be related to action understanding in infants as well. This notion emerged due to an apparent connection between the development of infants' action competencies and their ability to understand these actions performed by others at about the same age. For instance, infants begin to produce goal-directed grasps between four to five months (e.g., Bertenthal & Clifton, 1998), and are able to understand goal-directed grasping actions at around the same age (Woodward, 1998). The same relation exists between the emerging ability to engage in joint attention between nine and 12 months (Carpenter, Nagell, & Tomasello, 1998), and the ability to interpret gaze and pointing as goal-directed (e.g., Woodward, 2003). Moreover, both the ability to produce goal-directed action sequences (Bates, Carlson-Luden, & Bretherton, 1980) and the ability to subdivide action sequences into meaningful action steps (e.g., Baldwin et al., 2001) develop between nine to 12 months of age. Overall, these findings suggest a strong link between infants' own action competencies and their ability to understand others' actions. Before we further elaborate on the impact of own experience on action understanding in children in Section 5.3, we will review current findings of studies applying neurophysiological or eye tracking methods in order to shed light on action understanding in the developing child.

5.2 Action Understanding

As we have already outlined in previous sections of this work, contemporary theoretical accounts as well as empirical findings in adults propose a tight link between action execution and action perception in adults (see Schütz-Bosbach & Prinz, 2007 for a review). Accordingly, some researchers suggested that both action execution and action observation are already intrinsically linked in the developing child (Baldwin, 1897; Piaget, 1953). With growing evidence for the coupling between action execution and the understanding of others' actions in adults, researchers increasingly started to conduct congruent studies with infants and toddlers. A well-known and broadly investigated field in which the link between action perception and action execution becomes obvious in young children is *imitation* (cf. Herwig, 2014). Imitation is defined as the acquisition of new behavior due to the mere observation of a model demonstrating this behavior (cf. Daum & Aschersleben, 2014). Meltzoff (2005) claims that imitative behavior occurs because of an innate coupling between action and perception that allows even newborns to imitate facial gestures of adults (Meltzoff & Moore, 1977). In a study conducted by Meltzoff (1988) 14-months-old infants' delayed imitation was investigated. To this end, six actions were demonstrated by an adult model and after a one-week delay the infants' imitation of these actions was tested. The results indicated that infants in the imitation condition produced significantly more target actions compared to infants in a control group who were not exposed to the target actions. Hence, the mere observation of an action performed by someone else resulted in the production of the same action in 14-months-old infants. Accordingly, it was concluded, that action and action perception are already tightly linked in infancy. This led to the idea that measures of action understanding which are usually applied in studies with adults (see Section 4.2 for further information), should also provide information about action understanding in the developing child. As a consequence, methods like EEG, fMRI, or eye tracking were increasingly applied in studies with infants and toddlers in order to investigate their ability to understand others' actions. The underlying assumption beyond these experiments is that the link between action execution and action understanding is realized by a direct matching process guaranteed by the human mirror neuron system (e.g., Gallese et al., 1996). In the following subsections, according studies that provide evidence for a direct matching process in children are reviewed.

5.2.1 Empirical Evidence from Studies applying Neurophysiological Methods

The presence of a mirror neuron system from birth on was recently discussed (see Lepage & Théoret, 2007 for a review), and several studies provide evidence for the existence of a direct matching process in infants. For instance, neurophysiological studies demonstrated that infants as young as six months showed µ-rhythm suppression and significantly higher cortical activation in motor areas when they observed others' goal-directed actions (Nyström, 2008; Shimada & Hiraki, 2006). Shimada and Hiraki (2006) were first to show that infants' brain activity during action observation was comparable to their brain activity during action production. By applying near-infrared spectroscopy (NIRS), the authors identified infants' motor areas while they were playing with a toy. Subsequently, they either observed an adult playing with the toy or the toy moving on its own. Results indicated that infants' brain activity during observation was comparable to that during their own playing actions. Crucially, motor areas were selectively activated when infants observed someone else manipulating a toy, whereas a self-propelled toy did not cause an activation in the same brain regions. This study supports the assumption that observed actions are directly mapped on own motor representations, even in infancy. Further studies replicated these findings with nine- to 16-month-old infants (Lepage & Théoret, 2006; Marshall et al., 2011; Southgate, Johnson, Osborne, & Csibra, 2009; Stapel, Hunnius, van Elk, & Bekkering, 2010; van Elk, van Schie, Hunnius, Vesper, & Bekkering, 2008). For instance, Southgate et al. (2009) investigated 9-months-old infants' µ-rhythm desynchronization during the execution and observation of reaching actions. Results revealed a µ-rhythm desynchronization for both executing and observing grasping actions. Marshall et al. (2011) replicated this finding in a further EEG study, and additionally reported that the magnitude of µ-rhythm desynchronization during action execution and action observation is smaller for infants than for adults, indicating a developmental change in this measure. Further studies (e.g., Stroganova, Orekhova, & Posikera, 1999) have shown that not only the magnitude of the µ-rhythm changes over development, but moreover, that the frequency range of the µ-rhythm is lower (6-9 Hz) in infants than in adults (8-13 Hz). For further information about developmental changes of the µ-rhythm in infancy, see Marshall and Meltzoff (2011).

Beyond infancy, much less research investigating action understanding via neurophysiological methods has been conducted. To our knowledge, only one study (Meyer, Hunnius, Elk, Ede, & Bekkering, 2011) investigated 3-year-old preschoolers' µ-rhythm desynchronization during a joint action game. Somehow not surprising, the results found were equivalent to those found in studies with infants and adults – namely, a desynchronization of the µ-rhythm during both being actively engaged in the game and observing the interaction partner being engaged in the game.

Kilner and Blakemore (2007) discussed the development of the mirror neuron system in a broader age range – from infancy to adolescence. The authors suggest that pruning processes might modulate the functionality of the mirror neuron system far beyond early childhood, and that especially the connectivity between the mirror neuron system and other brain regions might develop in adolescence. Nevertheless, to date, no study has systematically investigated the development of the mirror neuron system so far, so it remains unclear whether, when, and how quantitative and qualitative changes occur. Moreover, while some authors proposed that a mirror neuron system is already established at birth by addressing imitative abilities of newborns (Meltzoff & Moore, 1983), no studies with human or primate newborns have been conducted to support this assumption so far.

Taken together, the studies outlined above indicate that a mirror neuron system is already present in early infancy and thus, a direct matching process is assumed to be functional from as early as six months after birth. Moreover, developmental changes of the mirror neuron system up to adolescence are assumed, although tangible evidence is missing so far.

5.2.2 Empirical Evidence from Studies applying Eye Tracking

Since the finding that anticipatory eye movements can be taken as indicators of a direct matching process (Flanagan & Johansson, 2003) was published, a number of infant studies intended to disentangle the relationship between anticipatory eye movements and action understanding in infancy. A first study in this field investigated 6- and 12-months-old infants' and adults' anticipatory eye movements during the observation of video-recorded transportation actions. Here, an actor moved three toys from one side of the screen into a bucket on the other side of the screen. Moreover, a "self-propelled" and a "mechanical" control condition were implemented for 12-months-old infants and adults, in which the toys moved to the bucket themselves, either in a natural motion trajectory or in a smooth-curved motion trajectory, respectively. Results revealed that in the human agent condition 12-months-old infants and adults directed their gaze predictively toward the action goal (the bucket), whereas 6-months-old infants' gaze was rather reactive. Moreover, in the two control conditions, infants' gaze was rather reactive, indicating that the interaction between a hand and the object was necessary for them to understand the action goals (Falck-Ytter et al., 2006). This result is in contrast with looking time studies indicating that infants are able to attribute goal-directedness to non-human agents in the same age range (e.g., Gergely et al., 1995; Luo & Baillargeon, 2005). However, this dissociation again demonstrates that different measures of action understanding might reflect different processes underlying the ability to infer others' goals. Nevertheless, the study by Falck-Ytter et al. (2006) provided first evidence that infants' predictive gaze behavior is related to their ability to understand others' actions, and thus indicates that a direct matching process is already present in infants.

A further study extended these results by investigating 10- to 11-months-old infants and adults. Here, both eye movements and hand movements were assessed and results indicated that eye movements preceded hand movements during both own actions and observing someone else performing a grasping action. However, during observation trials, adults were significantly faster in anticipating the action goal compared to infants. The authors explained this finding as evidence that the ability to perform own actions develops ahead of the ability to understand others' actions in infancy (Rosander & von Hofsten, 2011).

Recently, influential factors that might affect infants' anticipatory eye movements during action observation have been identified (Henrichs et al., 2012; Henrichs et al., 2014). Henrichs et al. (2012) were able to show that 12-months-old infants' anticipatory gaze shifts were significantly earlier when the observed agent reached for a large object compared to reaching for a small object. It was concluded that salient action goals facilitated infants' understanding of goal-directed actions. Moreover, a further study revealed that infants' were more accurate in anticipating an action goal during the observation of actions when the same goal was repeatedly approached by the agent's hand, compared to actions in which the agent reached for different action goals across trials. Hence, infants' understanding of others' actions is affected by the goal certainty of observed actions. A certain goal facilitates infants' ability to predict the action outcome (Henrichs et al., 2014).

Like neurophysiological studies, eye tracking studies investigating preschoolers', school children's or adolescents' action understanding are rare. One study ventured an attempt by comparing 4-year-old children's and adults' predictive eye movements during the observation of how a person prepared a snack. Results revealed no significant differences between adults' and preschoolers' predictive eye movements. Hence, no developmental changes could be identified within this study (Morgante et al., 2008). A further study considered developmental changes of saccadic eye movements by investigating 6- to 15-year-old children within several paradigms. In contrast to the study outlined above, developmental changes in the latency of saccadic eye movements became apparent. With increasing age up until 12 years, children's latencies of saccadic eye movements became shorter, whereas the peak velocity of saccades remained constant over all age groups (Bucci & Seassau, 2012). To our knowledge, this was the only study investigating developmental changes in saccadic eye movements over a broad age range. Nevertheless, the results of this study provide important evidence that the control of saccadic eye movements develops up to early adolescence. However, further studies are required to disentangle the relationship between anticipatory eye movements and action understanding across development.

5.3 Impact of Experience on Action Understanding

To date, several researchers claim that own experience with an action provides infants with knowledge about these actions and their caused effects, which should facilitate their ability to understand these actions performed by others (Gerson & Woodward, 2010; Hunnius & Bekkering, 2014; Meltzoff, 2005). In contrast to adults, there is no chance to investigate the effects of expertise in infancy. However, in order to investigate the relationship between own experience and action understanding in infants researchers draw back on two possibilities: (1) correlational studies that relate infants' own action abilities to measures of their action understanding during observation, and (2) interventional studies that modify infants' own action experience, and subsequently measure the effect of an intervention on infants' action understanding.

5.3.1 Evidence from Correlational Studies

As already mentioned in Section 5.2, there is an apparent connection between the development of action capabilities in infancy and the ability to understand these actions in others. Crucially, the development of new capabilities underlies huge individual variability in infancy, meaning that infants of the same age have varying amounts of experience with several actions. This allows researchers to either compare infants who have already mastered to perform a new action with infants that are not yet able to perform this new action (e.g., Loucks & Sommerville, 2012), or to correlate individual action abilities with indicators of action understanding (e.g., Gredebäck & Kochukhova, 2010).

For instance, Sommerville and Woodward (2005) habituated 10- and 12-months-old infants to a means-end action. Here, an agent repeatedly pulled one of two cloths in order to reach a toy. During test events, the toys were switched and the agent could either pull the new cloth in order to reach the old toy or to pull the old cloth in order to reach a new toy. Results indicated that 12-months-old infants looked longer at old cloth/new toy events, indicating that they understood the intention of the agent. Crucially, a positive correlation was found between infants' own ability to perform this means-end task and their looking time during old cloth/new toy trials. Interestingly, infants that were not able to produce this means-end task looked longer at new cloth/old toy trials, indicating that they were not able to represent the final goal of the action but rather represented the agent's action on a lower level, namely, that the agent intended to grasp the same cloth. Hence, they were surprised, when the agent grasped the new cloth. Thus, the own ability to perform means-end tasks, enabled infants to understand these action performed by others. Other studies have found further correlations between infants' own action capabilities and indicators of their understanding of others' actions (Gredebäck & Kochukhova, 2010; Kanakogi & Itakura, 2011; Kochukhova & Gredebäck, 2010; Loucks & Sommerville, 2012; van Elk, van Schie, Hunnius, Vesper, & Bekkering, 2008). For instance, van Elk et al. (2008) investigated 14- to 16-months-old infants' μ-rhythm during the observation of videos in which either crawling or walking infants were shown. Results revealed a correlation between infants' own crawling experience and the degree of μ-rhythm desynchronization during the observation of crawling infants, even when controlling the analyses for age. Moreover, in a recent study, the relationship between 4- to 6-months-old infants' manual dexterity skills and their cortical activation during the observation of manual actions has been investigated by applying functional near-infrared spectroscopy (fNIRS). Results indicated that the degree of cortical activation during action observation strongly correlated with infants' manual fine motor abilities (Lloyd-Fox, Wu, Richards, Elwell, & Johnson, 2015). Hence, the impact of own experience affects infants' brain activity in sensorimotor areas during action observation.

Concerning predictive eye movements, Gredebäck and Kochukhova (2010) reported a strong correlation between 25-months-old toddlers' ability to solve a puzzle and their goal-directed predictive eye movements when they observed someone else solving a similar puzzle. Crucially, a second age group of 18-

months-old toddlers was tested, but no significant correlation was found for this group. The authors explained this finding due to the observation, that 18-months-old toddlers were not able to solve the puzzle, hence, they were missing crucial own experience in order to understand others' puzzle actions. A similar result was found in a study comparing 10-months-old infants' and adults' goal-directed eye movements when observing feeding actions and combing actions. Although in both actions the effector (hand) and the goal (head) were the same, infants were able to only predict the action goal of feeding actions, whereas adults predicted the combing actions as well. This finding indicates that infants were able to understand the feeding action only due to their own experience with this action (Kochukhova & Gredebäck, 2010). Moreover, it has recently been shown, that infants' understanding of interactions between two individuals is also strongly dependent on their own experience with interactive actions (Henderson, Wang, Matz, & Woodward, 2013; Schmitow & Kochukhova, 2013).

Taken together, the findings outlined above indicate that the ability to understand others' actions is strongly linked to own action production abilities in early childhood. However, although the relationship between own experience and action understanding is apparent, it still remains unclear whether own experience *causes* improved action understanding in infants. To this end, interventional studies have been conducted, which will be reviewed in the next section.

5.3.2 Evidence from Interventional Studies

The findings outlined above gave rise to the assumption that active experience is the crucial factor for action understanding. In order to shed more light on this suggestion, interventional studies that give infants the possibility to perform a new action have been conducted. One prominent study in this field was conducted by Sommerville, Woodward and Needham (2005). Here, a group of 3-months-old infants, who were not able to produce goal-directed grasping actions yet, were given the opportunity to "grasp" toys by wearing sticky mittens. A second group of 3-months-old infants did not receive an active intervention, but observed another person grasping the toys. Subsequently, a modified version of the Woodward paradigm (1998) was implemented. Results indicated, that infants of the active experience group looked longer to new goal events, compared to those infants who merely observed a person acting. Moreover, looking times were correlated with infants' engagement during the active experience phase. These results impressively illustrate that experience with a completely new action rapidly improves the understanding of subsequently observed actions in very young infants. A similar finding was obtained within a study investigating 12-months-old infants' anticipatory gaze behavior following the spontaneous engagement in a containment activity. A strong correlation between infants' own actions and their gaze latencies has been found (Cannon, Woodward, Gredebäck, von Hofsten, & Turek, 2012). Several further studies that were recently conducted found beneficial effects of active experience on the ability to perceive others' actions, indicating that own experience enables infants to understand others' action (Cannon et al., 2012; Gerson, Schiavio, Timmers, & Hunnius, 2015). However, most studies reported here did not apply a systematic training, but rather gave infants the possibility to explore objects on their own for a while in order to gain active experience with possible actions. Nevertheless, one study trained 8-month-old infants for one week to use a rattle for five minutes per day that produced a specific sound. Moreover, infants were also presented with another sound for five minutes per day not related to any action. After training, infants were presented with the two familiar sounds and a further unfamiliar sound while an EEG was recorded. Results showed a stronger µ-rhythm desynchronization over motor areas when infants listened to the sound caused by the rattle, compared to the other two sounds (Paulus, Hunnius, van Elk, & Bekkering, 2012). This indicates that own experience with an action directly influences the perception of action related effects. However, it has to be mentioned, that the second sound was merely presented to infants without being related to an action. Hence, the results of this study do not discriminate between the impact of active and observational experience. To overcome this issue, a further training study of this research group investigated the impact of observational experience on µ-rhythm desynchronization in 9-months-old infants. To this end, infants observed their parents using a rattle for five minutes per day over a week, or listened to the same sound as in the previous study. Results of this study revealed that this training also led to a stronger μ-rhythm desynchronization when infants listened to the sound of the rattle, compared to the sound that was not action related (Paulus, Hunnius, & Bekkering, 2013). However, according to these studies it remains unclear, whether advantages in action understanding emerge due to motor experience, observational experience or an interaction between both. This problem is already known from studies investigating adult motor experts (see Section 4.3 for further information), and solved by studies that systematically manipulated the types of experience provided.

Recently, researchers from developmental psychology addressed this issue as well and intended to disentangle the influence of active motor experience and observational experience (Gerson, Bekkering, & Hunnius, 2015; Gerson & Woodward, 2013, 2014). For example, Gerson et al. (2015) applied both an active training and an observational training with 10-months-old infants. Infants were trained for one week to perform a means-end task on one toy, and moreover observed their parents performing a means-end task on another toy. Crucially, both actions led to two distinct sounds and were unfamiliar to the infants. After the completion of training sessions, infants' EEG was recorded while listening to both sounds. The results of this study revealed a greater desynchronization of infants' μ-rhythm when listening to the sound of that action that was actively trained, compared to listening to the sound of the observed action. Moreover, the degree of μ-rhythm desynchronization was directly related to infants' performance during the training sessions. Hence, this study provides evidence for an advantage of motor experience over observational experience.

Taken together, the studies outlined above demonstrated that active motor experience with an action has a superior effect on infants' ability to understand others' actions, whereas the role of observational experience remains somehow ambiguous. Nevertheless, own experience with an action definitely has a beneficial effect on action understanding in infants. Moreover, it has been shown – even for infants – that short-term experience with the own production of actions led to an increased ability to understand the same actions in others. This notion is of particular relevance for the present work, since we intend to investigate the influence of short-term experience in preschoolers and older children. However, to our knowledge, no studies with children older than three years exist that investigated the influence of experience on action understanding measured via gaze behavior. This gap needs to be filled because we do not know yet, whether the processes underlying action understanding develop continuously throughout childhood or whether these processes are fully developed and comparable to those of adults at a special age. Only a few studies shed some light on the development of anticipatory skills during adolescence, and one of them reported no differences between 11-13 year old teenagers and 14-16 year old teenagers, but differences between teenagers and adults (e.g., Barlaam, Fortin, Vaugoyeau, Schmitz, & Assaiante, 2012). Hence, there is some evidence that the ability to understand others' actions develops throughout childhood and adolescence and is object of maturation and refinement processes. Within our study, we aim to fill this gap by investigating the influence of task-specific short-term experience on action understanding in preschoolers and school children in order to disentangle whether developmental changes occur between different age groups.

6 Outline of the Project

The aim of the present thesis is to investigate the influence of short-term experience on action understanding, precisely on anticipatory eye movements and pupil dilation. Moreover, we aim to disentangle whether the ability to understand others' actions gradually develops throughout childhood or whether it is fully established already in preschool children.

According to the previous sections it can be summarized that four essential aspects can be taken as the basis for the present work: *First*, in accordance with modern theoretical accounts (e.g., direct matching account) and recent research findings (see Schütz-Bosbach & Prinz, 2007 for a review), action execution and action understanding are supposed to be tightly linked. *Second*, anticipatory eye movements and pupil size changes have been demonstrated to be indicators of action understanding during action observation (e.g., Flanagan & Johansson, 2003). *Third*, own motor experience with an action shapes action understanding during the observation of another person performing the same action (e.g., Mulligan & Hodges, 2013) and *fourth*, the aforementioned three points are true for adults as well as children.

Based on these four premises, the present work addresses three main research questions:

(1) Does short-term experience with an action have an impact on anticipatory eye movements during the observation of the same action?

To date, little is known about the impact of a relatively short amount of own experience with an action on gaze behavior during action observation. To our knowledge, only one study shed some light on this question by showing an influence of varying amounts of experience in playing tennis on predictive gaze behavior (Taya et al., 2013). However, although the aforementioned study delivers some valuable evidence for this thesis, research still lacks to answer the question whether even a brief period of experience affects anticipatory gaze behavior during action observation. Nevertheless, this is an important question which needs to be answered to further describe the functions of direct matching processes underlying action understanding. Hence, we intent to investigate whether a short amount of own experience would activate task-specific action plans that modulate anticipatory eye movements during action observation in such ways that participants would direct their gaze significantly earlier towards the action goals of the observed action.

Moreover, we aimed to disentangle how task-specific this effect would occur. We questioned whether experience with one specific action would also enhance action understanding of a similar action which shared several features with the trained action, or if this effect would only enhance action understanding for the trained action. Previous research has shown on the one hand that own experience with an action specifically enhances the understanding of the same action (e.g., Casile & Giese, 2006), but on the other hand, that experience in one domain can enable successful transfer to a related domain (Causer & Ford, 2014; Rosalie & Müller, 2014), depending on the similarity between both domains (Barnett & Ceci, 2002) and the level of expertise – with a higher level of expertise leading to a more successful transfer (Rosalie & Müller, 2012). According to these findings, it still remains unclear, whether short-term experience with one action only enhances action understanding of exactly the same action due to a task-specific activation of action plans, or whether transfer to other tasks occurs in spite of the short period of training, and therefore, a relatively low level of expertise.

In order to answer these questions, we employed a block stacking task, similar to that used in the study by Flanagan and Johansson (2003), in a pre-post eye tracking design. Between two blocks of action observation, participants either performed the block stacking task, puzzles, or a pursuit rotor task in order to gain own active experience. We assumed that brief manual experience with a block stacking task should activate task-specific action plans supporting a direct matching process during the observation of the same action. Further, puzzles were applied as a first control task with the purpose to activate similar action plans comparable to those of the block stacking task, as both tasks share several features. By contrast, the pursuit rotor task (which required participants to follow a moving red dot on a circular track with their index finger) was employed as a second control task and was considered to activate action plans different from those activated by the block stacking task and puzzles. We hypothesized that experience with the block stacking task and puzzles but not the pursuit rotor task would lead to shorter gaze latencies during observation of post-test trials.

The corresponding study will be described in further detail in Chapter 2 of this dissertation (Möller, Zimmer, & Aschersleben, 2015).

(2) Does short-term experience with an action have an impact on pupil size changes during the observation of the same action with an unexpected action outcome?

The second aim of the present work was to investigate whether short-term experience would have a task-specific impact on pupil size changes during the observation of actions with an unexpected outcome. Typically, pupil size changes provide information about the individuals' expectations in a certain situation, specifically when expectations are violated. Several recent findings demonstrated that the violation of existing expectations leads to a state of surprise in an individual which is measurable via pupil dilation (e.g., Gredebäck & Melinder, 2010; Morita et al., 2012). For the present work this implies that the observation of unexpected action outcomes should lead to an increase in pupil diameter in the observer. However, the influence of own experience with an action on pupillary responses in association with unexpected action outcomes during action observation is still unknown. To our knowledge, only one study sheds a little light on the question whether own experience has an influence on pupil dilation during observation: Morita et al. (2012) showed that adults' pupil size changed when observing impossible human body movements, whereas infants' pupil size did not indicate any change. This might be interpreted as first evidence that a higher amount of own experience with human body movements leads to a stronger surprise in the observer when expectations about possible body movements are violated.

According to these findings, in the second study of this thesis we questioned whether pupil size changes during the observation of unexpected action outcomes would vary as a function of own experience. To this end, we measured participants' pupil size changes during the observation of successful and unsuccessful block stacking task trials within the same design as applied in the first study. Crucially, trials in which the block stacking task was performed in an unsuccessful manner were considered to violate participants' expectations about the final state of the block stacking task, and should therefore result in pupil size changes. Moreover, participants received a short period of own action experience with the above mentioned three distinct manual tasks. In the case that own experience would have a task-specific influence on pupil size changes, a greater change in pupil size should occur when participants were trained to perform the block stacking task, compared the control tasks. The corresponding study will be described in further detail in Chapter 3 of this thesis.

(3) How does the influence of own action experience on action understanding change during childhood?

The third main question of this thesis was to disentangle how the influence of own short-term experience on anticipatory eye movements would change during childhood. Although previous studies have shown, that own action experience modulates the latency of goal-directed anticipatory saccades in infants and toddlers (Gredebäck & Kochukhova, 2010; Kochukhova & Gredebäck, 2010), nothing is known so far about the developmental course of this effect. Moreover, the aforementioned studies considered actions with which infants or toddlers have a rather high amount of experience, like feeding actions or solving puzzles, respectively. Hence, it is still unclear whether even short-term experience with a specific task would also modulate anticipatory gaze shifts during action observation in children. This question is of particular relevance, because to date it is still unknown how direct matching processes develop during childhood. Whereas some studies argue that a functional mirror neuron system exists even in newborns (Meltzoff & Moore, 1983, Meltzoff & Decety, 2003), other studies suggest that own experience modifies this mirror neuron system and modulate its functioning throughout childhood (Shimada & Hiraki, 2006; van Elk et al., 2008). Moreover, it is under debate how much experience is necessary to activate direct matching processes (see Lepage & Théoret, 2007 for a discussion).

Accordingly, we intended to investigate whether short-term experience would affect anticipatory eye movements during childhood and moreover, whether this effect would change during development. To this end, we investigated children of three age groups (4-6 years, 8-10, years, 11-14 years) with a child-oriented version of the aforementioned pre-post design which was applied in the study with adults.

We assumed that when a direct matching process was already fully functional in preschoolers they should direct their gaze significantly faster to action goals of the block stacking task after a task-specific short-term training, and no differences between the three age groups should occur. This study is described in further detail in Chapter 4.

Chapter 2: Effects of short-term experience on anticipatory eye movements during action observation

1 Research Questions & Hypotheses

The aim of the present study was to investigate the influence of short-term experience on predictive eye movements during action observation. Since anticipatory eye movements have been demonstrated to be indicators of a direct matching process (Flanagan & Johansson, 2003), we assumed that task-specific short-term experience with an action would activate underlying action plans and as a consequence should lead to shorter gaze latencies during the subsequent observation of the same task. Furthermore, we planned to disentangle whether only task-specific short-term experience would lead to shorter gaze latencies or whether experience with tasks similar to the observed action would also facilitate a direct matching process.

We employed a block stacking task, similar to that used in the study by Flanagan and Johansson (2003), in a pre-post eye tracking design. During pre- and posttest, participants watched short video clips showing an actor performing the block stacking task. Simultaneously, their eye movements were recorded by means of a Tobii T60 eye tracker. Intermediately, participants either performed the block stacking task, puzzles, or a pursuit rotor task. We assumed that brief manual experience with the block stacking task should activate task-specific action plans supporting a direct matching process during observation of post-test trials. Further, puzzles were applied as a first control task with the purpose to activate similar action plans comparable to those of the block stacking task, as both the block stacking task and puzzles were grasping tasks with four wooden objects which were moved from a fixed starting location to a fixed goal position. By contrast, the pursuit rotor task was employed as a second control task, which required participants to follow a moving red dot on a circular track with their index finger. We assumed that experience with the pursuit rotor task would activate action plans different from those activated by the block stacking task and puzzles. Therefore, we hypothesized that experience with the block stacking task and puzzles but not the pursuit rotor task would lead to shorter gaze latencies during observation of post-test trials. Additionally, participants were trained in two ways: with anatomical congruency (performing exactly the same action with the same hand) and with spatial congruency (performing the action with the same hand, but spatially congruent with the observed action). Hence, subjects either performed a backhand or a forehand movement during the training. By manipulating the spatial congruency between performing and observing the block stacking task but keeping the effector (i.e. the actor's and observer's hand) constant, we intended to find out whether different congruency conditions would affect anticipatory eye movements.

2 Methods

2.1 Participants

A total of 150 right-handed university students participated in the present study. All participants were recruited and tested at Saarland University and had normal or corrected-to-normal vision. Each participant was assigned to one of five experimental groups (1. Block Stacking Task_Forehand, $N = 30$, 15 males, $M_{age} = 25.07$ years, $SD = 3.65$ years; 2. Block Stacking Task_Backhand, $N = 30$, 15 males, $M_{age} = 23.97$ years, $SD = 2.47$ years; 3. Puzzle_Forehand, $N = 30$, 15 males, $M_{age} = 22.58$ years, $SD = 2.72$ years; 4. Puzzle_Backhand, $N = 30$, 15 males, $M_{age} = 24.49$ years, $SD = 2.34$ years; 5. Pursuit Rotor Task, $N = 30$, 15 males, $M_{age} = 23.10$ years, $SD = 3.48$ years). An additional $N = 24$ participants were excluded from analyses due to insufficient gaze recordings ($N = 18$), technical errors ($N = 2$), or experimenter errors ($N = 4$). Participants were paid for participation and gave their informed consent prior to taking part. The study was conducted in accordance with the standards specified in the 1964 Declaration of Helsinki.

2.2 Materials & Stimuli

Participants' eye movements were recorded by means of a Tobii T60 eye tracker (17" TFT Monitor, sampling rate 60 Hz, accuracy 0.4°, Tobii, Sweden, Stockholm) while they were observing the experimental videos. All stimuli were short video clips (AVI format, 25 Hz, 1280 x 1024 pixels, duration between 8 – 11 s) showing a male hand performing a block stacking task , which consisted of four single grasping movements (Grasping Movement 1 – Grasping Movement 4, see **Figure 3 b-e**). Hereby, the male actor was video-recorded (Canon Legria FS200) from a frontal, third-person perspective at a distance of 60 cm. Four wooden blocks of different length (L = 2.5 cm / 3.5 cm / 4.5 cm / 5.5 cm), but with identical width (W = 2.5 cm) and height (H = 2.5 cm) were placed on a wooden work surface (L = 42 cm, W = 8 cm, H = 8 cm) lying on a table. The actor sat beside the table and grasped the wooden blocks with his right hand from above to stack the blocks (from the widest to the narrowest) away from him (backhand movement) to the other end of the work surface. From the participants' view, the four blocks were aligned side by side at the right edge of the surface in the beginning, and then stacked to the left end of the work surface. The background of the scene, the table, the work surface and the agent were covered with black velvet so that only the four wooden blocks and the hand and forearm of the actor were visible on the recordings (see **Figure 3**). A metronome (Korg Ma-30; 50 bpm) was used to induce a steady speed of the single grasping movements.

Four different video-clips were recorded. The first one showed a completely performed block stacking task (test trial, see **Figure 3** a-e) and three further clips showed modified versions of the block stacking task (non-completion trials). Hereby, the agent put one, two or three wooden blocks on top of each other, but put the last, second last, or third last block in the wrong direction to the start-edge, respectively (see **Figure 3** f). After this movement, the video clip ended immediately so that the building of a complete tower failed. The non-completion trials were excluded from analysis as they only served the purpose to keep the participants alert during the experiment.

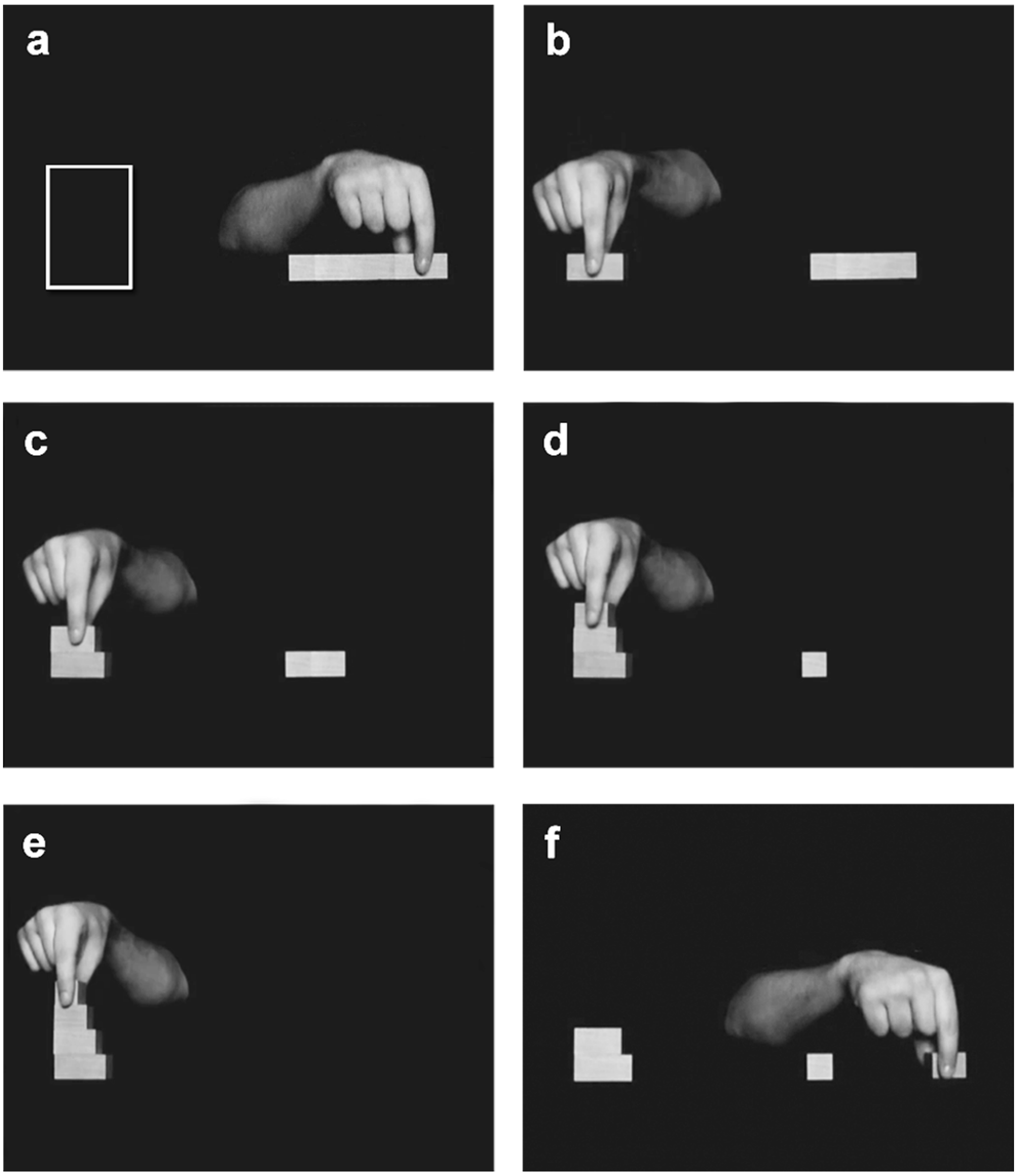

Figure 3. Video stimuli showing actor performing a block stacking task. a. Starting position (White rectangle shows AOI position. AOI was not visible for participants.), b. Goal position of grasping movement 1, c. Goal position of grasping movement 2, d. Goal position of grasping movement 3, e. Goal position of grasping movement 4, f. Goal position of grasping movement 3 in non-completion trial.

The four video recordings were digitally edited such that a central fixation point was added for 2,000 ms, followed by a still frame for 2,000 ms at the beginning of each video. At the end of each video-clip another still frame occurred for 2,000 ms, showing either the completely built-up tower or one of the three modified situations. Furthermore, the original sounds of the recordings were discarded. However, an artificial sound ('blopp', 200 ms) was added to the lifting movement of each wooden block and an action effect ('success sound' 1,600 ms) was added to the frames where the correctly built-up tower was visible. No action effect sound was inserted for non-completion trials. Six animal pictures (faces of mammals) with durations of 5,000 ms, and subsequent 4 beep-tones with durations of 5 ms accompanied by a black screen alternating with the original animal picture every 5 ms served as further attention grabbers[2]. The presentation of all stimuli and gaze recordings were controlled by Tobii Studio ™, Version 2.3.2.0.

Material for subject-performed tasks consisted of four wooden blocks (same as used for stimuli recordings) in order to perform the block stacking task. Furthermore, three simple puzzles (SIMM toys) were applied for the puzzles intervention. Puzzles consisted of four single wooden pieces, consistently recolored in blue, showing three animals (ladybug, elefant, and dolphin), and a wooden inlay form (L = 14.5 cm, W = 18 cm, H = 2.5 cm) in which the pieces should be placed (see **Attachment C**). Although puzzle pieces differed in shape from the wooden blocks of the block stacking task, they were of comparable size and weight. To realize the pursuit rotor task, a 17"-TFT monitor was positioned flatly on the desk in front of the participant showing a digital version of a pursuit rotor task (AVI format, 25 Hz, 800 x 600 pixels). A red dot (diameter = 2 cm) moved with a velocity of 5 sec/circuit ten times around a white circular track (diameter = 22.5 cm) on a black background.

2.3 Experimental Procedure

Each participant was tested during a single experimental session lasting approximately 30 minutes. Participants were seated at a desk 60 cm in front of the Tobii T60 eye tracker. The session started with the Manual Skills Scale of the M-ABC-2 (Petermann, 2011)[3]. Subsequently, the experiment proceeded

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[2] The attention grabbers and additional sounds were included in this design, as the same stimuli have been applied in a further study with preschoolers.

[3] Manual fine motor skills were measured by the Manual Skills Scale of the Movement Assessment Battery for Children (M-ABC-2; Petermann, 2011). These data are not considered further and are only mentioned for the sake of completeness.

with the first eye tracking phase in which participants should passively observe eight experimental trials (6 test trials, 2 catch trials) in a randomized order. After each second trial an attention grabber (mammal face) was shown, leading to three attention grabbers in the pre-test. Participants were instructed to pay full attention to the videos and to keep their hands still, while observing how the tower was built up. After completing the pre-test, participants were asked to perform one of three manual tasks in order to activate different action plans. Participants either performed a block stacking task in a backhand or forehand movement, puzzles in a backhand or forehand movement or a pursuit rotor task with their right hand. The block stacking task entailed stacking four wooden blocks (same as used for stimuli recordings) on top of each other in order to build up a tower. Hereby, the four wooden blocks were lined up either at a right or left location 20 cm in front of the participants. Locations were determined by two blue dots with a distance of 40 cm in-between. In the starting position, the widest block was placed on one of the two blue dots and the shorter ones were lined up pointing to the space between the two dots. Participants were asked to build a tower on either the left or right dot (depending on the starting position) with their right hand (see

Figure 4).

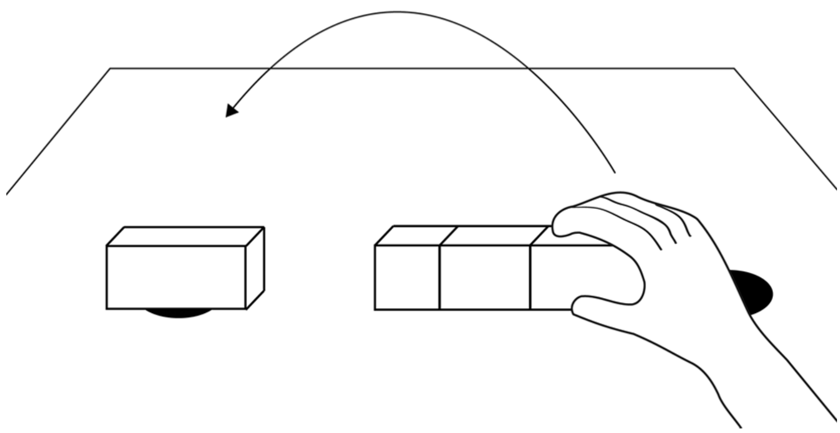

Figure 4. Illustration of participant performing a block stacking task in a forehand movement. Black dots indicate starting and goal positions.

Therefore, they either performed a forehand stacking movement or a backhand stacking movement. The Puzzle intervention involved three simple wooden puzzles. The setup for puzzles was similar to that applied to the block stacking task with puzzle pieces lining up either at the right or left blue dot pointing to the space between the two dots. The only difference between puzzles and the block stacking task was that the order of Puzzle pieces was randomized for every trial and participant. Therefore, compared to the block stacking task, the puzzles have not been completed in a fixed sequence, but instead with a new sequence in each repetition. Both the block stacking task and the puzzles were performed twelve times. Hereby, both tasks should be performed four times as accurately as possible, four times as fast as possible and four times as fast and accurately as possible in a blocked manner. During the Puzzle task, a different Puzzle was applied for each of the aforementioned instructions. The pursuit rotor task required participants to follow a red dot moving on a circular track with the index finger of their right hand for ten times. Participants were instructed to follow the moving dot as accurately as possible. They repeated the pursuit rotor task three times with a short break after each completion. Following the subject-performed task, the second eye-tracking phase took place, in which participants would again passively observe eight experimental trials (6 test trials, 2 catch trials) in a randomized order, with an attention grabber after each second trial. Participants were again instructed to pay full attention to the videos and to keep their hands still, while observing how the tower was built up.

2.4 Data Analyses

Gaze recordings of the six test trials were analyzed by using purpose-written software. Each test trial consisted of four single grasping movements. Therefore, we calculated gaze latencies for each grasping movement in each test trial. Latencies were calculated as the difference of the first fixation time on the area of interest (AOI, see **Figure 3** a) and the placement time of the wooden block at the goal position. Negative values indicate that participants' gaze arrived prior to the hand; positive values indicate that gaze arrived at the goal AOI after the block was placed there. For each grasping movement a maximum of six data points could be reached (one per trial). If a participant had less than three data points (e.g., because of insufficient gaze recording, blinks or no AOI-directed gaze behavior) in more than two grasping movements, the participant was completely discarded from analyses ($N = 10$).

Since the first grasping movement (the movement of the first block) showed a high number of missing values (19.4 % during pre-test, 19.8 % during post-test) and a high number of saccades with latencies higher than 100 ms (24.4 % during pre-test, 11.3 % during post-test), it was entirely discarded from analyses. This finding is in line with Flanagan and Johansson (2003), who demonstrated that participants' gaze shifts were delayed during the first grasping movement when observing another person performing a block stacking task. We assume that a certain time was required until participants fully directed their attention towards the ongoing action, hence, missing values and reactive saccades occurred to a higher degree.

Furthermore, we excluded remaining grasping movements having less than three data points from analyses (0.22 % during pre-test, 0.00 % during post-test). Reactive saccades with latencies higher than 100 ms (1.93 % of pre-test trials and in 1.26 % of post-test trials) were discarded from analysis, as our purpose was to investigate the impact of manual experience on anticipatory eye movements only. We assumed that saccades with latencies up to 100 ms are planned and elicited already during the on-going grasping movement (Land, 2009; Smit & Van Gisbergen, 1989) and therefore originated from an underlying anticipatory process (Mehta & Schaal, 2002; Wells & Barnes, 1998).

We then calculated means for grasping movements over trials, resulting in three mean values for the pre-test and three mean values for the post-test. Those values were further averaged into one score for pre-test and one score for post-test for each subject. Additionally, we calculated a difference score (Diff_Score = Post_Score - Pre_Score).

Statistics were analyzed using IBM SPSS Statistics (version 20.0). The level for significance was sat at $\alpha = 0.05$ and effect sizes were calculated using Cohen´s *d* for independent-samples *t*-tests and partial eta-squared (η_p^2) values for ANOVAs.

3 Results

3.1 Latencies

On average, participants anticipated the action goal in 90.2% of trials during pre-test and in 93.9 % of trials during post-test. An Analysis of Variance (ANOVA) with the between-subject factor Group (5) was calculated to compare mean latencies for pre-test trials. No significant main effect of *Group* for mean latencies of pre-test trials was obtained ($F(4,145) = 0.51$, $p = .73$, $\eta_P^2 = .014$). On average, participants' gaze preceded the action goal with a latency of M = -322.20 ms, SD = 82.20 ms during pre-test trials (see **Table 1**).

Table 1. Summary of means and standard deviations for gaze latencies

		Pre		Post	
Group		*M*	*SD*	*M*	*SD*
BST [a]	GM2	-301.96	85.2	-361.79	84.4
	GM3	-309.98	92.6	-379.77	79.4
	GM4	-388.97	111.5	-430.38	112.9
Puzzle [a]	GM2	-274.16	90.4	-306.83	78.2
	GM3	-295.21	100.3	-322.35	93.0
	GM4	-371.73	133.1	-386.02	118.5
PR [b]	GM2	-293.21	76.4	-323.58	87.3
	GM3	-293.73	65.3	-311.05	104.8
	GM4	-366.26	93.6	-362.12	110.5

Note. BST = Block Stacking Task; PR = Pursuit Rotor; GM = Grasping Movement; *M* = Mean (in ms); *SD* = Standard Deviation (in ms).
[a]*N = 60;* [b]*N =30.*

3.2 Congruency Conditions

Two independent-samples *t*-tests (2-tailed) on the pre-post difference (Diff_Score) were applied in order to test any differences for the backhand and forehand conditions in the block stacking task groups and puzzle groups. Pre-post differences (Diff_Score) did not significantly differ for anatomically and spatially congruent conditions in both block stacking task groups ($t(58) = .36$, $p = .72$, $d = .07$; *Forehand*: M = -53.9 ms, SD = 70.7 ms; *Backhand*: M = -60.8

ms, *SD* = 77.6 ms) and puzzle groups ($t(58) = -.476$, $p = .64$, $d = .12$; *Forehand*: $M = -28.4$ ms, $SD = 56.6$ ms; *Backhand*: $M = -21.0$ ms, $SD = 64.5$ ms). Therefore, both block stacking task groups and both puzzle groups were combined for further analyses.

3.3 Impact of Experience

A 2 (*Pre/Post*) x 3 (*Grasping Movement*) x 3 (*Group*) repeated measures MANOVA with the first two factors as within-subject factors and the third one as a between-subject factor was applied on mean gaze latencies to test whether the subject-performed tasks led to group differences in the ability to anticipate the action goal during the post-test. Results revealed a significant main effect of *Grasping Movement* (Wilks' $\Lambda = .53$, $F(2,144) = 63.06$, $p < .001$, $\eta_P^2 = .47$). Participants' gaze latencies became significantly shorter over grasping movements. Furthermore, a significant main effect of *Pre/Post* could be found (Wilks' $\Lambda = .83$, $F(1,145) = 30.79$, $p < .001$, $\eta_P^2 = .18$). Participants showed significantly shorter gaze latencies during post-test trials compared to pre-test trials. Of particular relevance to our hypotheses was a significant interaction between the factors *Pre/Post* and *Group* (Wilks' $\Lambda = .93$, $F(2,145) = 5.10$, $p = .007$, $\eta_P^2 = .07$).

Planned comparisons revealed that the block stacking task group showed a significantly larger pre-post difference than the puzzle group ($t(147) = -2.69$, $p = .008$, $d = 0.49$) and the pursuit rotor task group ($t(147) = -2.84$, $p = .005$, $d = 0.87$), whereas the puzzle group and the pursuit rotor task group did not significantly differ from each other ($t(147) = -.64$, $p = .52$, $d = 0.15$, see **Figure 5**). All other main effects and interactions were non-significant (all Wilks' $\Lambda > .96$, $F \leq 2.78$, $p \geq .07$).

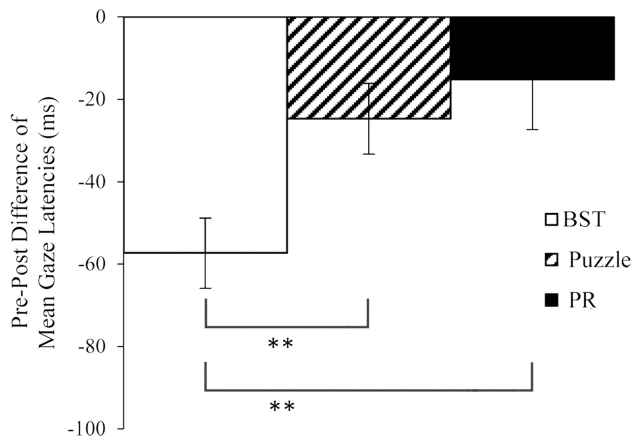

Figure 5. Pre-post differences of mean gaze latencies averaged over grasping movements (except grasping movement 1) for each experimental condition. BST = Block Stacking Task, PR = Pursuit Rotor Task. Vertical bars indicate standard errors. $**p < 0.01$.

4 Discussion

The aim of this study was to investigate whether short-term experience with manually performed tasks would activate task-specific action plans and therefore would lead to shorter gaze latencies during observation of the same or a similar task. To this end, we applied a pre-post design using eye tracking. First, participants observed short video clips of an actor performing a block stacking task. Subsequently, they either performed the block stacking task, puzzles or a pursuit rotor task. The block stacking task and puzzles were performed in two different congruency conditions (anatomically congruent / spatially congruent). Finally, participants again observed the same video clips shown during the pre-test. No significant effect of congruency could be found between both block stacking task groups and both puzzle groups, indicating that the performance of a congruent or incongruent anatomical movement (backhand vs. forehand) does not affect the latency of anticipatory fixations. This finding stands in line with studies showing sparse influence of postural congruency between the observer and the agent on behavioral results (Alaerts, Heremans, et al., 2009; Alaerts, Swinnen, & Wenderoth, 2009; Urgesi et al., 2006). Furthermore, Sartori et al. (Sartori, Begliomini, & Castiello, 2013) have recently shown that motor resonance occurred in the observer’s dominant hand, regardless of the hand preference being observed. This suggests that a direct mapping mechanism is able to convert others' movement features into the observer's optimal motor commands.

The most salient finding of our study was that participants who performed the block stacking task directed their gaze significantly faster to action goals during post-test trials, compared to participants who performed puzzles or the pursuit rotor task. We assume that this effect cannot be explained due to visual repetition, since studies investigating the influence of motor and visual experience on anticipatory skills during action observation have demonstrated that an improvement of anticipatory skills occurred independent of visual experience (Casile & Giese, 2006; Mulligan & Hodges, 2013). For example, Mulligan and Hodges (2013) manipulated the amount of visual experience in a training study, in which participants were trained to throw darts towards specific areas of a dartboard. Before and after the training, participants should predict landing positions of dart throws on temporally-occluded video stimuli. Participants were either trained to throw darts with or without vision. Furthermore, two control groups (observation-only, no practice) did not receive a motor training. Results have shown that both the vision and the no-vision group significantly improved to predict the landing position of dart throws during the post-test with no difference between them, whereas control groups did not improve at all, indicating that visual experience had no impact on the ability the predict action goals. In accordance with this finding, Calvo-Merino et al. (2006) conducted an fMRI study investigating expert dancers' perception of gender-specific movements. Results have shown that activation of the mirror neuron system is higher when observing dance movements of the own motor repertoire (performed by a dancer of the same gender) compared to observing visually familiar movements (performed by a dancer of the opposite gender). These results indicate that observed actions are understood in terms of their activated motor representations independent of visual knowledge about the actions.

Therefore, our finding suggests that short-term experience enhances the activation of task-specific action plans which enable the observer to predict the action goals of the same action faster. At this point it is assumed that anticipatory eye movements are strongly related to task-specific action plans in the observer.

Chapter 3: Pupil size changes during the observation of unexpected actions - The role of experience.

1 Research Questions and Hypotheses

Within the first experiment, we were able to show that short-term experience with a specific task led to shorter gaze latencies during the observation of the same task. Importantly, this effect was highly task-specific, and did not occur when experience with rather distinct tasks was given.

The aim of the present experiment was to investigate whether short-term experience with an action has a task-specific impact on pupil size changes during the observation of unexpected action outcomes. In a pre-post design, we presented participants video stimuli of an agent performing a block stacking task. In contrast to the first experiment, trials showing an actor performing incomplete versions of the block stacking task were of particular interest in this study. In these trials, the agent started to perform the block stacking task but placed either the second, third or fourth block to the wrong edge. Hence, the tower was not built up completely. We assumed that these trials would violate the expectations of the observer. Since the violation of expectations is measurable via pupil dilation (e.g., Preuschoff, 2011), we expected participants' pupil size to increase during the observation of trials in which the actor failed to build up the tower completely.

Importantly, in between the presentation of pre- and posttest trials participants either performed a block stacking task, puzzles or a pursuit rotor task. We questioned whether own short-term experience with a specific action would lead to a stronger prediction error during the observation of the same action in posttest trials. According to the results of the first experiment, we assumed that the prediction error (indicated by pupil dilation) during the observation of posttest trials should be strongest for participants that had performed the block stacking task.

Moreover, in order to disentangle the relationship between anticipatory eye movements and pupil dilation as measures of action understanding, we intended to investigate the correlation between both measures.

2 Methods

2.1 Participants

Ninety-eight university students who had participated within the first study of this thesis were considered for statistical analyses in the present experiment. An additional N = 54 participants were excluded from analyses due to not reaching analyses criteria for the present study. For this study, participants were grouped into three experimental groups (1. Block Stacking Task, $N = 40$, 17 males, M_{age} = 24.1 years, SD = 3.20 years; 2. Puzzles, $N = 40$, 24 males, M_{age} = 23.3 years, SD = 2.59 years; 3. Pursuit Rotor Task, $N = 18$, 8 males, M_{age} = 22.5 years, SD = 1.91 years). Participants were paid for participation and gave their informed consent prior to taking part. The study was conducted in accordance with the standards specified in the 1964 Declaration of Helsinki.

2.2 Materials & Stimuli

This study is a further analysis of the data collected within the first study of this thesis. All materials, stimuli and the experimental procedure are described within the first study of this thesis (Chapter 2). In contrast to the first study, all stimuli, including three non-completion trials, were considered for analyses. Non-completion trials (NC) differed from test trials (TT) in such ways that the agent put one, two or three wooden blocks on top of each other, but put the last, second last, or third last block in the wrong direction to the start-edge, respectively. After this movement, the video clip ended immediately so that the building of a complete tower failed. Non-completion trials are referred to as non-completion trial 2 – 4 (NC2, NC3, NC4), according to the incorrectly placed block that caused the unexpected outcome of the block stacking task.

2.3 Data Analyses

Pupil data of test trials and non-completion trials were analyzed by using Brain Vision Analyzer (version 2.0) and purpose written software (Python®). Initially, pupil data of both eyes was preprocessed in order to identify missing values in the data stream (typically caused by blinks). Missing values which affected up to 30 consecutive samples in the data stream (≈ 498 ms) were replaced by linearly interpolated values. Trials containing missing values after the interpolation procedure were discarded from analyses. Due to the relatively small number of trials (six test trials and two non-completion trials) per participant in pre- and posttest, participants with missing values in at least one test trial or one non-completion trial in either the pre- or posttest were completely discarded from further analyses ($N = 54$).

In order to define an appropriate time window in which the pupil size changed in response to unexpected (NC) compared to expected (TT) action outcomes, we first visually explored the complete data stream of test trials and non-completion trials. For this purpose, we calculated a baseline by averaging pupil size values during a period of 1000 ms preceding the onset of the block stacking task for each condition. Pupil dilation during the action period was calculated by subtracting the baseline value from each data point. Visual exploration revealed that pupil size values increased about 100 ms after offset of the unexpected grasping movement, and that this effect lasted for about 700 ms (see **Figure 7**). This latency is in accordance with previous research indicating that pupillary responses typically occur within 100-200 ms after the critical event (unexpected event, response toward a stimulus) and lasts for up to two seconds (Kloosterman et al., 2015; Scheepers et al., 2013).

Preliminary analyses revealed variations in pupil size prior to the grasping offsets between non-completion trials and test trials (see Fehler! Verweisquelle konnte nicht gefunden werden.). Hence, we calculated new baselines with durations of 500 ms directly preceding the offsets of the unexpected grasping movements (see **Figure 6**). Importantly, for each non-completion trial a different grasping offset was of interest, since the unexpected event occurred within different grasping movements (e.g., for NC2 the offset of the second grasping movement was of interest).

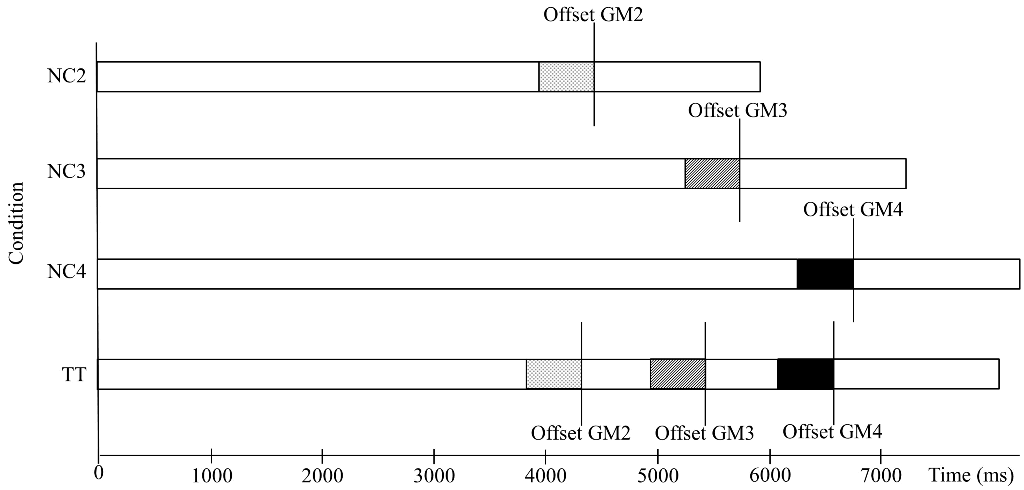

Figure 6. Grasping offsets and baseline values for each condition. Time 0 represents onset of the block stacking task. Vertical bars indicate grasping offsets of interest. Grey-scaled areas indicate baseline time periods (500 ms) for each condition. NC = non-completion trial; TT = test trial; GM = grasping movement.

In order to compare the pupil size changes of non-completion trials with that of test trials, three grasping offsets according to those of the non-completion trials were determined to calculate the baseline values in test trials (see **Figure 6**, lower row). Again, pupil dilation was calculated by subtracting the baseline value from every data point during the aforementioned 100-800 ms interval after grasping offset. Pupil data of the six test trials were averaged into one value, whereas pupil data of non-completion trials were analyzed seperately. Data of both eyes were merged.

Statistics were analyzed using IBM SPSS Statistics (version 20.0). The level for significance was sat at $\alpha = 0.05$ and effect sizes were calculated using Cohen´s *d* for *t*-tests and partial eta-squared (η_P^2) values for ANOVAs.

3 Results

3.1 Pupil Dilation over Time

Mean pupil dilation over time during the observation of each condition is shown in **Figure 7** for pre- and posttest averaged over all participants (*N* = 98).

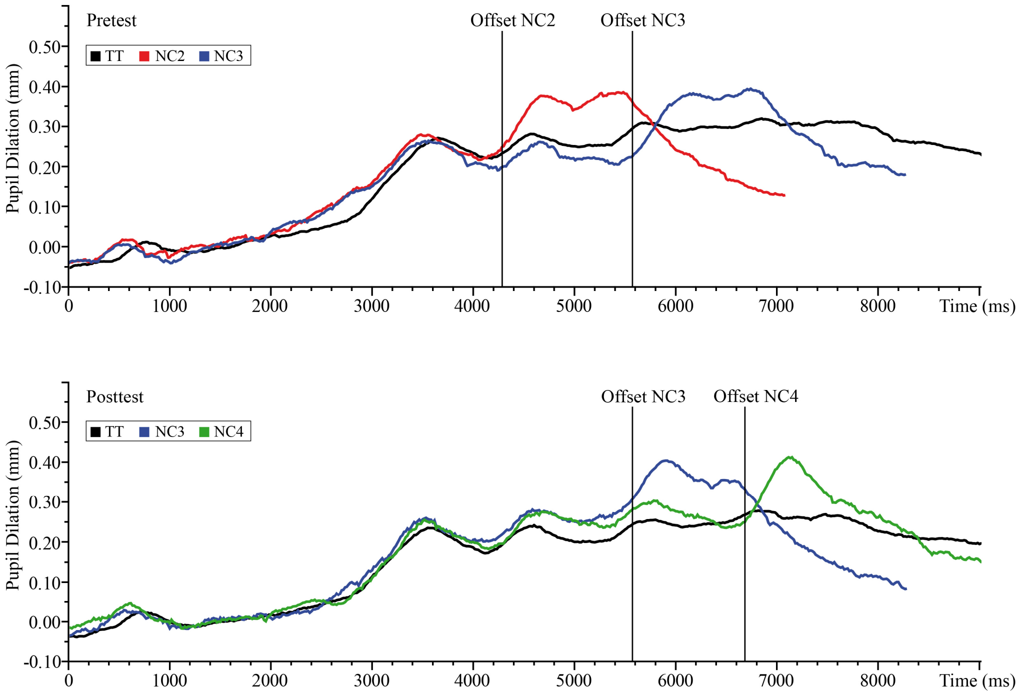

Figure 7 .Baseline-corrected dilation-by-time plot for non-completion trials and test trials during pre- and posttest (Baseline = 1000 ms interval prior to stimulus onset). Time 0 represents stimulus onset. Vertical bars indicate grasping offsets of interest of non-completion trials. Black lines indicate pupil dilation over time in test trials; red line indicates pupil dilation over time in non-completion trial 2; blue lines indicate pupil dilation over time in non-completion trial 3; green line indicates pupil dilation over time in non-completion trial 4. TT = test trial, NC = non-completion trial, *N* = 98.

The pupil started to slightly dilate after the onset (at 2000 ms) of the block stacking task following a similar pattern in all conditions. Mean pupil size of test trials continuously increased mainly in a steady pattern. In contrast, in NC2-4 trials the pupil strongly dilated approximately 100 ms following the unexpected grasping offsets. Moreover, the dilation curves in response to the unexpected grasping movements in NC2 and NC3 showed a bimodal shape, whereas the dilation curve of NC4 showed a unimodal curve. We assumed that the first peak might reflect the prediction error caused by the unexpected placement of the blocks, whereas the second peak might reflect the unexpected abrupt termination of the action. This assumption is supported by the finding that NC4 trials only showed a unimodal curve, most likely reflecting participants' violated expectation caused by the wrong placement of the last block, whereas participants were not surprised that the action ended as usual after the manipulation of the fourth block. Hence, for the following analyses, we decided to concentrate on a time window comprising the first peak of NC2-4 trials. Accordingly, we considered the 100-800 ms response interval following unexpected grasping offsets.

3.2 Prediction Error

From **Figure 7** it becomes clear that pupil dilation is directly related to different stimulus conditions, particularly to the unexpected events occurring within non-completion trials. In order to investigate whether pupil dilation values in response to non-completion trials statistically differed from pupil dilation values in test trials, we conducted two repeated-measures ANOVAs with the two within-subject factors *Grasping Offset* (2) and *Condition* (2) for pre- and posttest trials on the baseline-corrected mean pupil dilation values in the 100-800 ms response interval after grasping offsets. For pretest trials, the analyses revealed a significant main effect of *Grasping Offset* ($F(1,97) = 5.16$, $p = .025$, $\eta_p^2 = .05$) with significantly higher pupil dilation values for NC3 and the according time interval in test trials (TT_NC3) compared to NC2 and the according time interval in test trials (TT_NC2). Moreover, a significant main effect of *Condition* ($F(1,97) = 179.8$, $p < .001$, $\eta_p^2 = .65$), with higher pupil dilation values for non-completion trials (NC2: $M = .12$ mm, $SD = .08$ mm; NC3: $M = .13$ mm, $SD = .09$ mm) compared to test trials (TT_NC2: $M = .03$ mm, $SD = .04$ mm; TT_NC3: $M = .04$ mm, $SD = .05$ mm) was obtained. No significant interaction of *Grasping Offset* x *Condition* could be found ($F(1,97) = .07$, $p = .787$, $\eta_p^2 = .001$). Pupil dilation values of non-completion trials and test trials during pretest are illustrated within **Figure 8** a.

For posttest trials, the analyses revealed no significant main effect of *Grasping Offset* ($F(1,97) = 2.09$, $p = .151$, $\eta_P^2 = .02$) but a significant main effect of *Condition* ($F(1,97) = 107.3$, $p < .001$, $\eta_P^2 = .53$), with higher pupil dilation values for non-completion trials (NC3: $M = .11$ mm, $SD = .08$ mm; NC4: $M = .12$ mm, $SD = .09$ mm) compared to test trials (TT_NC3: $M = .04$ mm, $SD = .05$ mm; TT_NC4: $M = .01$ mm, $SD = .05$ mm).

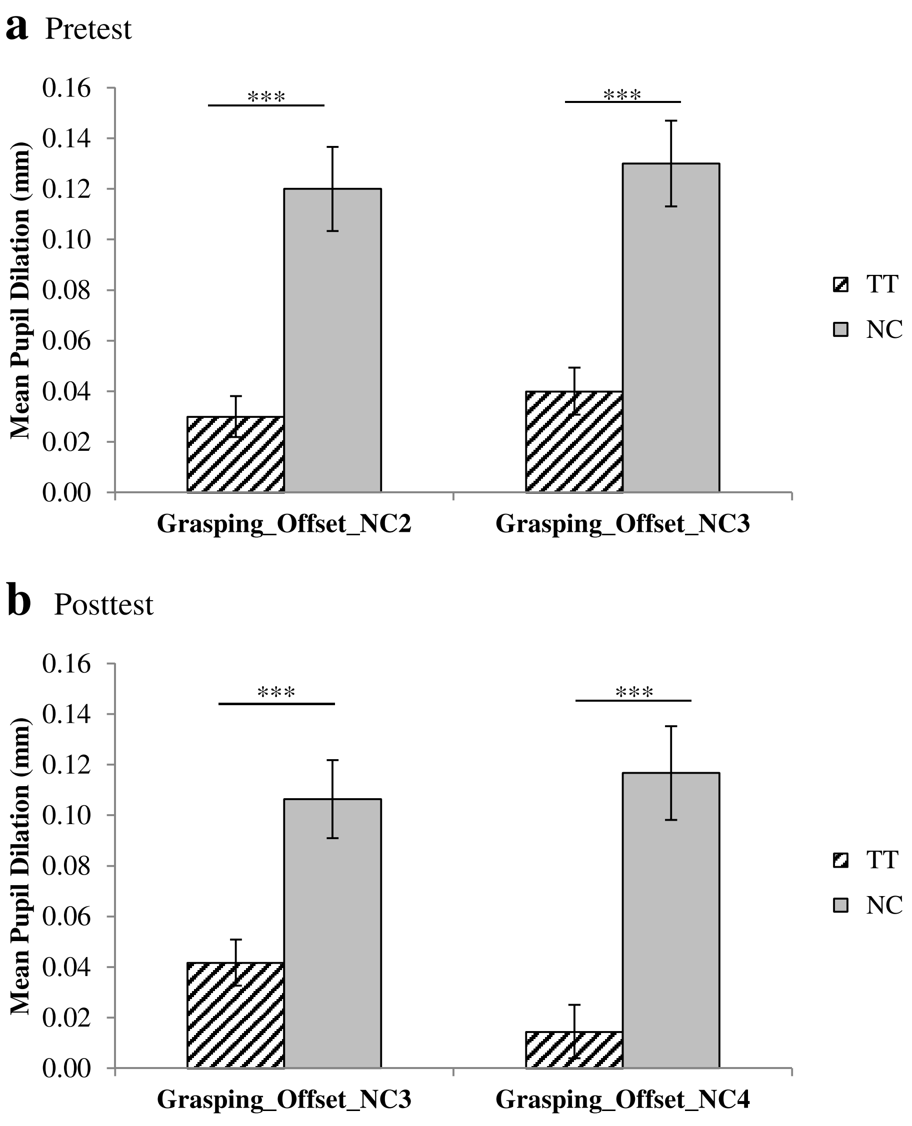

Figure 8. Mean pupil dilation values of test trials and non-completion trials for pretest and posttest. TT = Test trial, NC = Non-completion trial. Vertical bars indicate standard errors. ***p < .001.

Moreover, a significant interaction of *Grasping Offset* x *Condition* was obtained ($F(1,97) = 9.11$, $p = .003$, $\eta_p^2 = .09$) with a greater difference of pupil dilation values between NC4 and the according time period in test trials (TT_NC4) compared to pupil dilation values of NC3 and the according time period in test trials (TT_NC3). Pupil dilation values of non-completion trials and test trials during posttest are illustrated within **Figure 8** b.

Taken together, these results indicate that participants' pupils dilated significantly stronger following the presentation of non-completion trials compared to test trials during both pretest and posttest (see also **Figure 9**). Moreover, during pretest trials the extent of the prediction error was comparable for both non-completion trials, whereas it was greater for NC4 compared to NC3 during the posttest.

3.3 Impact of Experience

Before testing the influence of own manual experience on pupil dilation, we analyzed whether the three experimental groups differed in their pupil dilation values during pretest. To this end we again calculated a repeated-measures ANOVA on the mean pupil dilation values of pretest trials with the two within-subject factors *Grasping Offset* (2) and *Condition* (2), but included the between subject factor *Group* (3) for this analysis.

As previously reported in Section 3.2, a significant main effect of *Grasping Offset* ($F(1,95) = 5.32$, $p = .023$, $\eta_p^2 = .05$) was obtained with significantly higher pupil dilation values for NC3 and the according time interval in test trials (TT_NC3) compared to NC2 and the according time interval in test trials (TT_NC2). Moreover, analyses revealed a significant main effect for *Condition* ($F(1,95) = 181.77$, $p < .001$, $\eta_p^2 = .66$), indicating that mean pupil dilation values were significantly higher for non-completion trials compared to test trials. Of particular relevance for our further analyses was, whether there were group differences in mean pupil dilation values during the pretest. Results indicated no significant main effect of *Group* ($F(2,95) = .85$, $p = .431$, $\eta_p^2 = .02$), but a marginally significant interaction of *Group* x *Condition* ($F(2,95) = 2.93$, $p = .058$, $\eta_p^2 = .06$). All other interactions remained non-significant (all

*F*s $\leq .29$, all *p*s $\geq .753$). In order to further investigate the marginal *Group* x *Condition* interaction effect, we calculated post-hoc comparisons (independent-sample *t*-tests) on the difference scores between non-completion trials and test trials of mean pupil dilation values during pretest. Results revealed no significant differences between groups for the difference score related to NC2 (all $t \leq -1.25$, all $p \geq .215$) and no significant differences between groups for the difference score related to NC3 (all $t \leq -1.12$, all $p \geq .269$). Hence, all three experimental groups showed equally strong prediction errors as a result of the observation of unexpected actions during the pretest (see **Figure 9** a).

Pupil dilation values of the two non-completion trials presented within the pretest were considered separately for analyses for the following reasons: On the one hand, the two non-completion trials presented during the pretest differ from those two non-completion trials presented during the posttest – during the pretest, NC2 and NC3 were presented, whereas during the posttest NC3 and NC4 were presented. Hence, only one non-completion trial (NC3) was repeatedly shown in both subtests. The other two non-completion trials (NC2 and NC4) strongly differ in their content, since the unexpected action occurs at completely different time points within these trials. This might be reflected in variations of participants' pupil response towards the presentation of the specific non-completion trials. This apprehension finds support in the analyses reported in Section 3.2, indicating that participants showed a stronger prediction error for NC4 trials compared to NC3 trials. In contrast, during pretest participants showed an equally strong pupil response towards both non-completion trials.

Moreover, we investigated the influence of short-term experience on pupil dilation in NC3 only, since this trial allows the most proper analysis due to its identical repetition in pre- and posttest. Descriptive statistics for pupil dilation values of NC3 during pre- and posttest are illustrated for each group in **Table 2**.

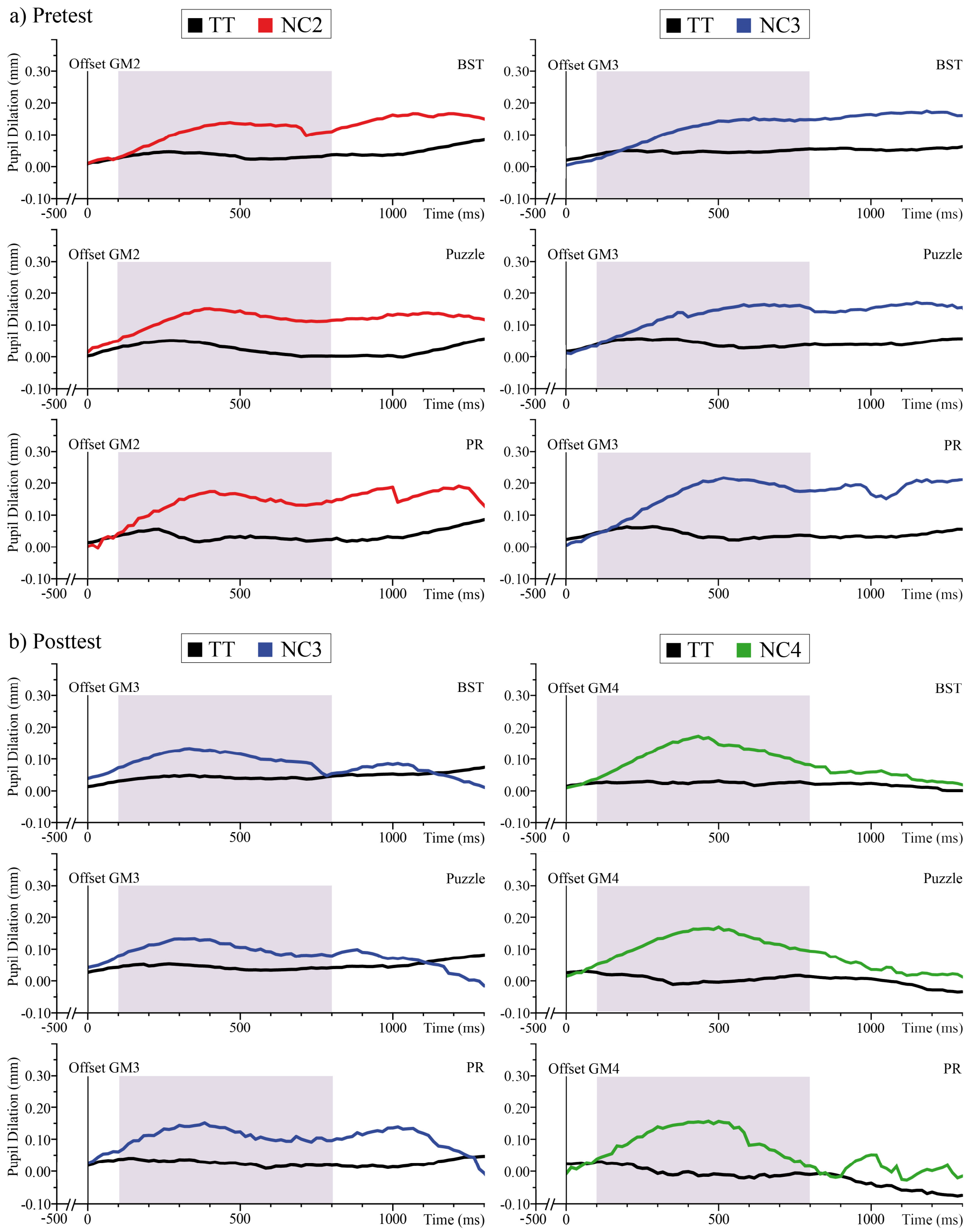

Figure 9. a) Mean pupil dilation values of test trials and non-completion trials during pretest separately for each experimental group. b) Mean pupil dilation values of test trials and non-completion trials during posttest separately for each experimental group. TT = Test trial, NC = Non-completion trial, GM = Grasping Movement, BST = Block Stacking Task, PR = Pursuit Rotor Task. Grey areas indicate time interval of interest.

Table 2. Summary of means and standard deviations of pupil dilation values for NC3

		Pre		Post	
Group		*M*	*SD*	*M*	*SD*
BST [a]	NC3	.11	.07	.10	.08
	TT_NC3	.05	.06	.04	.05
Puzzle [a]	NC3	.13	.10	.11	.07
	TT_NC3	.04	.04	.05	.05
PR [b]	NC3	.16	.09	.11	.08
	TT_NC3	.04	.03	.03	.04
Total [c]	NC3	.13	.09	.11	.08
	TT_NC3	.04	.05	.04	.05

Note. BST = Block Stacking Task; PR = Pursuit Rotor; NC3 = Non-completion trial 3; TT = Test trial; *M* = Mean (in mm); *SD* = Standard Deviation (in mm).
[a]*N = 40;* [b]*N =18;* [c]*N =98.*

In order to investigate whether task-specific short-term experience would have an influence on the degree of participants' pupil dilation during the observation of NC3, we calculated a 2 (*Pre/Post*) x 2 (*Condition*) x 3 (*Group*) repeated measures ANOVA with the first two factors as within-subject factors and the third one as a between-subject factor on mean pupil dilation values of NC3 and TT_NC3. Results revealed a significant main effect of *Pre/Post* ($F(1,95) = 5.72$, $p = .019$, $\eta_P^2 = .06$). Mean pupil dilation values of NC3 and the according time interval in test trials were significantly lower during posttest (NC3: *M* = .11 mm, *SD* = .08 mm; TT_NC3: *M* = .04 mm, *SD* = .05 mm) compared to pretest (NC3: *M* = .13 mm, *SD* = .09 mm; TT_NC3: *M* = .04 mm, *SD* = .05 mm). Moreover, again a significant main effect of *Condition* was obtained ($F(1,95) = 116.3$, $p < .001$, $\eta_P^2 = .55$), indicating that pupil dilation values of NC3 were significantly higher than mean pupil dilation values of the according time interval in test trials. Further, a marginally significant interaction effect of *Pre/Post* x *Condition* was obtained ($F(1,95) = 3.15$, $p = .079$, $\eta_P^2 = .03$), indicating that the difference between NC3 and test trials during the pretest was larger than during the posttest. Post-hoc comparisons (dependent-sample *t*-tests) revealed that mean pupil dilation values of NC3 significantly decreased during the posttest ($t(97) = 2.03$, $p = .045$, $d = .24$), whereas mean pupil dilation values remained constant for the according time interval during test trials (TT_NC3) during both pretest and posttest ($t(97) = .49$, $p = .62$, $d = .00$).

Of particular relevance to our hypotheses was the impact of the task-specific training on pupil dilation values between the three experimental groups. However, no significant main effect of *Group* ($F(2,95) = .33$, $p = .722$, $\eta_p^2 = .01$), neither a significant interaction effect of *Group* x *Pre/Post* ($F(2,95) = 1.23$, $p = .284$, $\eta_p^2 = .03$) was obtained, indicating no differences in mean pupil dilation values between the three experimental groups. Thus, no impact of task-specific short-term experience on pupil dilation could be found. All other interactions remained non-significant (all Fs ≤ 2.12, all ps ≥ .126).

3.4 Correlation between Anticipatory Gaze and Pupil Dilation

Here, we intended to investigate whether the latencies of anticipatory eye movements are related to the extent of pupil size changes during the observation of unexpected actions. To this end, we calculated bivariate correlations between the mean latency of anticipatory eye movements during pretest trials and the difference scores of pupil dilation values during pretest trials. Results indicate neither a significant correlation between the mean gaze latency of pretest trials and the difference score related to NC2 ($r(95) = -.03$, $p = .754$) nor the difference score related to NC3 ($r(95) = -.07$, $p = .524$) during pretest. Hence, the ability to anticipate action goals is not related to the extent of the prediction error during the observation of unsuccessful actions.

4 Discussion

The aim of the present experiment was to investigate whether task-specific short-term experience has an impact on pupil dilation during the observation of unsuccessfully performed actions. To this end, we assessed participants' pupil size in a pre-post design in which participants observed short video clips of an actor performing a block stacking task in either a successful or in an unsuccessful way. In between, they either performed the block stacking task, puzzles or a pursuit rotor task. Finally, participants again observed the same video clips shown during the pre-test.

Overall, our results demonstrate that participants were surprised when observing unexpected action sequences compared to successfully performed actions, indicated by higher pupil dilation values following the occurrence of the unexpected event. This finding is in line with a number of studies reporting pupil dilation as a result of surprise or an expectation error (e.g., Kloosterman et al., 2015; Lavín, San Martín, & Rosales Jubal, 2014). Moreover, we found that participants did not seem to be merely surprised by the unexpected grasping event, but rather that participants did not expect the action to be terminated abruptly after the unexpected grasping movement which was indicated by a second peak in pupil dilation during trials in which further grasping movements would have been possible. This observation demonstrates that pupil dilation is closely related to a variety of expectation errors which is supported by previous studies reporting pupillary responses as a consequence of violations of expectations in gambling tasks (Preuschoff, 2011), in the perception of body movements (Morita et al., 2012), or in the perception of social interactions (Gredebäck & Melinder, 2011). However, to our knowledge no study has investigated so far, whether own experience with an action might influence the extent of the pupillary response in relation to unexpected events. Although, we could not find an influence of task-specific experience on pupil dilation, we were able to show that the pupillary response decreases when an unexpected event is presented for a second time. This might be the case because of the visual experience the participants obtained throughout the experiment. We know that people are very proficient in using subtle cues to predict other people's actions (e.g., Ambrosini et al., 2015), and moreover, that the prediction process is continuously updated throughout the course of the observed action (Kilner et al., 2007). Hence, it is possible that our participants integrated the specific kinematic cues of unsuccessful actions in their prediction process for further trials. Since one of our non-completion trials was presented twice it is likely that the updated cue information helped participants to predict the outcome of the unsuccessful action and as a result caused a slightly less pronounced prediction error. Crucially, our finding can neither be explained by a mere habituation of the pupil response towards the continuous repetition of stimuli (e.g., Lowenstein & Loewenfeld, 1952), nor by upcoming fatigue during the experiment (e.g., Hess, 1972), since the pupillary responses remained stable for test trials between the pre- and posttest. Rather, our result might reflect that visual experience with specific unexpected events caused participants to be aware of these types of actions and integrate them as possible outcomes in their prediction process.

However, manual experience with specific tasks did not cause any task-specific changes in pupil responses, whereas we could find clear effects of manual short-term experience on anticipatory eye movements. One possible explanation for these findings might lie in the underlying neurophysiological substrates of anticipatory eye movements and pupil dilation. As already outlined above, anticipatory eye movements are assumed to belong to a neural network involved in action planning and action monitoring. Neuroimaging studies have supported this view by showing that anticipatory eye movements are delayed during the observation of manual actions when according brain areas are inhibited by applying TMS pulses (Elsner et al., 2013). In contrast, pupillary responses in relation to unexpected events are known to be directly linked to a brain structure referred to as locus coeruleus (e.g., Koss, 1986; Rajkowski et al., 1993), which is the main cortical structure associated with the regulation of the neuro-transmitter norepinephrine (Aston-Jones & Cohen, 2005). Hence, it is very likely that motor experience influences anticipatory eye movements and pupillary responses to a different degree. Since eye movements are part of an action plan, it is intuitively clear that motor experience activates specific action plans in a person which in return improve the perception of the same action. In contrast, pupillary responses are not directly innervated by motor information, therefore, task-specific motor experience might not have influenced participants' pupil dilation. However, at this point we also need to mention that our analyses of pupil responses were only based on one trial per pre- and posttest, hence, our data might not be robust enough to uncover effects of experience. Nevertheless, it has been discussed in earlier studies that pupil responses most likely reflect a different aspect of a person's expectation than other measures of action understanding

(Daum et al., 2012). Our studies support this view by showing that anticipatory eye movements reflect an individual's expectation of upcoming events, whereas pupil dilation reflects the violation of an individual's expectation following an unexpected outcome of an action.

Taken together, this study supports previous findings that pupil responses reflect the violation of expectations in an individual and that the extent of this response is independent of own task-specific experience with the observed action.

Chapter 4: The role of experience on action understanding in children aged 4 – 14 years

1 Research Questions and Hypotheses

In our first study (Chapter 2: Effects of short-term experience on anticipatory eye movements during action observation) we were able to show that task-specific short-term experience with an action leads to shorter gaze latencies during the subsequent observation of the same task in adults. The aim of the present study was to investigate the influence of short-term experience on predictive eye movements during action observation in children. To this end, we again employed a block stacking task in a pre-post eye tracking design similar to that used in the study with adults. During pre- and posttest, children watched short video clips showing an agent performing the block stacking task. Simultaneously, their eye movements were recorded by means of a Tobii T60 eye tracker. Intermediately, children either performed the block stacking task or puzzles. Puzzles were applied as a control task and have previously been shown to cause a pre-post effect in adults but to a significantly smaller degree than the block stacking task. Therefore, we hypothesized that experience with the block stacking task should lead to significantly shorter gaze latencies during observation of posttest trials than experience with puzzles.

As previous studies have discussed the existence of a mirror neuron system already from birth on and its development throughout childhood (Kilner & Blakemore, 2007; Lepage & Théoret, 2007), one main question of this study was whether the impact of short-term experience on action understanding would change during development. Some studies argue in favor of a functional mirror neuron system even in newborns (Meltzoff & Moore, 1983) whereas other studies suggest that in spite of an existing rudimentary mirror neuron system already present in infancy own experience modifies this mirror neuron system and modulates its functioning throughout childhood (Shimada & Hiraki, 2006; van Elk et al., 2008). To this end, we investigated children of three age groups (Experiment 1: 4-6 years, Experiment 2: 8-10, years, Experiment 3: 11-14 years) in order to disentangle the influence of task-specific short-term experience with an action on predictive eye movements.

2 Experiment 1: Preschoolers (4-6 years)

2.1 Methods

2.1.1 Participants

Eighty-four preschoolers aged four to six years (M_{age} = 5.63 years, *SD* = 0.81 years, *Range*: 4.00 – 6.92 years) and *N* = 1 preschooler with an age of 3.92 years were considered for analyses in the present experiment. Preschoolers were recruited and tested at their day nursery or were invited to our lab at Saarland University. All preschoolers were right-handed, had normal or corrected-to-normal vision and were assigned to one of four experimental groups (1. Block Stacking Task_Forehand, *N* = 22, 11 males, M_{age} = 5.70 years, *SD* = 0.67 years; 2. Block Stacking Task_Backhand, *N* = 23, 11 males, M_{age} = 5.46 years, *SD* = 0.98 years; 3. Puzzle_Forehand, *N* = 20, 9 males, M_{age} = 5.74 years, *SD* = 0.75 years; 4. Puzzle_Backhand, *N* = 20, 12 males, M_{age} = 5.63 years, *SD* = 0.82 years) Additional *N* = 36 preschoolers were excluded from analyses due to insufficient gaze recordings (because of interruptions in the kindergarten; looking away from the eye tracker; fatigue). Moreover, ten preschoolers were discarded from analyses due to turning out to be left-handed during the experiment (*N* = 7), and technical errors (*N* = 3). All parents were paid 7.50 Euro for participation and gave their informed consent prior to taking part. The experiment was conducted in accordance with the standards specified in the 1964 Declaration of Helsinki.

2.1.2 Materials & Stimuli

The identical stimuli (video clips, AVI format, 25 Hz, 1280 x 1024 pixels, duration between 8 – 11 s) as in the first study (section 2.3.2) were used, except for two further video clips showing two more non-completion conditions of the block stacking task. These two further non-completions trials were added in order to capture preschoolers' attention. Hereby, the agent put two or three wooden blocks on top of each other, but when the second last or last block arrived at its goal position the block beyond it unexpectedly disappeared (see **Figure 10**). After that, the agent transported the block back to its starting position and subsequently, the video clip ended.

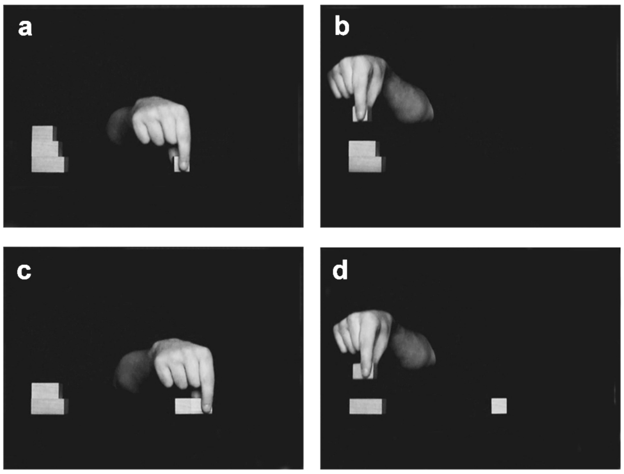

Figure 10. Video stimuli showing agent performing a block stacking task in new non-completion trials. a. Starting position of grasping movement 4, b. Goal position of grasping movement 4; block 3 disappeared, c. Starting position of grasping movement 3, d. Goal position of grasping movement 3; block 2 disappeared.

These two further video clips were again digitally edited such that a central fixation point was added for 2,000 ms, followed by a still frame for 2,000 ms at the beginning of each video. At the end of each video-clip, while the agent transports the block back to the starting position, a fade-out effect was added for 1,000 ms with the scene becoming increasingly darker until a completely black screen was visible. Furthermore, the original sounds of the recordings were again discarded. However, an artificial sound ('blopp', 200 ms) was added to the lifting movement of each wooden block and a further artificial sound ('blopp', 300 ms) was added when the block disappeared. All non-completion trials were excluded from analysis as they only served the purpose to keep the preschoolers alert during the experiment. An image (.jpg format, 1280 x 1024 pixels) showing a huge yellow smiley in front of a black background with a duration of 5,000 ms served as a further attention grabber.

Eye movements were recorded by means of a Tobii T60 eye tracker (17” TFT Monitor, sampling rate 60 Hz, accuracy 0.4°, Tobii, Sweden, Stockholm) during the observation of the experimental videos. The presentation of all stimuli and gaze recordings were controlled by Tobii Studio™ (Version 2.3.2.0).

Material for subject-performed tasks was also identical to that used in the first study. It consisted of four wooden blocks with different lengths (L = 2.5 cm / 3.5 cm / 4.5 cm / 5.5 cm) but same height (H = 2.5 cm) and width (W = 2.5 cm) in order to perform the block stacking task. Furthermore, three simple puzzles (SIMM toys) were applied for the puzzles intervention. Puzzles consisted of four single wooden pieces, consistently recolored in blue, showing three animals (ladybug, elephant, and dolphin), and a wooden inlay form (L = 14.5 cm, W = 18 cm, H = 2.5 cm) in which the pieces should be placed (see **Attachment C**). Although puzzle pieces differed in shape from the wooden blocks of the block stacking task, they were of comparable size and weight.

Manual dexterity was assessed by the Manual Dexterity Scale for 3-6 year old children of the Movement Assessment Battery for Children (M-ABC-2(Petermann, 2011), which consists of three manual tasks (Posting Coins, Threading Beads, Bicycle Trail I).

2.1.3 Experimental Procedure

Preschoolers were either tested at their day nursery or were invited to the lab at the Developmental Psychology Unit at Saarland University and tested during an individual experimental session lasting approximately 45 minutes. Preschoolers were seated at a desk 60 cm in front of the Tobii T60 eye tracker and the entire session was video-recorded. The session started with the experimenter narrating a cover story (see **Attachment A & B**) in order to catch the preschoolers’ attention, to introduce the block stacking task and to explain the task concerning the incompletion-trials: preschoolers were asked to sound a horn as fast as possible whenever they saw one of the incompletion-trials occur during the presentation of the experimental stimuli. This task was implemented in order to keep the preschoolers attentive during the presentation of the stimuli. Afterwards, four practice trials (2 test trials, 2 non-completion trials) were presented in order to familiarize the preschoolers with the task. Unless preschoolers were able to correctly detect the non-completion trials and consequently sound the horn, the four practice trials were repeated once and preschoolers were given feedback about when to sound the horn correctly. Preschoolers were instructed to pay full attention to the upcoming videos and to keep their hands still during the presentation of the stimuli. Subsequently, the experiment proceeded with the first eye tracking phase in which the preschoolers should passively observe ten experimental stimuli (6 test trials, 4 non-completion trials) in a randomized order. After five stimuli an attention grabber (smiley image) occurred for five seconds during which the preschooler was verbally praised, reminded to be attentive and encouraged that already half of the task was accomplished.

After completing the pretest, preschoolers were asked to perform either the block stacking task in a backhand or forehand movement or puzzles in a backhand or forehand movement. The block stacking task entailed stacking four wooden blocks on top of each other in order to build up a tower. Hereby, the four wooden blocks were lined up either at a right or left location 10 cm in front of the preschoolers. Locations were determined by two red dots with a distance of 30 cm in-between. In the starting position, the widest block was placed on one of the two red dots and the shorter ones were lined up pointing to the space between the two dots. Preschoolers were asked to build a tower on either the left or right dot (depending on the starting position) with their right hand only. Therefore, they either performed a forehand stacking movement or a backhand stacking movement. The puzzle intervention involved three simple wooden puzzles. The setup for puzzles was similar to that applied to the block stacking task with puzzle pieces lining up either at the right or left red dot pointing to the space between the two dots. The only difference between puzzles and the block stacking task was that the order of Puzzle pieces was randomized for every trial and child. Therefore, compared to the block stacking task, the puzzles have not been completed in a fixed sequence, but instead with a new sequence in each repetition. Both the block stacking task and the puzzles were performed ten times. Hereby, both tasks should be performed five times as accurately as possible and five times as fast and accurately as possible in a blocked manner. During the puzzle task, one of the three puzzles was randomly applied for each of the aforementioned instructions.

Following the intervention phase, the second eye-tracking phase took place, in which preschoolers again passively observed ten experimental trials (6 test trials, 4 non-completion trials) in a randomized order, with the attention grabber (smiley image) occurring after the fifth stimulus. Preschoolers were again instructed to pay full attention to the videos, to keep their hands still, while observing how the tower was built up and to sound the horn whenever a non-completion trial occurred.

After completing the second eye tracking phase, the Manual Dexterity Scale of the Movement Assessment Battery for Children (M-ABC-2; Petermann, 2011) was applied. First, preschoolers were asked to perform the *Bicycle Trail I* task, in which they should trace a narrow outline with a red pen without crossing the black border lines. For the case that the preschoolers made errors during the first trail (crossing the black border) a second attempt was carried out. The attempt with the least errors was considered for analyses, with errors of that attempt summed up into one score. Second, preschoolers performed the *Posting Coins* task in which they should insert game coins into a bank box with both hands successively, beginning with their dominant hand. Importantly, 3- and 4-year-old children had to insert six coins into the bank box with both hands successively, whereas 5- and 6-year-old children had to insert twelve coins into the bank box with both hands successively. Completion time was measured by using a stopwatch. Third, preschoolers performed the *Threading Beads* task, in which they should thread cubic beads on a string. Beads were initially lined up in front of the preschooler and had to be threaded one-by-one on the string. Again, 3- and 4-year-old children had to thread six beads on the string, whereas 5- and 6-year-old children had to thread twelve beads on the string. Completion time was measured by using a stopwatch.

2.1.4 Data Analyses

Gaze recordings of the six test trials were analyzed in the same way as in our first study by using purpose-written software (Python™). Each test trial consisted of four single grasping movements. We therefore calculated gaze latencies for each grasping movement in each test trial. Latencies were calculated as the difference of the first fixation time on the area of interest (AOI) and the placement time of the wooden block at the goal position. Negative values indicate that preschoolers' gaze arrived prior to the hand; positive values indicate that gaze arrived at the goal AOI after the block was placed there.

For each grasping movement a maximum of six data points could be reached (one per trial). Preschoolers' data was completely discarded when having less than three data points (because of insufficient gaze recordings due to no AOI-directed gaze behavior, or looking away from the eye tracker) in more than two grasping movements (N = 36). Further, the first grasping movement (the movement of the first block) showed a high number of missing values (57.3 % during pretest, 66.5 % during posttest) and a high number of reactive saccades with latencies higher than 100 ms (25.1 % during pretest, 18.4 % during posttest), thus, it was entirely discarded from analyses. This finding is in line with our first study and Flanagan and Johansson (2003) demonstrating that participants' gaze shifts were delayed during the first grasping movement when observing another person performing a block stacking task.

Moreover, reactive gaze with latencies higher than 100 ms (6.33 % of pretest trials and in 6.67 % of posttest trials) was discarded from analysis in the remaining grasping movements, as our purpose was to investigate the impact of manual experience on anticipatory eye movements only. This procedure was already applied within the first study of this thesis. We assumed that saccades with latencies up to 100 ms are planned and elicited already during the on-going grasping movement (Land, 2009; Smit & Van Gisbergen, 1989) and therefore originated from an underlying anticipatory process (Mehta & Schaal, 2002; Wells & Barnes, 1998), as already discussed in the first study.

Finally, comparable to our first study, we again excluded remaining grasping movements having less than three data points after the exclusion of latencies > 100 ms from analyses (5.49 % during pretest, 1.11 % during posttest). Following this procedure, *N* = 49 preschoolers remained having sufficient (at least three data points) data for all three grasping movements in pre- and posttest and *N* = 27 preschoolers having sufficient data in two of three grasping movements in pre- and posttest. Therefore, *N* = 76 preschoolers could be considered for statistical analyses. However, *N* = 9 preschoolers had to be discarded from statistical analyses due to having insufficient (less than three data points) data in more than two grasping movements in pre- or posttest trials after the exclusion of reactive saccades (with latencies > 100 ms).

For statistical analyses, we calculated mean gaze latencies for grasping movements over trials, resulting in three mean gaze latency values for the pretest and three mean gaze latency values for the posttest. Those values were further averaged into one score for pretest and one score for posttest for each preschooler. Moreover, we calculated mean percentage scores of anticipatory eye movements for each grasping movement over trials, resulting in three mean percentage values for pretest and posttest.

Raw scores of the Manual Dexterity Scale of the Movement Assessment Battery for Children (M-ABC-2; Petermann, 2011) were converted into three standard scores (*M* = 10, *SD* = 3).

Statistics were analyzed using IBM SPSS Statistics (version 20.0). The level for significance was sat at $\alpha = 0.05$ and effect sizes were calculated using Cohen´s *d* for independent-samples *t*-tests and partial eta-squared (η_P^2) values for ANOVAs.

2.2 Results

2.2.1 Latencies

On average, preschoolers' gaze preceded the subgoals of the block stacking task with a latency of *M* = -277.2 ms, *SD* = 110.3 ms and *M* = -282.1 ms, *SD* =

90.3 ms during pretest trials and posttest trials, respectively (see **Table 3**). An Analysis of Variance (ANOVA) with the between-subject factor *Group* (4) was calculated to compare mean gaze latencies for pretest trials between the four experimental groups. No significant main effect of *Group* for mean latencies of pretest trials was obtained ($F(3,72) = 2.47$, $p = .07$, $\eta_P^2 = .09$), indicating that all groups had comparable mean gaze latencies during pretest trials.

Table 3. Summary of means and standard deviations for gaze latencies

	[a]**BST_F** *M* *(SD)*	[b]**BST_B** *M* *(SD)*	[b]**Puzzle_F** *M* *(SD)*	[c]**Puzzle_B** *M* *(SD)*
Pre	-226.2 (106.3)	-309.1 (95.0)	-271.8 (92.6)	-305.2 (131.9)
Post	-252.3 (106.0)	-293.4 (88.9)	-287.6 (76.9)	-297.5 (85.6)

Note. BST = Block Stacking Task; F = forehand; B = backhand *M* = Mean (in ms); *SD* = Standard Deviation (in ms).
[a]*N* = 20; [b]*N* = 19; [c]*N* = 18

Preschoolers anticipated (latencies up to 100 ms) the subgoals of the block stacking task in 76.4 % of trials during pretest and 75.4 % of trials during posttest. A 3 (*Grasping Movement*) x 2 (*Pre/Post*) repeated measures MANOVA with both factors as within-subject factors was calculated to compare mean percentage values of anticipatory saccades over grasping movements during pre- and posttest. A significant main effect of *Grasping Movement* for mean percentage of anticipatory saccades was revealed (Wilks' $\Lambda = .45$, $F(2,83) = 50.5$, $p < .001$, $\eta_P^2 = .55$), whereas no significant main for effect for *Pre/Post* (Wilks' $\Lambda = 1.0$, $F(1,84) = 0.32$, $p = .57$, $\eta_P^2 = .00$), and no significant interaction between both factors was obtained (Wilks' $\Lambda = .96$, $F = 1.97$, $p = .15$, $\eta_P^2 = .05$). The percentage of preschoolers' anticipatory saccades increased over grasping movements comparably in pre- and posttest (see **Table 4**).

Table 4. Mean percentage of anticipatory saccades during pre- and posttest

	GM2 *M (SD)*	**GM3** *M (SD)*	**GM4** *M (SD)*
Pre	64.3 (26.5)	75.7 (24.6)	89.2 (18.5)
Post	59.2 (28.7)	75.3 (21.9)	91.6 (12.8)

Note. GM = Grasping Movement; *M* = Mean (percentage); *SD* = Standard Deviation (percentage).

2.2.2 Congruency Conditions

Two independent-samples *t*-tests (two-tailed) on the pre-post difference (Diff_Score) were applied in order to test any differences for the backhand and forehand conditions in the block stacking task groups and puzzle groups. Pre-post differences (Diff_Score) did not significantly differ for anatomically and spatially congruent conditions in both block stacking task groups ($t(37) = 1.43$, $p = .16$, $d = .46$, *Forehand*: $M = -25.6$ ms, $SD = 73.5$ ms; *Backhand*: $M = 15.7$ ms, $SD = 105.1$ ms) and puzzle groups ($t(35) = .72$, $p = .47$, $d = .24$, *Forehand*: $M = -15.7$ ms, $SD = 70.9$ ms; *Backhand*: $M = 7.72$ ms, $SD = 121.1$ ms). Therefore, both block stacking task groups and both puzzle groups were combined for further analyses.

2.2.3 Manual Experience

A 2 (*Pre/Post*) x 3 (*Grasping Movement*) x 2 (*Group*) repeated measures MANOVA with the first two factors as within-subject factors and the third one as a between-subject factor was applied on mean gaze latencies to test whether the subject-performed tasks led to group differences in the ability to anticipate the action goal during the posttest. Results revealed a significant main effect for *Grasping Movement* (Wilks´$\Lambda = .30$, $F(2,45) = 51.7$, $p < .001$, $\eta_P^2 = .70$), but no significant main effect for *Pre/Post* (Wilks' $\Lambda = 1.0$, $F(1,46) = .01$, $p = .92$, $\eta_P^2 = .00$) or *Group* ($F(1,46) = 2.14$, $p = .15$, $\eta_P^2 = .05$), indicating that preschoolers' gaze latencies became significantly shorter over grasping movements but did not differ between pre- and posttest trials or groups. The predicted interaction between the factors *Group* and *Pre/Post* was not significant (Wilks' $\Lambda = .98$, $F(1,46) = .90$, $p = .35$, $\eta_P^2 = .02$), indicating that pre-post differences of mean gaze latencies were comparable for both groups. All other interactions were non-significant (all Wilks' $\Lambda > .98$, $F < .69$, $p > .51$, $\eta_P^2 < .03$). Due to missing values in several grasping movements, $N = 27$ preschoolers could not be considered for the aforementioned analysis. Hence, a further 2 (*Pre/Post*) x 2 (*Group*) repeated measures MANOVA was calculated on averaged mean gaze latency values over grasping movements for pre- and posttest. Results again revealed no significant main effect of *Pre/Post (*Wilks' $\Lambda = 1.0$, $F(1,74) = .21$, $p = .65$, $\eta_P^2 = .003$) or *Group* ($F(1,74) = 1.0$, $p = .32$, $\eta_P^2 = .01$). Furthermore, the predicted interaction between the factors *Pre/Post* and *Group* remained non-significant (Wilks' $\Lambda = 1.0$, $F(1,74) = .003$, $p = .96$, $\eta_P^2 = .00$), again indicating that pre-post differences of mean gaze latencies were comparable for both groups.

2.2.4 Age

In order to investigate whether preschoolers' ability to anticipate the action goals of the block stacking task improves with increasing age, a bivariate correlation (one-tailed) between mean gaze latencies of pretest trials and preschoolers' age was calculated. Results revealed no significant correlation (Pearson's $r(76) = .05$, $p = .34$), indicating that the ability to anticipate the action goals of the block stacking task during observation does not improve with increasing age between four and six years.

We further investigated the relationship between preschoolers' age and the pre-post difference of mean gaze latencies by calculating a bivariate correlation (one-tailed). Results revealed no significant correlation, Pearson's $r(76) = -.01$, $p = .48$., indicating that preschoolers between four to six years did not show a larger pre-post difference with increasing age.

2.2.5 Manual Dexterity

On average, preschoolers made less than two mistakes in the *Bicycle Trail I* task ($M = 1.78$, $SD = 2.27$). Completing the *Posting Coins* task with the dominant hand and the non-dominant hand took $M = 18.56$ sec, $SD = 5.15$ sec and *M* = 21.56 sec, *SD* = 6.01 sec, respectively. On average, preschoolers completed the *Threading Beads* task in *M* = 50.02 sec, *SD* = 14.74 sec.

The relationship between manual dexterity and anticipatory eye movements was analyzed by calculating correlations (Pearson's *r*) between latencies of pretest trials and standard scores of the Manual Skills Scale (M-ABC-2). On average, preschoolers reached a mean of *M* = 8.09 points, *SD* = 3.27 points (range: 1 - 14 points) in the *Posting Coin*s task with the dominant hand and *M* = 7.16 points, *SD* = 3.71 points (range: 1 – 14 points) with the non-dominant hand. Further, preschoolers achieved *M* = 8.22 points, *SD* = 2.98 points (range: 1 – 14 points) in the *Threading Beads* task and *M* = 8.42 points, *SD* = 3.88 points (range: 1 – 13 points) in the *Bicycle Trail I* task. Results revealed no significant correlations between the standard scores of the Manual Dexterity Scale and mean gaze latencies of pretest trials, all $r(76) \leq .18$, $p \geq .13$.

2.3 Discussion

The aim of the first experiment was to investigate the influence of short-term experience on predictive eye movements during action observation in preschoolers aged four to six years. Results showed that preschoolers in this age group are able to anticipate the action goals during the observation of a manually performed grasping action. Moreover, we found that the percentage of anticipatory saccades increased over grasping movements, meaning that preschoolers seemed to be able to make predictions more easily when the action is approaching its final goal. However, in contrast to our study with adults, we were not able to show an influence of short-term experience on predictive eye movements within this age group, neither for experience with the block stacking task nor for experience with puzzles. Furthermore, we could not find a relationship between age or manual dexterity and the ability to anticipate action goals or the influence of short-term experience on anticipatory eye movements, respectively. This indicates that the ability to predict action goals seems to remain stable from four to six years of age, and moreover, it seems that fine motor skills do not have an influence on the ability to predict action goals during observation. This finding is in line with our first study, showing that adults' manual dexterity did not relate to their ability to predict the action goals during observation.

In the second experiment, we investigated whether short-term experience had an influence on predictive eye movements during action observation in school children aged eight to ten years.

3 Experiment 2: Children (8-10 years)

3.1 Methods

3.1.1 Participants

Eighteen (N = 9 males) school children aged eight to ten years (M_{age} = 9.48 years, SD = 0.77 years, Range: 8.00 – 10.42 years) were considered for analyses in the present experiment. All children were right-handed and had normal or corrected-to-normal vision and were tested at Saarland University. All children were assigned to the block stacking task forehand condition. Additional four children were excluded from analyses due to not reaching analyses criteria (N = 2), turning out to be left-handed during the experiment (N = 1), or experimenter errors (N = 1). All parents were paid 7.50 Euro for participation and gave their informed consent prior to taking part. The experiment was conducted in accordance with the standards specified in the 1964 Declaration of Helsinki.

3.1.2 Materials & Stimuli

The identical stimuli as in the previous experiment were used. Eye movements were again recorded by means of a Tobii T60 eye tracker (17" TFT Monitor, sampling rate 60 Hz, accuracy 0.4°, Tobii, Sweden, Stockholm) during the observation of the experimental videos. The presentation of all stimuli and gaze recordings were controlled by Tobii Studio™ (Version 2.3.2.0).

Manual dexterity was assessed by the Manual Dexterity Scale for 7-10 year old children of the Movement Assessment Battery for Children (M-ABC-2, Petermann, 2011), which consists of three manual tasks (Placing Pegs, Threading Lace, Bicycle Trail II).

3.1.3 Experimental Procedure

The experimental procedure was the same as in the previous experiment with the exception of the tasks performed within the Manual Dexterity Scale of the Movement Assessment Battery for Children (M-ABC-2; Petermann, 2011). Children were asked to perform the *Bicycle Trail II* task, a drawing task in which children should trace a narrow outline with a red pen without crossing the black border lines. For the case that the children made errors during the first trail (crossing the black border) a second attempt was carried out. The attempt with the least errors was considered for analyses, with errors of that attempt summed up into one score. Second, children should *place pegs* onto a plug board with both hands successively, beginning with their dominant hand. Completion time was measured by using a stopwatch. Third, children should *thread a lace* into a perforated plate. The plate contained eight holes and the child's task was to thread the rope alternately from above or beyond the plate through the holes. Completion time was measured by using a stopwatch.

3.1.4 Data Analyses

Gaze recordings of the six test trials were analyzed in the same way as in the first experiment by using purpose-written software (Python™). Again, children’s data was completely discarded when having less than three data points in more than two grasping movements (N = 2). Further, the first grasping movement (the movement of the first block) showed again a high number of missing values (46.3 % during pretest, 47.2 % during posttest) and a high number of reactive saccades with latencies higher than 100 ms (16.7 % during pretest, 13.0 % during posttest), thus, it was entirely discarded from analyses.

Moreover, reactive saccades with latencies higher than 100 ms (3.70 % of pretest trials and in 1.85 % of posttest trials) were discarded from analysis in the remaining grasping movements as well, for the same reasons already discussed in the first experiment. Finally, we excluded remaining grasping movements having less than three data points after the exclusion of latencies > 100 ms from analyses (0.03 % during pretest, 0.00 % during posttest). Following this procedure, $N = 15$ children remained having sufficient (at least three data points) data for all three grasping movements in pre- and posttest and $N = 3$ preschoolers having sufficient data in two of three grasping movements in pre- and posttest. Therefore, $N = 18$ children could be considered for statistical analyses.

For statistical analyses, we again calculated mean gaze latencies for grasping movements over trials, resulting in three mean gaze latency values for the pretest and three mean values for the posttest. Those values were further averaged into one score for pretest and one score for posttest for each child. Additionally, we calculated mean percentage scores of anticipatory eye movements for each grasping movement over trials, resulting in three mean percentage values for pretest and posttest.

Raw scores of the Manual Dexterity Scale of the Movement Assessment Battery for Children (M-ABC-2; Petermann, 2011) were converted into three standard scores ($M = 10$, $SD = 3$).

Statistics were analyzed using IBM SPSS Statistics (version 20.0). The level for significance was sat at $\alpha = 0.05$ and effect sizes were calculated using Cohen´s *d* for independent-samples *t*-tests and partial eta-squared (η_P^2) values for ANOVAs.

3.2 Results

3.2.1 Latencies

On average, children's gaze preceded the subgoals of the block stacking task with a mean latency of $M = -341.3$ ms, $SD = 74.7$ ms and $M = -347.2$ ms, $SD =$

88.2 ms during pretest trials and posttest trials, respectively. Children anticipated (with latencies up to 100 ms) the subgoals of the block stacking task in 88.2 % of trials during pretest and 86.4 % of trials during posttest. A 3 (*Grasping Movement*) x 2 (*Pre/Post*) repeated measures MANOVA with both factors as within-subject factors was calculated to compare mean percentage values of anticipatory saccades over grasping movements during pre- and posttest. No significant main effect of *Grasping Movement* for mean percentage of anticipatory saccades (Wilks' Λ = .78, $F(2,16) = 2.29$, $p = .13$, $\eta_P^2 = .22$), no significant main effect of *Pre/Post (*Wilks' Λ = .99, $F(1,17) = 0.14$, $p = .72$, $\eta_P^2 = .01$), and no significant interaction between both factors were obtained (Wilks' Λ = .93, $F(2,16) = 0.58$, $p = .57$, $\eta_P^2 = .07$). The percentage of children's of anticipatory saccades did not increase over grasping movements and were comparable in pre- and posttest (see **Table 5**).

Table 5. Mean percentage of anticipatory saccades during pre- and posttest

	GM2 *M (SD)*	**GM3** *M (SD)*	**GM4** *M (SD)*
Pre	80.5 (21.6)	90.7 (20.0)	93.5 (11.6)
Post	82.4 (21.0)	88.9 (18.1)	88.0 (23.4)

Note. GM = Grasping Movement; *M* = Mean (in percentage); *SD* = Standard Deviation.

3.2.2 Manual Experience

A 2 (*Pre/Post*) x 3 (*Grasping Movement*) repeated measures MANOVA with both factors as within-subject factors was applied on mean gaze latencies to test whether experience with the block stacking task led to differences in the ability to anticipate the action goal during the posttest. Results revealed a significant main effect for *Grasping Movement* (Wilks´ Λ = .41, $F(2,12) = 8.53$, $p = .005$, $\eta_P^2 = .59$), but no significant main effect for *Pre/Post* (Wilks' Λ = 1.0, $F(1,13) = .003$, $p = .96$, $\eta_P^2 = .00$), indicating that children's gaze latencies became significantly shorter over grasping movements but did not differ between pre- and posttest trials. An interaction between the factors *Grasping Movement* and *Pre/Post* was non-significant (Wilks' Λ = .68, $F = 2.8$, $p = .10$, $\eta_P^2 = .32$).

3.2.3 Manual Dexterity

On average, children made less than two mistakes in the *Bicycle Trail II* task (M = 1.11, SD = 1.23). Completing the *Placing Pegs* task with the dominant hand and the non-dominant hand took M = 28.06 sec, SD = 3.81 sec and M = 31.61 sec, SD = 6.09 sec, respectively. On average, children completed the *Threading Lace* task in M = 22.11 sec, SD = 4.31 sec.

The relationship between manual dexterity and anticipatory eye movements was analyzed by calculating correlations (Pearson's r) between latencies of pretest trials and standard scores of the Manual Skills Scale (M-ABC-2). On average, children reached a mean of M = 7.22 points, SD = 3.34 points (range: 1 - 11 points) in the *Bicycle Trail II* task. Further, children achieved a standard mean of M = 8.33 points, SD = 2.57 points (range: 3 - 13 points) in the *Placing Pegs* task with the dominant hand and M = 9.06 points, SD = 2.92 points (range: 4 – 14 points) with the non-dominant hand. In the *Threading Lace* task, children achieved M = 10.72 points, SD = 2.54 points (range: 6 – 14 points). Results revealed no significant correlations between the standard scores of the Manual Dexterity Scale and latencies of pretest trials, all $r(18) \leq .34$, $p \geq .17$.

3.3 Discussion

The aim of the second experiment was to investigate the influence of short-term experience on predictive eye movements during action observation in school children aged eight to ten years. Results showed that children in this age group are able to anticipate the action goals during the observation of a manually performed grasping action. However, we were again not able to show an influence of short-term experience with a block stacking task on predictive eye movements within this age group. Furthermore, we could not find a relationship between manual dexterity and the ability to anticipate action goals or the influence of short-term experience on anticipatory eye movements, respectively. This again indicates that manual fine motor skills do not have an influence on the ability to predict action goals during observation.

In the third experiment, we investigated whether short-term experience had an influence on predictive eye movements during action observation in teenagers aged 11 to 14 years.

4 Experiment 3: Teenagers (11-14 years)

4.1 Methods

4.1.1 Participants

Thirty-eight teenagers aged 11-14 years (M_{age} = 13.08 years, *SD* = 1.15 years, *Range*: 11.33 – 14.92 years) were considered for statistical analyses in the present experiment. All teenagers were right-handed and had normal or corrected-to-normal vision and were tested at Saarland University. Each teenager was assigned to one of two experimental conditions (1. Block Stacking Task_forehand, *N* = 19, 5 males, M_{age} = 13.01 years, *SD* = 1.13 years; 2. Puzzle_forehand, *N* = 19, 8 males, M_{age} = 13.15 years, *SD* = 1.19 years). Additional *N* = 13 teenagers were excluded from analyses due to insufficient gaze recordings (*N* = 7), turning out to be left-handed during the experiment (*N* = 3), experimenter errors (*N* = 1) or other reasons (*N* = 2). All parents were paid 7.50 Euro for participation and gave their informed consent prior to taking part. The experiment was conducted in accordance with the standards specified in the 1964 Declaration of Helsinki.

4.1.2 Materials & Stimuli

The identical stimuli as in the first two experiments were used. Eye movements were again recorded by means of a Tobii T60 eye tracker (17" TFT Monitor, sampling rate 60 Hz, accuracy 0.4°, Tobii, Sweden, Stockholm) during the observation of the experimental videos. The presentation of all stimuli and gaze recordings were controlled by Tobii Studio™ (Version 2.3.2.0).

Manual dexterity was assessed by the Manual Dexterity Scale for 11-16 year old children of the Movement Assessment Battery for Children (M-ABC-2;

Petermann, 2011), which consists of three manual tasks (Turning Pegs, Triangle with Nuts and Bolts, Bicycle Trail III).

4.1.3 Experimental Procedure

The experimental procedure was the same to that in the previous two experiments with the exception, that the cover story was omitted. However, teenagers were also asked to sound the horn, whenever they saw a non-completion trial.

Moreover, teenagers performed the Manual Dexterity Scale of the Movement Assessment Battery for Children (M-ABC-2; Petermann, 2011) for 11-16 year old teenagers. Teenagers were asked to perform the *Bicycle Trail III* task, a drawing task in which they should trace a narrow outline with a red pen without crossing the black border lines. For the case that the teenagers made errors during the first trail (crossing the black border) a second attempt was carried out. The attempt with the least errors was considered for analyses, with errors of that attempt summed up into one score. Second, teenagers should *turn pegs* which were sticking in a plug board with both hands successively, beginning with their dominant hand. Completion time was measured by using a stopwatch. Third, teenagers should *build a triangle* from given material (three side parts, three bolts and three nuts) with both hands. Completion time was measured by using a stopwatch.

4.1.4 Data Analyses

Gaze recordings of the six test trials were analyzed in the same way as in the previous two experiments by using purpose-written software (Python™). Again, teenagers' data was completely discarded when having less than three data points in more than two grasping movements ($N = 2$). Further, the first grasping movement (the movement of the first block) showed again a high number of missing values (22.4 % during pretest, 26.3 % during posttest) and a high number of reactive saccades with latencies higher than 100 ms (16.2 % during pretest, 17.1 % during posttest), thus, it was entirely discarded from analyses.

Moreover, reactive saccades with latencies higher than 100 ms (0.15 % of pretest trials and in 1.32 % of posttest trials) were discarded from analysis in the remaining grasping movements as well, for the same reasons discussed before. No grasping movements occurred having less than three data points after the exclusion of latencies > 100 ms from analyses; therefore, no further data had to be excluded. Following this procedure, $N = 38$ teenagers remained having sufficient (at least three data points) data for all three grasping movements in pre- and posttest and could be considered for statistical analyses.

For statistical analyses, we again calculated mean gaze latencies for grasping movements over trials, resulting in three mean gaze latency values for the pretest and three mean values for the posttest. Those values were further averaged into one score for pretest and one score for posttest for each child. Additionally, we calculated mean percentage scores of anticipatory eye movements for each grasping movement over trials, resulting in three mean percentage values for pretest and posttest.

Raw scores of the Manual Dexterity Scale of the Movement Assessment Battery for Children (M-ABC-2; Petermann, 2011) were converted into three standard scores ($M = 10$, $SD = 3$).

Statistics were analyzed using IBM SPSS Statistics (version 20.0). The level for significance was sat at $\alpha = 0.05$ and effect sizes were calculated using Cohen´s *d* for independent-samples *t*-tests and partial eta-squared (η_P^2) values for ANOVAs.

4.2 Results

4.2.1 Latencies

On average, teenagers' gaze preceded the subgoals of the block stacking task with a mean latency of $M = -385.3$ ms, $SD = 68.2$ ms and $M = -392.6$ ms, $SD = 64.4$ ms during pretest trials and posttest trials, respectively (see **Table 6**). Teenagers anticipated (with latencies up to 100 ms) the subgoals of the block stacking task in 95.3 % of trials during pretest and 93.3 % of trials during posttest.

Table 6. Summary of means and standard deviations for gaze latencies

	[a]BST_F *M (SD)*	[b]Puzzle_F *M (SD)*
Pre	-387.9 (47.1)	-382.2 (85.6)
Post	-417.1 (49.5)	-368.2 (69.2)

Note. BST = Block Stacking Task; F = forehand; *M* = Mean (in ms); *SD* = Standard Deviation (in ms).
[a]*N* = 19; [b]*N* = 19

A 3 (*Grasping Movement*) x 2 (*Pre/Post*) repeated measures MANOVA with both factors as within-subject factors was calculated to compare mean percentage values of anticipatory saccades over grasping movements during pre- and posttest. A significant main effect of *Grasping Movement* for mean percentage of anticipatory saccades (Wilks' Λ = .84, $F(2,36) = 3.47$, $p = .04$, $\eta_P^2 = .16$) was revealed, whereas no significant main effect for *Pre/Post* was obtained (Wilks' Λ = .96, $F(1,37) = 1.72$, $p = .20$, $\eta_P^2 = .04$). However, a significant interaction between the factors *Grasping Movement* and *Pre/Post* was revealed (Wilks' Λ = .80, $F(2,36) = 4.49$, $p = .02$, $\eta_P^2 = .20$). Post-hoc comparisons showed that mean percentage values of pre- and posttest differed significantly for the second grasping movement ($t(37) = 2.49$, $p = .02$, $d = .44$), whereas mean percentage values did not differ between pretest and posttest for the third ($t(37) = -.62$, $p = .54$, $d = .06$) and forth ($t(37) = .00$, $p = 1.0$, $d = .00$) grasping movement (see **Table 7**).

Table 7. Mean percentage of anticipatory saccades during pre and posttest

	GM2 *M (SD)*	GM3 *M (SD)*	GM4 *M (SD)*
Pre	95.6 (8.39)	96.1 (7.18)	94.3 (10.5)
Post	89.9 (16.2)	95.6 (10.0)	94.3 (11.8)

Note. GM = Grasping Movement; *M* = Mean (in percentage); *SD* = Standard Deviation.

4.2.2 Manual Experience

A 2 (*Pre/Post*) x 3 (*Grasping Movement*) x 2 (*Group*) repeated measures MANOVA with the first both factors as within-subject factors and the third one as a between-subject factor was applied on mean gaze latencies to test whether task-specific experience with the block stacking task led to differences in the ability to anticipate the action goals of the block stacking task during the observation of posttest trials. Results revealed a significant main effect for *Grasping Movement* (Wilks' $\Lambda = .70$, $F(2,35) = 7.45$, $p = .002$, $\eta_P^2 = .30$), but no significant main effect for *Pre/Post* (Wilks' $\Lambda = .99$, $F(1,36) = .54$, $p = .47$, $\eta_P^2 = .02$), or *Group* ($F(1,36) = 2.20$, $p = .15$, $\eta_P^2 = .06$), indicating that teenagers' gaze latencies became significantly shorter over grasping movements but did not differ between pre- and posttest trials and groups. However, the predicted interaction between the factors *Pre/Post* and *Group* was significant (Wilks' $\Lambda = .89$, $F(1,36)= 4.51$, $p = .041$, $\eta_P^2 = .11$). Planned comparisons revealed that the block stacking task group showed significantly shorter mean gaze latencies in posttest trials ($t(18) = 2.51$, $p = .02$, $d = .60$), whereas mean gaze values of the puzzle group did not differ between pre- and posttest ($t(18) = -.83$, $p = .42$, $d = .29$, see **Figure 11**).

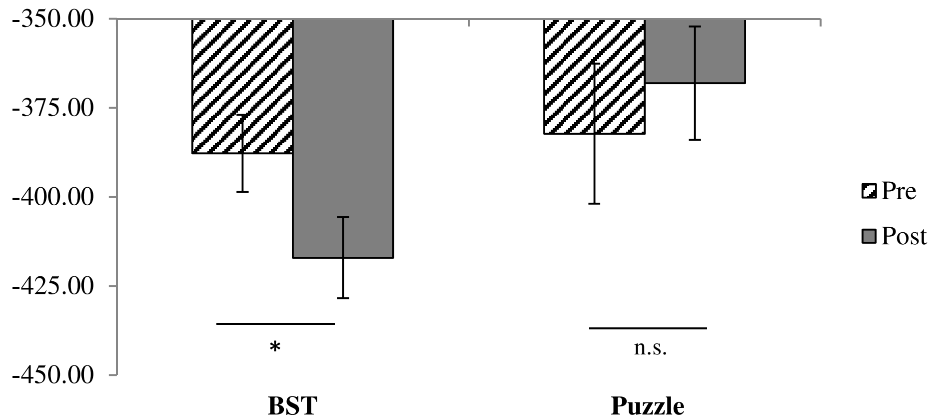

Figure 11. Mean gaze latencies for pre- and posttest averaged over grasping movements (except grasping movement 1) for both experimental conditions. BST = Block Stacking Task. Vertical bars indicate standard errors. *p < 0.05. n.s. = p > .05.

4.2.3 Manual Dexterity

On average, teenagers made less than two mistakes in the *bicycle trail III* task, $M = 1.76$, $SD = 2.52$. Completing the *turning pegs* task with the dominant hand and the non-dominant hand took $M = 23.3$ sec, $SD = 4.59$ sec and $M = 24.6$ sec, $SD = 4.84$ sec, respectively. On average, teenagers completed the *Triangle* task in $M = 51.1$ sec, $SD = 16.0$ sec.

The relationship between manual dexterity and anticipatory eye movements was analyzed by calculating correlations (Pearson's *r*) between latencies of pretest trials and standard scores of the Manual Skills Scale (M-ABC-2). On average, teenagers reached a mean of $M = 9.13$ points, $SD = 3.17$ points (range: 1 - 13 points) in the *Bicycle trail III* task. Further, teenagers achieved a standard mean of $M = 6.50$ points, $SD = 3.49$ points (range: 1 - 16 points) in the *Turning Pegs* task with the dominant hand and $M = 8.05$ points, $SD = 2.85$ points (range: 1 – 15 points) with the non-dominant hand. In the *Triangle* task, teenagers achieved $M = 6.71$ points, $SD = 2.82$ points (range: 1 – 12 points). Results revealed no significant correlations between the standard scores of the Manual Dexterity Scale and latencies of pretest trials, all $r(38) \leq .26$, $p \geq .116$.

4.3 Discussion

The aim of the third experiment was to investigate the influence of short-term experience on predictive eye movements during action observation in teenagers aged 11 to 14 years. The most salient finding of this experiment was that teenagers who performed the block stacking task directed their gaze significantly faster to action goals during post-test trials, compared to teenagers who performed puzzles, indicating the influence of task-specific short-term experience on anticipatory eye movements. In accordance with the previous two experiments and the study with adults, we could not find a relationship between manual dexterity and the ability to anticipate action goals or the influence of short-term experience on anticipatory eye movements, respectively. This again indicates that manual fine motor skills do not have an influence on the ability to predict action goals during observation.

5 Discussion

The aim of the present study was to investigate the influence of task-specific short-term experience on the ability to predict action goals of the same or a similar action during observation in children. Moreover, we aimed to disentangle whether the impact of short-term experience on action understanding would change during childhood. To this end, we investigated three age groups of children (4-6 years, 8-10 years, and 11-14 years) with a pre-post design using eye tracking. First, children observed short video clips of an actor performing a block stacking task. Subsequently, they either performed the same block stacking task or puzzles. For preschoolers, the block stacking task and puzzles were performed in two different congruency conditions (anatomically congruent / spatially congruent). For the other two age groups, only the spatially congruent condition was performed. Finally, children again observed the same video clips shown during the pre-test. No significant effect of spatial or anatomical congruency could be found between both block stacking task groups and both puzzle groups in preschoolers, indicating that the execution of a congruent or incongruent anatomical movement (backhand vs. forehand) did not affect the ability to predict action goals. This finding is in line with our first study indicating that the different congruency conditions did not influence the ability to predict action goals. As already discussed in the study with adults, this finding is in correspondence with studies showing sparse influence of postural congruency between the observer and the agent on behavioral results (Alaerts, Heremans, et al., 2009; Alaerts, Swinnen, et al., 2009; Urgesi et al., 2006) and on motor resonance (Sartori et al., 2013). This illustrates that a direct matching mechanism flexibly transforms others' movement features into the observer's optimal motor commands.

Concerning action understanding, we were able to show that children from four years up to 14 years of age are able to understand others' grasping actions indicated by goal-directed predictive eye movements during observation of the block stacking task. This finding is in accordance with several other studies showing that even infants are able to anticipate the action goals of others' actions (e.g., Falck-Ytter et al., 2006; Kochukhova & Gredebäck, 2010).

However, our data suggests that although preschoolers are able to anticipate the subgoals of a block stacking task, the percentage of anticipated subgoals increases with the course of the ongoing action, indicating that preschoolers are more likely able to predict later action steps compared to earlier action steps. This finding is in line with the predictive coding account (Kilner et al., 2007) which suggests that information about the ongoing action is continuously updated and integrated in the prediction process of ongoing actions. Hence, later action steps benefit from available information about prior action steps. However, in our studies, adults and children older than eight years were able to anticipate early action steps of the block stacking task to the same extent as later action steps. This might indicate that the prediction process of older children and adults is more proficient, whereas preschoolers seem to have more difficulties to represent the final action goal at early stages of the ongoing action. This interpretation makes sense in such ways that several studies have shown that the mirror neuron system adapts in relation to prior experience (e.g., Calvo-Merino et al., 2005). Hence, it is reasonable to assume that higher age is associated with a number of different experiences that modulate the functioning of the mirror neuron system which allows older children and adults to make more precise predictions at earlier steps of ongoing actions.

The most important finding of this study was that short-term experience influenced anticipatory eye movements in teenagers between 11 and 14 years, but not in younger children. Teenagers who had performed the block stacking task showed shorter gaze latencies during post-test trials compared to teenagers who had performed puzzles. This finding is in line with our first study showing that short-term experience enables adult observers to predict the action goals of the same action faster. Moreover, the influence of experience on the ability to predict action goals has recently been reported in several studies for adults (e.g., Mulligan & Hodges, 2013) as well as infants (e.g., Sommerville et al., 2005). In accordance with these studies, we assume that short-term experience enhances the activation of task-specific action programs which enable the observer to predict the action goals of the same action faster. Interestingly, only the oldest age group of the present study showed this effect, although even infants have been demonstrated to show an improved ability to understand others' actions after a period of own experience. This finding might be directly linked to the fact that the brain undergoes a fast and remarkable development within the first months of life. Hence, it might be the case that a short amount of experience is enough to modulate infants' action-observation matching system, whereas the brain of preschoolers and young school children might be less sensitive to a brief period of training with grasping actions. Some authors suggest that the mirror neuron system – the neuronal substrate underlying action understanding – develops from infancy up to adolescence through pruning processes and through the influence of experience on the developing brain (Kilner & Blakemore, 2007). Thus, our data might reflect that the pruning of the mirror neuron system at the age of 11 years is proceeded so far, that it allows young teenagers to benefit even from a brief period of training during the observation of the same action. Another possible explanation could be that due to developmental changes of saccadic eye movements only the older age group was able to benefit from a short-term training. A study, investigating the development of saccadic eye movements in 6- to 15-year-old children with several paradigms reported that children's latencies of saccadic eye movements became shorter with increasing age up until 12 years (Bucci & Seassau, 2012). In our study, the oldest age group comprised teenagers between 11 and 14 years, hence, the latencies of saccadic eye movements of this group were developed further than those of the other two age groups. It might be possible that the effect of task-specific experience only occurred in the oldest age group because their control of saccadic eye movements allowed them to produce faster saccades than during pretest trials, whereas preschoolers or young school children already reached their limit and could not produce faster eye movements. A third possible explanation might be that the amount of training was not sufficient enough for children between four to ten years to impact predictive eye movements during action observation. In order to verify or falsify this assumption further studies with varying amounts of training periods are necessary.

In sum, the present study was able to show that children between four and 14 years are able to predict action goals of observed actions, although developmental changes in the percentage of anticipated action goals became apparent. Moreover, only teenagers between 11 to 14 years showed an effect of short-term experience in their ability to anticipate the action goals of the block stacking task. This might be due to developmental changes in the mirror neuron system, in the control of saccadic eye movements or due to a too short training period for the younger age groups. Further studies are necessary to investigate these possible explanations in a systematical manner. However, our study provides evidence that a direct matching process is already present in childhood and that anticipatory eye movements are strongly related to task-specific action plans at least from the age of 11 years onwards.

Chapter 5: General Discussion

The present dissertation aimed to investigate whether a relatively short amount of manual experience with an action would improve action understanding during the subsequent observation of the same action in adults and children.

To this end, we conducted three studies in which we employed a block stacking task similar to that used in the prominent study by Flanagan and Johansson (2003) in a pre-post eye tracking design. During pre- and posttest, adults as well as children watched short video clips showing an actor performing the block stacking task. Intermediately, participants either performed the same block stacking task or one of two control tasks (puzzles or pursuit rotor task). We assumed that short-term experience with the block stacking task should activate task-specific action plans supporting a direct matching process during the observation of posttest trials. Further, puzzles were applied as a first control task with the purpose to activate similar action plans comparable to those of the block stacking task, as both the block stacking task and puzzles shared several features. In the study with adults, a second control task – a pursuit rotor task – was employed, which required participants to follow a moving red dot on a circular track with their index finger. We assumed that experience with the pursuit rotor task would activate action plans different from those activated by the block stacking task and puzzles, hence, not having an influence on action understanding during the observation of posttest trials.

In the first two studies reported within this thesis, we aimed to investigate the impact of task-specific short-term experience on different measures of action understanding in adults. Specifically, we investigated whether a brief period of experience would affect anticipatory eye movements or pupil dilation during observation of the same action. In the third study, we took a closer look at the developmental course of action understanding by investigating whether the impact of short-term experience on anticipatory eye movements would change from early childhood to adolescence.

5.1 The Impact of Short-term Experience on Anticipatory Eye Movements

Within the first and the third study of the present dissertation, we investigated the impact of task-specific short-term experience on anticipatory eye movements. The results of these two studies indicated that adults as well as children between four and 14 years showed anticipatory eye movements during the observation of someone else performing a block stacking task. This finding is in line with previous research which has shown that anticipatory eye movements occur during both action execution and action observation (Falck-Ytter et al., 2006; Flanagan & Johansson, 2003; Gesierich et al., 2008). Within these studies, anticipatory eye movements have been interpreted as indicators of activated action plans in the observer, or in other words, that anticipatory eye movements reflect a direct matching process. A recent study using transcranial magnetic stimulation (TMS) and eye tracking confirmed this interpretation by showing that anticipatory eye movements during observation are indeed directly linked to the observer's corresponding action plans (Elsner et al., 2013). These results provide strong evidence that the ability to predict observed actions is realized by a direct matching process located in the mirror neuron system of the observer which is measurable via anticipatory gaze behavior.

5.1.1 The Impact of Short-term Experience

According to the findings described above, we questioned whether a brief amount of experience with the block stacking task would activate task-specific action plans, which in return would enhance action understanding during observation of the same block stacking task. We were indeed able to show that short-term experience with a block stacking task enhanced participants' action understanding during the subsequent observation of the same block stacking task in such ways that participants directed their gaze significantly faster to the action goals of the block stacking task. In contrast, participants who had performed a pursuit rotor task or puzzles did not show this effect at all or to a lesser extent, respectively. This finding indicates that short-term experience with an action activates task-specific action plans which enable a person to perceive the action goals of the same action faster when observing someone else performing this action. This finding is in line with previous studies demonstrating that short-term action experience has an influence on the ability to recognize and predict actions during observation (Casile & Giese, 2006; Marshall et al., 2009; Quandt et al., 2011). However, whereas previous studies could find this effect for behavioral or neurophysiological measures, evidence for an impact of short-term experience on gaze behavior is sparse. To our knowledge, only one other study shed some light on this issue by showing that participants with a higher amount of experience were able to predict action outcomes faster and more precise (Taya et al., 2013). However, although the aforementioned study delivered some valuable evidence for this thesis, it did not systematically investigate whether short-term experience would affect participants' gaze behavior. Hence, with our study we were able to fill this gap by showing that even a brief amount of experience is sufficient enough to activate task-specific action plans that enable an observer to predict the action goals of others' actions faster.

5.1.2 Congruency

Within our studies adults and children between four and six years were trained in two ways: (1) with anatomical congruency which means that participants performed the action exactly like they had observed it – with exactly the same anatomical movement (backhand movement). On the other hand, participants were trained (2) with spatial congruency which means that they performed the block stacking task spatially congruent with the observed video stimuli. This resulted in a forehand movement in contrast to the movement seen in the video clips. By varying the anatomical congruency between the performed and observed action, we intended to investigate whether the specific kinematics of an action would have an impact on the ability to anticipate the action goals of the same action after the training.

No significant effect of congruency could be found in both adults and children in our studies, indicating that the performance of a congruent or incongruent anatomical movement (backhand vs. forehand) does not affect participants' latency of anticipatory fixations. This finding stands in line with studies showing sparse influence of postural congruency between the observer and the agent on behavioral results (Alaerts, Heremans, et al., 2009; Alaerts, Swinnen, et al., 2009; Springer et al., 2011; Urgesi et al., 2006). Furthermore, Sartori et al. (2013) have recently shown that motor resonance occurred in the observer's dominant hand, regardless of the hand preference being observed. This suggests that a direct mapping mechanism is able to convert others' movement features into the observer's optimal motor commands.

5.1.3 Visual Experience vs. Motor Experience

Another aspect which needs to be discussed is whether the effect of short-term experience on anticipatory eye movements occurred due to visual or motor experience. We argue that this is not caused by visual experience, since studies investigating the influence of motor and visual experience on anticipatory skills during action observation have demonstrated that an improvement of anticipatory skills occurred relatively independent of visual experience (Casile & Giese, 2006; Mulligan & Hodges, 2013). For example, in a training study conducted by Mulligan and Hodges (2013) the amount of visual experience was systematically manipulated. Specifically, two groups of participants were trained to throw darts towards specific areas of a dartboard whereas two other groups did not receive a motor training. The two motor training groups differed in such ways that one group was trained blindfolded, and thus, only gained motor experience, whereas participants of the other group were allowed to view their own actions. The two control groups differed in such ways that one group was allowed to observe other participants throwing darts at the board, whereas the other group was neither allowed to observe dart throws nor to perform dart throws. Before and after the training, all participants were asked to predict landing positions of dart throws on temporally-occluded video stimuli. The results of this study have shown that both the vision and the no-vision motor training group significantly improved to predict the landing position of dart throws during the post-test with no difference between them, whereas control groups did not improve at all, indicating that visual experience had no impact on the ability the predict action goals. This finding finds support in other studies showing a superior effect of motor experience over visual experience on the ability to understand others' actions (Calvo-Merino et al., 2006; Casile & Giese, 2006). The results of these studies indicate that observed actions are understood in terms of their activated motor representations independent of visual knowledge about the actions.

Although visual and motor experience are confounded in our study, our results still contain some evidence that visual repetition did not cause an improved action understanding during the observation of posttest trials: Participants who received a training with the pursuit rotor task did not show shorter gaze latencies during posttest trials. This finding indirectly provides evidence, that visual experience with the block stacking task did not cause an improved action understanding in posttest trials. Hence, according to the studies reported above and our finding that the pursuit rotor group did not show any effect of visual experience, we assume that the motor training was the crucial aspect to activate underlying action plans.

5.1.4 Transfer

Moreover, the finding that participants directed their gaze significantly faster to action goals of a block stacking task after they received a brief amount of training with this action can also be interpreted in the light of transfer between related domains. According to Thorndike's (1906, 1914) identical elements theory, transfer is most likely to occur between tasks with identical elements. This assumption is in line with our findings that the most successful transfer occurred between experience with the block stacking task and the observation of post-test trials. In contrast, experience with puzzles, which can be considered as a similar, but not identical task, led to some degree to transfer, although to a significantly lesser extent than the block stacking task. The pursuit rotor task as a rather distinct task did not lead to successful transfer at all during the observation of the block stacking task. Further, Barnett and Ceci (2002) proposed a taxonomy of transfer with the purpose to classify contextual and content dimensions along which transfer could occur. In the context of this taxonomy, our results can be discussed as *near* transfer effects. Whereas experience with the block stacking task led to clear near (same content, same context) transfer effects during the perception of the block stacking task, experience with puzzles was transferred to a lesser extent during the observation of the block stacking task. This can be explained by a larger distance between both tasks in the content dimension (similar content, same context). Experience with the pursuit rotor task did not show successful transfer, again explained by a farther distance between the tasks (different content, same context). The occurrence of transfer has further been discussed to be dependent on experience. A recent model (Rosalie & Müller, 2012) considers the degree of expertise on successful transfer, assuming that a higher level of expertise is characterized by an increase in experience and as a consequence, leads to a higher extent of successful transfer. Studies investigating the influence of experience on successful transfer between tasks have shown, that experience in one domain will enable successful transfer in a related domain (Causer & Ford, 2014; Rosalie & Müller, 2014). Concerning our results, this implies that even a small amount of experience with the block stacking task facilitates the perception of the same task, whereas experience with different tasks does not allow successful transfer. Again, puzzles can be considered as a similar task to the block stacking task and therefore, leading to a less pronounced transfer.

5.1.5 Task-Specificity

Within our studies, we were able to show that the effect of short-term experience occurred in a highly task-specific manner. This finding is supported by the fact that we were not able to find any correlation between the ability to predict action goals and manual dexterity. Hence, participants who had higher manual dexterity scores did not automatically show a better ability to anticipate grasping actions. This means, that the ability to anticipate action goals is strongly dependent on the task – specifically, how much experience an individual possesses with a task in order to activate action programs which enable action understanding. This interpretation is in line with studies showing that experience with one action usually leads to an improved understanding of exactly this action, indicated by e.g., higher recognition rates, more precise prediction of action outcomes, stronger neurophysiological responses, or better imitation abilities (Casile & Giese, 2006; Marshall et al., 2009; Quandt et al., 2011). In our study, we were able to show that even a brief period of own experience causes a task-specific improvement in action understanding, indicated by shorter gaze latencies of goal-directed saccades.

5.1.6 Interim Conclusion

To sum up, in accordance with the direct matching hypothesis short-term experience with the same task led to task-specific changes in the latency of anticipatory eye movements during observation. These changes cannot be explained due to visual experience, but rather by active motor experience with an action. Moreover, differences in the spatial and anatomical congruency between an observed action and the trained action did not have an impact on the ability to anticipate action goals of the same action. Taken together, our studies provide evidence that anticipatory eye movements can be taken as indicators of activated task-specific action knowledge, and thus, supporting the assumption that action execution and action perception are intrinsically linked.

5.2 The Impact of Short-term Experience on Pupil Dilation

Within the second study we investigated whether task-specific short-term experience has an impact on pupil dilation during the observation of unsuccessfully performed actions. Pupil size changes have previously been reported to be one possibility to assess action understanding in an observer (Gredebäck & Melinder, 2010) in such ways that participants' pupils dilated whenever an unexpected action outcome was observed. This result is explained by the assumption that the prediction error reflects individuals' expectations about the action outcome – that participants understood where the action should have led to – but that the evaluation of the observed action outcome resulted in a mismatch between what was expected and what actually happened. As a consequence, a state of surprise occurred in the observer which could be measured via pupil dilation.

5.2.1 Prediction Error

In our study, participants observed successfully and unsuccessfully performed versions of the block stacking task. The results indicated higher pupil dilation values when participants observed the unexpected action outcomes compared to successfully performed actions. This finding is in line with several recent studies reporting pupil dilation as a result of surprise or a violation of expectations (e.g., Kloosterman et al., 2015; Lavín, San Martín, & Rosales Jubal, 2014). Hence, participants were able to understand the correct action goal of the block stacking task, and were surprised by the violation of their expectation about how the action should be completed. Moreover, participants were surprised by the unexpected abrupt termination of the action, which demonstrates that pupil dilation is a measure that is related to a broad variety of expectation violations – rather than merely reflecting the violation of expected action outcomes. This finds support in several studies reporting pupillary responses as a consequence of violations of expectations in gambling tasks (Preuschoff, 2011), in the perception of body movements (Morita et al., 2012), or in the perception of social interactions (Gredebäck & Melinder, 2011). With our study, we were able to demonstrate that an unexpected event within a simple grasping action results in pupil dilation as well.

5.2.2 The Impact of Short-term Experience

Since we were able to show that anticipatory eye movements can be influenced by own short-term experience, we questioned whether a different measure of action understanding – pupil dilation – would also be impacted by own experience. Although, we could not find an influence of task-specific motor experience on pupil dilation, we were able to show that the pupillary response decreases when an unexpected event is presented visually for a second time. It is possible, that this finding can be explained due to the fact that participants used the visual experience to discriminate kinematic cues of the unsuccessful actions earlier when observing them a second time. Some recent studies have shown that people are very proficient in perceiving and using subtle kinematic cues in order to understand others' actions (Ambrosini et al., 2015). It is very likely that participants perceived minimal kinematic differences between the successful and unsuccessful action sequences so that they were able to use this information for their prediction process. In line with this, it is important to note that the prediction process is characterized by a continuous updating and integrating of new information (Kilner et al., 2007). Hence, when gaining new information about unsuccessful actions, this information is directly fed in the prediction processing system and can be used for future predictions. Moreover, the moment the first unsuccessful action occurred might have prompted the participants' preparedness of these trials, which might have inhibited the extent of surprise when they observed an error for the second time. However, although it has been previously reported that the pupillary response decreased when stimuli have been repeatedly presented (e.g., Lowenstein & Loewenfeld, 1952) or by upcoming fatigue during the experiment (e.g., Hess, 1972), it is unlikely that the effect found in our study was caused by these reasons. On the one hand, the unsuccessful trials were only presented once per test block with several successful trials and attention grabbers in between. Hence, no habituation towards these trials could have happened. On the other hand, our study was relatively short, so that it is unlikely that participants experienced some upcoming fatigue during the experiment. Moreover, pupillary responses remained stable for test trials, although the number of test trials was three times higher for both pre- and posttest. Hence, an effect of habituation or tiredness would have been more likely for those trials. As such, we argue that our result reflects that visual experience with specific unexpected events caused participants to be aware of these types of actions and integrate them as possible outcomes in their prediction process.

5.2.3 Dissociation between Measures of Action Understanding

Within this thesis, we investigated two measures of action understanding – anticipatory eye movements and pupil dilation. One of our main research questions was, whether these two measures are related to each other to some degree. A recent study reported that higher pupil sizes indicated the preparation of saccadic eye movements in an anti-saccade paradigm (Wang, Brien, & Munoz, 2015). However, this design differed in many aspects from our study, especially in the fact that we applied pupil dilation as a post-hoc measure, whereas the authors of the aforementioned study measured pupil dilation online. Moreover, our stimuli were rather complex compared to an anti-saccade paradigm, and even more important, contained a perceivable action outcome. Thus, pupil dilation in our study indicated an evaluation process after the observation of an action outcome, rather than a preparatory process to elicit or inhibit a saccade. Nevertheless, the aforementioned study suggested that pupil dilation is modulated by neural structures, namely the superior colliculus and the frontal eye field, that are responsible for the preparation of saccades in an anti-saccade paradigm.

However, we were not able to show any relation between anticipatory eye movements and pupil dilation within our studies. This might be due to several reasons: One possible explanation for these findings might lie in the brain structures underlying anticipatory eye movements and pupil dilation during action understanding. As described in previous sections, anticipatory eye movements are supposed to be part of the motor system in the brain which is activated in a somatotopically manner during action observation and action execution. Neuroimaging studies have supported this assumption by showing that anticipatory eye movements are delayed during the observation of manual actions when according brain areas are inhibited by applying TMS pulses (Elsner et al., 2013). In contrast, pupil responses that reflect prediction errors or surprise have been reported to be linked to the locus coeruleus (Koss, 1986; Rajkowski et al., 1993), which is the main cortical structure associated with the regulation of the neuro-transmitter norepinephrine (Aston-Jones & Cohen, 2005). Due to these different underlying neural substrates, it is very likely that motor experience only affects anticipatory eye movements, whereas pupil dilation remains unaffected. This makes sense, when considering that eye movements are part of a motor program that can be activated by experience, whereas pupillary responses are driven by a brain structure responsible for arousal and focusing attention.

Another possible explanation for the missing relationship between anticipatory eye movements and pupil dilation is the fact that we applied anticipatory eye movements as an online measure, whereas we applied pupil dilation as a post-hoc measure of action understanding. A dissociation between online and post-hoc measures has previously reported for predictive gaze and looking time in infants (Daum et al., 2012). Although both measures were integrated by the age of three years, it is still evident that post-hoc measures indicate a different type of expectation than online measures. For the results of our thesis, we argue, that anticipatory eye movements reflect expectations about upcoming action steps, whereas pupil dilation reflects the evaluation of the action outcome after the action was completed. Although both measures clearly indicate action understanding, they reflect different aspects of it.

5.2.4 Interim Conclusion

Taken together, the second study oh this thesis supports previous findings that pupil responses reflect the violation of expectations in an individual. Hence, pupil responses are suited to measure action understanding in an observer. However, in contrast to anticipatory eye movements, the extent of this response was independent of own task-specific experience with the observed action. Nevertheless, it can be assumed that visual experience had an influence on the strength of the prediction error.

5.3 Development of Action Understanding

One aim of this thesis was to disentangle whether developmental changes in the ability to understand others' actions would occur during childhood, and whether the impact of experience would affect action understanding indicated by anticipatory eye movements.

The results of the third study of the present thesis indicate that children from four years up to 14 years of age are able to understand others' grasping actions indicated by goal-directed anticipatory eye movements during observation of a block stacking task. This finding is in accordance with several other studies showing that even infants are able to anticipate the action goals of others' actions (e.g., Falck-Ytter et al., 2006; Kochukhova & Gredebäck, 2010).

Moreover, our results indicate a developmental change in action understanding reflected by an increase in the percentage of anticipated subgoals of the observed block stacking task. Whereas school children and teenagers are able to reliably anticipate every subgoal of the block stacking task, preschoolers were more likely to anticipate later action steps compared to earlier action steps. We explain this finding in such ways that preschoolers need more information about an action to generate a precise prediction of the action goal compared to older children and adults. The predictive coding account (Kilner et al., 2007) suggests that information about the ongoing action is continuously updated and integrated in the prediction process of ongoing actions, and that top-down processes are integrated in the prediction process. Hence, in order to reliably generate predictions, an individual needs to possess prior knowledge about kinematics and their possible outcome, about contexts in which actions occur, and moreover, a functional direct matching system. Our results can be explained by both – that preschoolers lack specific action knowledge that would have allowed them to produce faster predictions – or, that the direct matching process of preschoolers is not yet fully developed. Both interpretations make sense in such ways that several studies have shown that the mirror neuron system adapts in relation to prior experience (e.g., Calvo-Merino et al., 2005), and moreover, that the mirror neuron system underlies developmental changes due to pruning processes of the brain (e.g., Kilner & Blakemore, 2007). Hence, it is reasonable to assume that higher age is associated with a number of different experiences that modulate the functioning of the mirror neuron system which allows making more precise predictions at earlier steps of ongoing actions. This assumption is also supported by two recent studies showing a developmental trend in the ability to plan actions (Barlaam et al., 2012; Jongbloed-Pereboom, Nijhuis-van der Sanden, Saraber-Schiphorst, Crajé, & Steenbergen, 2013). Jongbloed-Pereboom and colleagues (2013) reported an increased anticipatory action planning in children ranging from three to 10 years. Moreover, Barlaam et al. (2012) was able to show that teenagers between 11 and 16 years differed from adults in their anticipatory abilities to control their body postures in a lifting task, indicating that anticipatory abilities underlie developmental processes from childhood throughout adolescence up to adulthood.

The most important finding of this study was that short-term experience influenced anticipatory eye movements in teenagers between 11 and 14 years, but not in younger children. We explain our findings in such ways that our data might reflect that the mirror neuron system is developed so far at the age of 11 years that it allows young teenagers to benefit even from a brief period of training during the observation of the same action, whereas younger children might need more experience in order to benefit from it to the same extent. This interpretation is in line with studies discussing that own experience modifies this mirror neuron system and modulates its functioning throughout childhood (Shimada & Hiraki, 2006; van Elk et al., 2008).

Another possible explanation is the occurrence of developmental changes of saccadic eye movements during childhood. A study, investigating the development of saccadic eye movements in 6- to 15-year-old children with several paradigms reported that children's latencies of saccadic eye movements became shorter with increasing age up until 12 years (Bucci & Seassau, 2012). In our study, the oldest age group comprised teenagers between 11 and 14 years, hence, the latencies of saccadic eye movements of this group were developed further than those of the other two age groups, which might have resulted in the finding that only the older age group was able to benefit from a short-term training.

5.3.1 Interim Conlusion

In sum, the present study was able to show that children between four and 14 years are able to predict action goals of observed actions, although developmental changes became apparent. Moreover, only teenagers between 11 to 14 years showed an effect of short-term experience in their ability to anticipate the action goals of the block stacking task, which might be explained due to developmental changes in the mirror neuron system, or in the control of saccadic eye movements. However, our study provides evidence that a direct matching process is already present in childhood and that anticipatory eye movements are strongly related to task-specific action plans.

5.4 Limitations & Implications for Future Research

Our studies provide valuable evidence for the interface between action and perception and the impact of short-term experience on this relationship. However, some limitations need to be discussed in the following sections.

5.4.1 Study 1

In the first study, we were able to show a task-specific influence of short-term experience on anticipatory eye movements. However, we were not entirely able to show whether this effect occurred due to visual or motor experience, or a combination of both. Although our results indicate some evidence for the impact of motor experience, further studies are necessary to disentangle the specific influence of visual and motor experience on the ability to anticipate action goals.

Moreover, although to a lesser extent, experience with puzzles also led to shorter gaze latencies during the observation of the block stacking task. Further research is necessary to investigate the influence of task-specific experience in order to determine which aspects are crucial to activate task-specific action plans. In our study, one aspect that might have made a difference between puzzles and the block stacking task is the sequential or non-sequential way of training: Whereas the block stacking task was repeatedly performed in a fixed sequence, the puzzle pieces were placed in into the goal position in a random sequence. It might be possible that participants were able to predict the action goals of the block stacking task faster due to this sequential structure. This assumption is in line with studies showing that people easily learn sequential order – even when they are not conscious about them (Nissen & Bullemer, 1987; Weiermann, Cock, & Meier, 2010). Hence, future studies could investigate whether the sequential structure of an action improves the activation of underlying task-specific action plans, and therefore, improves action understanding in a subsequent observation of the same action. Moreover, the amount of training was fairly small and to this point, it remains unclear whether a longer period of training would have yielded a more successful transfer effect in the puzzle group.

Furthermore, our study provided indirect evidence for a direct matching process in adults, and that action plans can be activated by own experience. In order to investigate the activation of task-specific action plans further, future studies could implement different types of training – for instance, motor imagery in which no open behavior is required. Several previous studies suggest that action plans can be activated by own action, observation, or even by the mere imagination of an action (Filimon, Nelson, Hagler, & Sereno, 2007; Jeannerod, 2001), and that eye movements are comparable during action execution, action observation and action imagery (Causer et al., 2013). Hence, it would be of interest whether an imagined short-term experience with an action would also result in shorter gaze latencies during the observation of an action.

5.4.2 Study 2

Within the second study, we intended to investigate the impact of short-term experience on prediction errors measured via pupil dilation. Moreover, we intended to disentangle the relationship between anticipatory eye movements and pupil dilation. However, since this study was a further analysis of already collected data, it contains some weaknesses. First, we were only able to analyze pupil dilation in relation to unexpected action outcomes for one trial, which makes our results less reliable. Moreover, we compared anticipatory eye movements of test trials with pupil dilation values of unsuccessful action trials. Hence, it is not clear, whether both measures are really independent of each other or whether this independence occurred because of the different stimulus material. Further studies are necessary to systematically investigate the dissociation between online and post-hoc measures of action understanding. A first attempt in that direction was realized by Daum and colleagues (2012) who reported a dissociation between predictive gaze and looking time in infancy and early childhood. Concerning predictive gaze and pupil dilation during action observation, Gredebäck & Melinder, (2010) argued for a dual process account in which predictive saccades reflect the prediction of upcoming action goals, whereas pupil dilation reflects the evaluation of action outcomes.

However, the relationship between anticipatory eye movements and pupil dilation requires further studies that systematically investigate both measures in action sequences with an expected and unexpected action outcome. Moreover, it is important to compare pupil dilation as an online and as a post-hoc measure. Some recent studies provide evidence, that pupil dilation as an online measure is directly related to the preparation of goal-directed saccades (Mathôt et al., 2015; Wang et al., 2015), indicating that both measures relate to each other when applied online.

5.4.3 Study 3

Within the third study, we intended to investigate the impact of short-term experience on anticipatory eye movement in children, and whether there are some developmental changes between four to 14 years. We cannot clearly answer the question why preschoolers did not show an effect of short-term experience on anticipatory eye movements. One reason might be that the training duration was too short for preschoolers to activate task-specific action plans. This issue is supported by the observation that only preschoolers had difficulties in the beginning to perform the block stacking task themselves. Whereas older children and adults were able to perform the block stacking task immediately, many preschoolers needed some guidance in the first trials. This might reflect that preschoolers did not have a representation about the final action goal of the block stacking task in the beginning. Further studies are necessary to investigate whether more training trials would bring up the same effect as in teenagers or adults.

Another limitation of our third study is that we assessed many preschoolers in their kindergartens, whereas older children were tested in our lab. It is possible that the data of preschoolers suffered from influences due to the different testing situation (e.g., noise in the kindergarten; disruptions because of people entering the room; different light conditions). This problem is reflected in the high number of dropouts, which had to be discarded from analyses mainly because of insufficient gaze data. In order to make clear statements about the influence of short-term experience on gaze behavior in preschoolers, it is necessary to conduct further studies in which these problems are controlled.

Moreover, we used the same stimuli for adults as well as children. It might be possible that the velocity of the single grasping actions was too high for younger children. Since saccadic eye movements develop throughout childhood up to adolescence (Bucci & Seassau, 2012) it might be possible that young children reached their limit in the velocity of their saccadic eye movements already during the pretest. Here, it would be necessary to produce stimuli with a lower velocity to investigate whether the high velocity masked the influence of short-term experience.

Chapter 6: Conclusion & Outlook

The present thesis provides evidence for a relationship between action and perception. By demonstrating that adults as well as children are able to anticipate the action goals of a manually-guided action, we indirectly showed that action execution as well as action perception draw on the same representations. Moreover, we were able to show that a short amount of experience with an action is sufficient enough to activate task-specific action knowledge in adults and teenagers. Although preschoolers and school children did not benefit from a short-term training, we were able to show a developmental course in the prediction of action goals in these age groups. Future studies should aim to further investigate the impact of short-term experience on anticipatory gaze. One possibility would be to investigate whether short-term motor imagery training would also lead to comparable effects. Corresponding results would support the idea of shared representations of action execution, action observation and action imagery. Moreover, neurophysiological methods should be applied to identify neural substrates underlying action understanding. A further important research question is, whether different measures of action understanding (e.g., predictive gaze, μ-rhythm, pupil dilation) relate to each other, or whether they reflect completely different aspects of action understanding. It is important for future research to distinguish these measures in terms of their specific function and which type of information they provide.

Moreover, it is important to consider children older than two years in future studies. To date, most studies are conducted with infants, but less in known about the developmental course during childhood or adolescence. Future research needs to fill this gap – eventually by conducting longitudinal studies – in order to describe the developmental course of action understanding.

In conclusion, this thesis provides evidence that anticipatory eye movements can be taken as indicators of active task-specific action knowledge during action observation, and that pupil dilation reflects the violation of expected action outcomes. Moreover, action understanding has been demonstrated to underlie developmental processes throughout childhood.

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Appendix

Appendix A. Cover Story (German) for Study 3: Experiment 1 (4-6 year-old preschoolers) and Experiment 2 (8-10 year-old children)

Part I: Pretest

„Schau mal – das ist der Max. Weißt du, was Max für ein Tier ist?“

(Antwort Kind)

„Richtig, das ist ein Frosch. Aber Max ist ein ganz besonderer Frosch – Max ist ein Wetterfrosch. Weißt du, was ein Wetterfrosch macht?“

(Antwort Kind)

„Nun, ein Wetterfrosch kann dir sagen, wie das Wetter morgen wird – ob es regnet oder ob die Sonne scheint. Und dann weißt du, was du anziehen musst. Max ist der Wetterfrosch von einem Freund von mir – vom Olli. Und Olli ist ein Gärtner und muss immer draußen arbeiten. Es ist wichtig für ihn, dass er weiß, wie das Wetter wird. Aber schau mal, Max ist sehr klein und manchmal kann er den Himmel nicht richtig sehen und kann nicht genau sagen, wie das Wetter wird. Deshalb baut Olli ihm eine Treppe – schau.“

(Turm vor dem Kind aufbauen)

„Guck, nun kann der Max diese Treppe hochklettern und wenn er ganz oben ist, sieht er den Himmel viel besser. Manchmal ist Olli aber ein bisschen vergesslich oder ungeschickt und dann passieren ihm Fehler beim Bau der Treppe. Schau.“

(Fehlerversionen vorzeigen)

„Weißt du was? Es wäre toll, wenn du Olli helfen könntest, dass er die Treppe immer richtig aufbaut. Olli baut die Treppe gleich am Bildschirm und immer, wenn er einen Fehler macht, musst du ganz laut auf diese Tröte drücken. Dann weiß Olli, dass er etwas falsch gemacht hat. Willst du Olli helfen?“

(Antwort Kind)

„Super, dann lass uns mal schauen, wie der Olli den Turm baut.“

(Eye-Tracking Pretest)

Part II: Intervention + Posttest

„So, super, dass du dem Olli so toll gezeigt hast, wann er Fehler macht. Er hat ganz schön viele Fehler gemacht, nicht wahr? Ich glaube, wir müssen Olli zeigen, wie er die Treppe richtig bauen kann. Kannst du ihm nochmal helfen?“

(Antwort Kind)

„Super, am besten baust du die Treppe jetzt mal und zeigst dem Olli, wie das richtig geht. Bau die Treppe mal so genau wie möglich.“ (Wiederholung 5 x)

(Kind baut 5 x so genau wie möglich)

„Super, ich glaube, Olli hat es langsam verstanden und du kannst jetzt schneller bauen. Bau die Treppe mal so schnell du kannst.“ (Wiederholung 5 x)

(Kind baut 5 x so schnell wie möglich)

„Super! Wollen wir jetzt nochmal schauen, ob der Olli was gelernt hat?“

(Antwort Kind)

„Ok! Aber falls der Olli noch Fehler macht, musst du wieder ganz laut auf die Tröte drücken, ja?“

(Antwort Kind)

„Super! Dann schau nochmal, wie Olli die Treppe baut und drücke auf die Tröte, wenn er einen Fehler macht.“

(Eye-Tracking Posttest)

Appendix B. "Max" – Frog for Cover Story

Appendix C. Puzzles for Puzzle Intervention.

Ehrenwörtliche Erklärung

Ich erkläre hiermit ehrenwörtlich, dass ich die vorliegende Arbeit ohne unzulässige Hilfe Dritter und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe. Die aus fremden Quellen direkt oder indirekt übernommenen Gedanken sind als solche kenntlich gemacht. Bei der Auswahl und Auswertung des Materials sowie bei der Herstellung des Manuskripts habe ich Unterstützungsleistung von folgenden Personen erhalten:

Prof. Dr. Gisa Aschersleben

Prof. Dr. Hubert Zimmer

Prof. Dr. Gustaf Gredebäck

Weitere Personen waren an der geistigen Herstellung der vorliegenden Arbeit nicht beteiligt. Dritte haben von mir weder unmittelbar noch mittelbar geldwerte Leistungen für Arbeiten erhalten, die im Zusammenhang mit dem Inhalt der vorgelegten Dissertation stehen.

Die Arbeit oder Teile davon wurden bisher weder im Inland noch im Ausland in gleicher oder ähnlicher Form einer anderen Prüfungsbehörde als Dissertation vorgelegt. Ferner erkläre ich, dass ich nicht bereits eine gleichwertige Doktorprüfung an einer Hochschule endgültig nicht bestanden habe.

Saarbücken, 16.03.2016

Corina Möller