The Ontogeny of Action Anticipation: Processing of Goals and Movements in Development

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Abstract

The ability to attend to other's actions in a proactive manner is relevant in our daily lives, as it enables fluid interactions with others and to plan our actions accordingly. This proactive attention is reflected by anticipatory eye-movements. We perform a predictive gaze-shift towards the goal of another's action, before that action is fulfilled. It has been shown that the ability to anticipate other's actions emerges in the first year of life (e.g., Falck-Ytter, Gredebäck & von Hofsten, 2006). Thereby, influential developmental theories suggest that infants primarily rely on information of the goal when they anticipate actions of others, and this ability is essential for social-cognitive development. A much-noticed study demonstrated that 11-month-olds flexibly anticipate a human hand to always grasp the same object, even after it swapped positions with another object (Cannon & Woodward, 2012). In contrast, other studies observed flexible goal-anticipations only from later ages on. In these studies, infants primarily anticipated the action in relation to movements (e.g., Daum, Attig, Gunawan, Prinz, & Gredebäck, 2012). This suggests that rather lower-level mechanisms, such as statistical learning of movement patterns, underlie action anticipation early in development. Given this debate, it remains an open question, whether and under what circumstances infants and children anticipate actions in relation to goals.

The current work focuses on the overall question of how flexible infants, children and adults use their knowledge about goals and movements to anticipate others actions. Three eye-tracking studies were conducted over a wide age range, including infants, young (2- to 5-year-olds) and older children (5-13 years), adolescents (15-18 years), as well as younger and older adults. One study additionally included individuals with autism-spectrum-condition (ASC).

In particular, Study 1 investigated whether and under what circumstances one-year-olds, 32-month-olds and adults flexibly anticipate other's actions as goal-directed. It was assessed over 6 experiments, whether various factors such as the type of agent (human vs. animated agent) influence goal-anticipations. Results showed that in none of the 6 experiments did infants and children anticipate the action in relation to the goal. Instead, infants and children anticipated the action in relation to the movement pattern. This challenges theoretical claims and results of previous studies (e.g., Cannon & Woodward, 2012), and indicates that infants and young children do not primarily use goal information when anticipating the actions of others.

Study 2 investigated the ability to anticipate action goals further and included individuals with ASC. It was examined whether children, adolescents and adults with and without ASC encode an action as goal-directed when they are provided with an additional cue. Thus, participants were presented with an agent repeatedly taking different paths to reach the same of two goals. Results revealed that typically developed participants of all age groups anticipated the action in relation to the goal after a few repetitions, whereas individuals with ASC needed more time to perform goal-directed anticipations. This implies that individuals with ASC have problems in using prior information, and that statistical learning mechanisms are impaired in ASC.

Finally, Study 3 tested whether 2- and, 5-year-olds, younger and older adults flexibly process movements of another's action and integrate contextual changes in their action anticipations. Participants observed an agent repeatedly taking one of two paths to reach a goal. Then this path became blocked and only the other path was passable. Results demonstrated that younger and older adults flexibly integrated contextual changes in their action anticipations, whereas both children groups anticipated towards the blocked path. The results are not in line with the claim that young children take contextual changes for their action anticipations into account, but rather suggest that statistical learning in relation to movement information is a strong mechanism in early development.

In summation, the present thesis shows that early in development, statistical learning processes play a dominant role for action anticipation. Infants and children primarily process other's actions in relation to frequency information about movement patterns (Study 1 and 3). In contrast, no evidence was found for the claim that infants primarily anticipate other's actions in relation to goals (Study 1). Results rather suggest that additional cues are necessary for encoding an action as goal-directed (Study 2). In conclusion, this thesis provides evidence that lower-level abilities underlie action anticipation in early development, whereas the integration of higher-level cues such as goals or situational constraints develops later (Ruffman, Taumoepeau, & Perkins, 2012).

Abstract (deutsch)

Die Fähigkeit, Handlungen anderer Personen proaktiv (also vorausschauend) wahrzunehmen, ist für unser tägliches Leben von Bedeutung. Es ermöglicht uns unsere Handlungen an die der anderen anzupassen und schafft flüssige, zwischenmenschliche Interaktionen. Diese proaktive Aufmerksamkeit spiegelt sich unter anderem in unseren Augenbewegungen wider. Wenn wir die Handlungen anderer beobachten, machen wir prädiktive Augenbewegungen zu dem Ziel der Handlung, bevor das Ziel überhaupt erreicht ist. Es konnte gezeigt werden, dass sich diese Fähigkeit zur Handlungsantizipation bereits im ersten Lebensjahr entwickelt (e.g., Falck-Ytter, Gredebäck, & von Hofsten, 2006). Dabei haben einflussreiche entwicklungspsychologische Theorien angenommen, dass bereits Säuglinge primär die Ziele einer Handlung verarbeiten. Eine vielbeachtete Studie zeigte, dass 11 Monate alte Säuglinge Ziele flexibel antizipieren können: Sie antizipieren, dass eine Hand weiterhin eines von zwei Zielen ergreifen wird, sogar nachdem die beiden Zielobjekte Platz getauscht haben. Dies zeigt, dass die Säuglinge das spezifische Ziel der Handlung verarbeitet haben und die Handlung dementsprechend antizipieren. Im Gegensatz dazu konnten andere Studien diese flexiblen Zielantizipationen nur bei älteren Kindern feststellen. In diesen Studien antizipierten Säuglinge primär die Handlung entsprechend der Bewegungsinformation (e.g., Daum et al., 2012). Dies könnte ein Hinweis dafür sein, dass eher statistisches Lernen von Bewegungsmustern den Handlungsantizipationen in der frühen Entwicklung zugrunde liegt. In Anbetracht dieser Debatte, bleibt es eine offene Frage, ob und unter welchen Umständen Säuglinge und Kinder Handlungsziele antizipieren.

Die vorliegende Arbeit konzentriert sich auf die Frage, wie flexibel Säuglinge, Kinder und Erwachsene Wissen über Ziele und Bewegungen verwenden um Handlungen anderer zu antizipieren. Es wurden drei Eye-tracking-Studien mit verschiedenen Altersgruppen durchgeführt, darunter Säuglinge, junge Kinder (2-5 Jährige), ältere Kinder (5-13 Jährige), Jugendli-

che (15-18 Jährige), sowie junge und ältere Erwachsene. Eine Studie testete zusätzlich auch Kinder, Jugendliche und Erwachsene mit Autismus-Spektrum-Störung (ASS).

Im Genaueren, untersuchte Studie 1 ob und unter welchen Umständen Einjährige, 32-Monatige und Erwachsene flexibel Handlungen anderer als zielgerichtet antizipieren. Es wurde über 6 Experimente untersucht, ob verschiedene Faktoren wie beispielsweise die Art des Agenten (menschlich oder animiert/nicht-menschlich) Zielantizipationen beeinflussen. Die Ergebnisse zeigten, dass Säuglinge und Kinder in keinem der 6 Experimente die Handlung in Bezug auf das Ziel antizipierten. Stattdessen antizipierten Kinder die Handlung in Bezug auf das Bewegungsmuster. Dieses Ergebnis stellt daher theoretische Behauptungen und vorhergehende Studienresultate (z.B., Cannon & Woodward, 2012) in Frage, und deutet darauf hin, dass junge Kinder und Säuglinge nicht primär Ziele antizipieren.

Studie 2 untersuchte die Fähigkeit zur Zielantizipation weiter und inkludierte auch Personen mit ASS. Es wurde getestet ob Kinder, Jugendliche und Erwachsene mit und ohne ASS eine Handlung als zielgerichtet enkodieren, wenn ein zusätzlicher Hinweis das Handlungsziel verstärkt. Daher wurde den Versuchsteilnehmern ein Agent präsentiert, der wiederholt verschiedene Wege nimmt um immer zu demselben Ziel zu gelangen. Die Ergebnisse zeigten, dass die Probanden aus allen drei Altersgruppen ohne ASS die Handlung nach ein paar Wiederholungen entsprechend dem Ziel antizipierten. Im Gegensatz dazu benötigten Probanden mit ASS mehr Wiederholungen um das Ziel zu antizipieren. Dies ist ein Indikator dafür, dass Personen mit ASS Probleme haben könnten, vorhergehende Informationen zu nutzen und daher womöglich statistische Lernmechanismen bei ASS beeinträchtigt sind.

Zu guter Letzt, untersuchte Studie 3 ob 2- und 5-Jährige, jüngere und ältere Erwachsene Bewegungsinformationen anderer flexibel verarbeiten und kontextuelle Veränderungen in ihre Handlungsantizipationen miteinbeziehen. Hierfür wurde den Probanden ein Agent präsentiert, der wiederholt einen von zwei Wegen nahm um zu einem Ziel zu gelangen. Dann wurde dieser Weg plötzlich unterbrochen und nur der andere Weg war passierbar. Die Ergebnisse zeigten, dass jüngere und ältere Erwachsene diese kontextuelle Veränderung flexibel in ihre Antizipationen integrieren konnten und auf den durchgehenden Weg antizipierten. Im

Gegensatz dazu, antizipierten die 2- und 5-Jährigen auf den blockierten Pfad. Die Ergebnisse sind daher nicht mit der Behauptung vereinbar, dass Kinder schon von früh an situative Änderungen in ihren Handlungsantizipationen berücksichtigten. Es scheint eher, dass sie sich auf die vorher gelernte Bewegungsinformation verlassen und deutet darauf hin, dass statistisches Lernen von Bewegungsmustern ein starker Mechanismus in der frühen Entwicklung ist.

Zusammenfassend demonstriert die vorliegende Arbeit dass in der frühen Entwicklung statistische Lernprozesse eine vorherrschende Rolle für die Handlungsantizipation spielen. Säuglinge und Kinder verarbeiten die Handlungen anderer primär in Bezug zu Häufigkeitsinformationen von Bewegungsmustern (Studie 1 und 3). Im Gegensatz dazu konnte kein Nachweis gefunden werden für die Annahme, dass junge Kinder vorwiegend Ziele von Handlungen anderer verarbeiten und antizipieren (Studie 1). Die Ergebnisse zeigen eher, dass zusätzliche zielverstärkende Hinweise notwendig sind um das Handlungsziel zu enkodieren (Studie 2). Abschließend zeigt diese Arbeit, dass in der frühen Entwicklung eher einfache, perzeptuelle Mechanismen der Handlungsantizipation zugrunde liegen, während die Integration von abstrakteren Hinweisen, wie Ziele oder situative Einschränkungen, später in der Entwicklung erfolgt (Ruffman et al., 2012).

1 Introduction

As human beings, we are constantly engaged in social interactions and are thus confronted with other people and their various actions. When someone offers us their hand to greet us, we respond with a handshake. When we walk in a crowded pedestrian area, we must avoid collisions with oncoming people and move out of their way. In our daily life, we - as adults - usually do this automatically without much “thought”.

These fluid interactions are partly possible due to our proactive visual attention. It has been shown that we are not just passive observers of other’s behavior, but attend to other’s actions in a proactive manner (Flanagan & Johansson, 2003). Imagine you invited your friend over for a cup of tea and you sit at a table across from each other. You observe your friend lifting her arm and starting to move her hand towards her cup. Immediately, your eyes would shift towards the cup before your friend’s hand arrives there to grasp it. The moment you look at the cup, you notice that it is empty. Right away, you grab the tea pot and refill your friend’s cup. This example demonstrates the usefulness of predictive gaze shifts. You perform a predictive gaze shift towards the goal of another’s action, before the action is actually fulfilled. This allows you to attend to important events in time, namely *as* they unfold, and to plan your responding actions in a timely manner; no matter whether the situation is cooperative, such as folding a blanket together, or competitive, such as grabbing the last cookie before your sibling does (Gredebäck & Falck-Ytter, 2015). But how do we visually anticipate another’s action? What information do we process in order to form expectations about another’s behavior, so we make fast and effective predictive gaze-shifts? And more importantly, how does this ability develop? Do infants anticipate actions similar to adults or are there developmental differences? To be successful in social situations, we need to understand other people’s actions. We need to *understand* what others are doing in order to adapt our behavior to them and plan our actions smoothly and accordingly.

A better understanding of these processes and how they develop will not only inform current developmental theories but will help us to better understand individuals that may have problems with the processing of other's actions, such as those with autism-spectrum-disorder.

The current thesis examines by means of three eye-tracking studies, what kind of information children and adults use to visually anticipate other's actions. These studies focus on whether goal- or movement information is relevant for action processing and how flexibly this information is used. The first chapter of this thesis introduces the topic to the reader and gives an overview of current relevant theories.

1.1 Action Understanding

How do people come to understand others? This question has a long history in psychology and is culminated in the question of how children develop a Theory of Mind (cf., Wellman, 2014), namely the ability to attribute mental states to ourselves and to others (Sodian, 2005). Children start to distinguish the mental states of others from their own at around 3.5 to 4 years, which indicates a key milestone in theory-of-mind development (e.g., Wimmer & Perner, 1983). However, there is a consensus that the development of Theory of Mind begins earlier and even infants have abilities that precede mental state attribution. For example, it has been shown that infants prefer social cues from early on, as infants only a few weeks old show a preference for the faces of other people (Johnson & Morton, 1991; cf., Sodian, 2005). However, from early on infants also attend to the behavior of other people, which enables them to anticipate, understand and react to other's actions (cf., Uithol & Paulus, 2014). A whole field of research on action understanding within infants has emerged over the last decades (e.g., Behne, Carpenter, Call, & Tomasello, 2005; Falck-Ytter, Gredebäck, & von Hofsten, 2006; Repacholi & Gopnik, 1997; Woodward, 1998), whereby the used research methods as well as interpretations of results are manifold. Thus, it seems important to take a closer look on what *action understanding* actually entails (cf., Uithol & Paulus, 2014).

So far, this term has been used and defined in various ways in the literature. Mostly skills such as identifying actions, recognizing the goal of an action and determining the underlying intention of an action have been subsumed under this umbrella term (cf., Thompson, Bird, & Catmur, 2019). However, this broad use of the term is not very conducive to research because there is no agreement as to what it exactly means. This complicates the scientific discourse on underlying mechanisms, as well as the development of appropriate assessment methods (Thompson et al., 2019; Uithol, Rooij, Bekkering, & Haselager, 2011). As a result, recent approaches have tried to clarify and conceptualize the various abilities and mechanisms underlying action understanding (e.g., Hunnius & Bekkering, 2014; Thompson et al., 2019; Uithol & Paulus, 2014).

As an example, Uithol and Paulus (2014) provided a theoretical framework on early social cognition, where they distinguish four different types of action understanding. These four types will be shortly introduced, and the relevance of Uithol and Paulus' model (2014) discussed.

The first type, (1) *action classification,* includes the recognition of an action. This means that observed movements are classified into certain actions through a categorization process. For example, observing someone bringing a spoon with their hand towards their mouth can be "understood" by classifying it as an eating action. The observed movements are assigned to a specific action category, such as eating or grasping. This recognition process allows us to make sense of movements and enabling us to generate predictions about how the action is going to unfold. As an example, Uithol and Paulus (2014) cite, among others, the study by Behne and colleagues (2005). This study demonstrated that 12- and 18-month-olds could classify an action as teasing or reaching, depending on whether the actor was unwilling to give them a toy (teasing) or unable to grasp the toy (reaching). Infants showed more impatient reactions in the unwilling than in the unable condition, which implies that they adequately classified the actor's movements into distinct action categories (Behne et al., 2005).

Another form of action understanding is (2) *target prediction.* This form includes the anticipation of an action target *before* the action is completed. Here, most importantly, not only the continuation of the movement is predicted (as is the case with action recognition), but also the target or the end location of an action. Uithol and Paulus (2004) further differentiate between a target as an object and a target as a location. For example, when 6-month-olds observe a feeding action, they look at the actor's mouth before the spoon arrives (Kochukhova & Gredebäck, 2010). Here the target, the mouth, would be an example for location prediction, as the mouth is always at the same location. In contrast, for object prediction the specific object is anticipated no matter where it is located (e.g., Woodward, 1998). Moreover, the prediction of a target is more difficult when several targets are available and additional information is necessary to make accurate predictions (Uithol & Paulus, 2004). For example, 8-month-olds can use information of the type of hand grip (precision or whole-hand grasp) an actor makes to anticipate whether the actor is going to grasp a large or small object (Ambrosini et al., 2013).

The next mechanism, (3) *super-ordinate action recognition*, includes the recognition of the higher-order goal of an action, such as the goal "to eat" when observing someone grasping a cookie, or "to drink" when seeing someone grasping a glass of water. This type of action understanding is more complex as the same action can have several higher-order goals. This is why additional information is necessary in order to recognize the super-ordinate action goal. A cookie can be grasped in order to either be eaten, to be given to someone else, or to be put away.

Last but not least, (4) *response selection* indicates the appropriate response to an action (Uithol & Paulus, 2004). For example, during a feeding situation, one-year-olds open their mouth in anticipation of being fed with a spoon (van Dijk, Hunnius, & van Geert, 2009; cf., Uithol & Paulus, 2014). This indicates that they also acquired some form of action understanding, as they can show an adequate reaction to another's action.

According to Uithol and Paulus (2014), different abilities and neurocognitive mechanisms underlie each of these four types of action understanding, indicating that competencies can vary in these different types of action understanding. For example, one can show adequate reaction to another's action (maybe acquired through associative learning mechanisms) but might not have sophisticated abilities in predicting the target of that action. This illustrates that action understanding is a multi-faceted construct (see also Apperly, 2012; Warnell &

Redcay, 2019). The conclusion that someone "has" or "has not" acquired action understanding thus seems inappropriate, as these action understanding-types have different developmental pathways. Therefore one should investigate these various mechanisms that underlie the different types of action understanding, rather than examine "whether and at what age infants understand actions" (Uithol & Paulus, 2014, p. 610).

1.1.1 Action Understanding and the Role of Intention Attribution

Many findings from infancy research on action understanding have been interpreted to the extent that infants can infer other's intentions (e.g., Luo, 2011; Luo & Baillargeon, 2010; Woodward, 1999). For instance, Woodward and Cannon (2013) state, that infants use their "conceptual knowledge about intentional action" to visually anticipate other's actions (p. 389). Similarly Luo (2011) speaks of "early intentional understanding" (p. 454) in relation to 3-month-olds' perception of goal-directed actions performed by a moving box. However, these widely used but rich claims about infants' abilities concerning the understanding of other's actions have been criticized. Uithol and Paulus (2014) argue that intention attribution does not play a significant role in their model. Others emphasized as well the importance of distinguishing skills such as target prediction or action recognition from intention attribution (Hunnius & Bekkering, 2014; Ruffman, Taumoepeau, & Perkins, 2012). It seems crucial to not over-interpret recent study results in infancy research (Haith, 1998; Hunnius & Bekkering, 2014). For example, the observation that infants react differently when an experimenter is unable rather than unwilling to give them a toy (Behne et al., 2005), does not allow the conclusion that infants have attributed the underlying intention of the experimenter's actions. Since the ability to attribute intentions to other's is tied to language (e.g., Astington & Baird, 2005; Ruffman, 2014; Uithol & Paulus, 2014), lower level interpretations may be more appropriate for explaining infants' behavior (Ruffman et al., 2012; Hunnius & Bekkering, 2014; Uithol & Paulus, 2014).

In fact it has been claimed that even we as adults rarely attribute intentions to others in our daily routine interactions, especially when we are not explicitly asked to (see Uithol &

Paulus, 2014 for a detailed discussion; as well as Low & Edwards, 2018, for empirical evidence). It rather seems that we think about intentions of other's when we are confronted with more complex actions or actions that take place in a more distant future, since our "usual" actions are often the result of daily routines.

This is also in line with a two-systems-approach of social cognition. Apperly and Butterfill (2009) propose that social information is processed by two distinct systems: One system is responsible for explicit processing, such as the attribution of beliefs, whereas the second system is responsible for implicit action understanding. Explicit processing is highly flexible but cognitively demanding. As explicit information has a propositional format (i.e., "sentence-like"; cf., Apperly & Butterfill, 2009, p. 957), it is tied to language and executive functions, which is why it develops slower, typically at around four years of age (e.g., Wimmer & Perner, 1983). The second system, on the other hand, develops earlier and is more efficient (as it is not tied to language) but it is limited in its flexibility. In adults, both systems work in parallel, with the efficient system being relevant for online interaction and the flexible system being relevant for explicit processing (Apperly & Butterfill, 2009).

Nevertheless, others have shown that sometimes knowledge is acquired first on an explicit level and later on an implicit one, indicating that implicit knowledge is not always developing earlier than explicit knowledge (Schuwerk & Paulus, 2016). It could be possible, that sometimes knowledge has to be acquired explicitly before automatization processes enable an efficient and fast treatment of information implicitly (cf., Schuwerk & Paulus, 2016). Interestingly, it has also been demonstrated that these two systems can work together, in the sense that the explicit system can inform the implicit one. Paulus, Schuwerk, Sodian and Ganglmayer (2017) presented children with several agents that verbally announced to which one of two possible goals they will go. Adults and 3.5-year-olds could use that explicit information to make correct visual anticipations about the agent's goal-choice, indicating that explicit, verbal information can influence implicit processes. However, 2.5-year-olds could only "use" the two systems separately. On the one hand they could process the explicit information when making verbal predictions about the agent's choice. Whereas, on the other hand they learned implicitly about the agent's path choice (through repeated observation) as they correctly visually anticipated the agent's actions. This demonstrates that the two systems can be separated and their interplay seems to develop around 3 years of age (Paulus et al., 2017).

To sum up, it is important to distinguish forms of action understanding from the ability to attribute intentions to others. Notably, adults do not seem to attribute intentions all the time when they interact with others. Thus, it seems very promising to distinguish explicit from implicit information processing, as suggested by a two-systems-approach (e.g., Apperly & Butterfill, 2009).

1.1.2 Looking Behavior as an Assessment of Action Understanding – Comparison of Two Approaches

"Before language develops, looking is … a major gateway to the infant's mind" (Gredebäck, Johnson, & von Hofsten, 2009, p.1), thus the analysis of infants' looking behavior has become one of the most important measures in infancy research (Aslin, 2007). In relation to action understanding, two different types of assessments of infants' looking behavior can be distinguished: (1) The post-hoc approach measures infants' expectations about an action after the action is completed through looking times, whereas (2) the online approach measures infants' expectations about how an action is going to unfold through anticipations, for example revealed by their anticipatory eye-movements (cf., Daum et al., 2012). In the next section the post-hoc approach is introduced first and the online approach after, with a brief history of the development of eye-tracking techniques and their relevance for research.

1.1.2.1 Post-hoc approach

This approach assesses infants' expectations about an event after the event has been completed (i.e. post hoc). Therefore, infants are habituated to a specific event in a first familiarization phase, usually until they reach a specified habituation criterion. In most studies this criterion is specified as a 50% decline in the mean looking time during three consecutive trials compared to the first three trials (Aslin, 2007). Afterwards two test events are presented. These test events are systematic variations of the original event from the familiarization phase based on two dimensions, whereas each test event represents one dimension (cf., Woodward, 1998). Longer looking times of infants to one test event in relation to the other indicate that this test event is new to them and they were able to distinguish the two events. They observed the change of one dimension and thus encoded the event in relation to the other dimension. In relation to measuring the understanding of other's actions, this means that infants build up expectations about an action in the familiarization phase. For the following test phase, two events are presented. Infants show longer looking times to one event in relation to the other, when their expectation about the outcome of an action is violated in that event. Thus the evaluation of the action outcome happens when the action has been already completed.

One of the most important looking-time paradigms in relation to action understanding was provided by Woodward (1998). She habituated infants with a hand reaching for one of two objects that were mounted on a stage. For test events, the objects positions were swapped and two different versions of the event were presented: In one, the hand reached for the same object as in the familiarization phase but had to take a different movement path. In the other event, the hand reached for the other object, but took the same movement path as in the familiarization event. Infants showed longer looking times when the hand reached for the other object in the old location. This indicates, according to the author, that they encoded the action in relation to the goal and not in relation to the movement path (Woodward, 1998). Many more studies used this post-hoc approach to assess various aspects of action understanding within infants (e.g., Brandone & Wellman, 2009; Gergely, Nádasdy, Csibra, & Bíró, 1995; Guajardo & Woodward, 2004; Kamewari, Kato, Kanda, Ishiguro, & Hiraki 2005; Luo, 2011; Luo & Baillargeon, 2005).

The use of habituation based looking-time paradigms has a long history in developmental psychology and was implemented, inter alia, to measure infants' physical understanding (e.g., Spelke, Breinlinger, Macomber, & Jacobson, 1992) or object permanence (Baillargeon, Spelke, & Wasserman, 1985). In fact, it has been stated that "without looking time measures, we would know very little about nearly any aspect of infant development" (Aslin, 2007, p. 48). Nevertheless, the use of looking time measures also has its' downsides and limitations. One of the main problems is that the looking time towards an event is a very global and unspecific measure (e.g., Hunnius, 2007). It does not give us any information about the "microstructure" behind looking, such as number or sequence of fixations or the times the infant looks away (Aslin, 2007). All of these metrics are rejected; therefore, lots of information is lost. This was also nicely demonstrated in a study by Yeung, Denison and Johnson (2016). They assessed infants overall looking time towards three different events, but also analyzed infants' fixations towards specific areas in the scene. Indeed there were no differences between the events when analyzing only the total looking time, but interestingly infants showed different fixation patterns in the three test events. This implies that the assessment of total looking times was too global and insensitive to detect any differences, whereas a more fine-grained analysis of infants scanning patterns provided more information about their competences.

Since many different factors can influence looking times, we primarily do not know why infants did not show a novelty reaction towards a stimulus. This includes for instance perceptual or attentional influences (infants might just not have attended towards critical aspects of the scene), but also differing prior experiences that infants bring into the lab and affect their habituation procedure (Aslin, 2007; Haith, 1998). Therefore, we need to be very cautious when drawing strong conclusions out of looking time-paradigms (Aslin, 2007; Haith, 1998; Hunnius, 2007). Originally, looking time-paradigms were developed to assess lower-level sensory or perceptual processes, which is why possible perceptual explanations of infants looking behavior need to be excluded in order to draw stronger conclusions about infants competences (Haith, 1998).

In sum, careful consideration must be given when inferring higher-level abilities to infants out of results from habituation-based looking-time studies. Information we gain out of these experiments is limited, especially when we want to make inferences about underlying processes. However, more advanced and precise eye-tracking measures are nowadays available that enable us expand our knowledge about infants' competencies (Hunnius, 2007).

1.1.2.2 Online approach

One possibility to assess action understanding *online*, namely as the action unfolds (instead of once it has already been completed), is the analyzation of predictive eye-gazes. Another's expectation about an action can be measured through their visual attentional shift towards the action goal. The use of more advanced techniques, such as corneal reflection eye-tracking, enables researchers to survey eye-movements with a better spatial and temporal resolution. If participants shift their gaze reliably and systematically towards an area before something happens, this gaze shift is defined as predictive (Gredebäck, Johnson, et al. 2009). However, if participants fixate an area after an event has already occurred then this is defined as reactive (Gredebäck, Johnson, et al. 2009).

Flanagan and Johansson (2003) were the first to discover anticipatory eye-movements within adults when their participants executed a block stacking task themselves, but also when they observed someone else perform the task. Adults fixated the action goal before it was reached. Similar observations were made by Falck-Ytter et al. (2006) not only for adults but also for 12-month-old infants. They presented participants a human agent reaching for objects and placing them into a bucket on the other side of the table. Adults as well as infants looked at the bucket before the hand arrived there; thus, they processed the manual action predictively, revealed by their anticipator eye-gazes.

The use of this measure provides insight into how actions of other's are processed and is therefore a reliable measure for investigating the development of action understanding from infancy to adulthood (see also chapter 1.3). Since measuring anticipatory eye-movements does not need a prior habituation or learning phase, it is well suitable also for older children and adults, and allows therefore the comparison of several populations (cf., Hunnius & Bekkering, 2014). The assessment of anticipatory eye-movements does not only give us more information about which aspects of an action are attended to but also allows us to track these processes over time, namely throughout the complete stimulus set (Gredebäck, Johnson, et al., 2009). This enables researchers to investigate learning processes (see e.g., Henrichs, Elsner, Elsner, Wilkinson, & Gredebäck, 2014) as well as changes in attention over time. In contrast to looking-time paradigms, which assess whether infants are sensitive towards changes of a specific aspect of a situation, anticipatory eye-movements directly measure expectations (Hunnius & Bekkering, 2014).

Furthermore, previous studies that assessed both post-hoc and online measures provided evidence for a dissociation of the two measurements in infants and children (e.g., Daum et al., 2012; Gredebäck & Melinder, 2010; Paulus et al., 2011). For example, Daum et al. (2012) observed that 9-month-olds encoded an action as goal-directed according to the post-hoc looking time assessment whereas this goal-encoding process was not reflected in their anticipations. Nine-month-olds anticipated the action in relation to the movement and not to the goal. These results therefore question whether the same conclusions can be drawn from the two approaches and indicate that they might not measure the same underlying mechanism. Daum et al. (2012) suggest that two information processes that are first dissociated but become integrated later in life are the reason for the complementary results. Others propose that simply two different components of action understanding are measured (Uithol & Paulus, 2014).

While looking time-studies were previously conducted by the use of observers who tracked infants looking times manually via video cameras with stopwatches or computer keyboards, the use of automatic eye-tracking provides a more objective and reliable option to track gaze-behavior (Oakes, 2012). The first to implement the idea of tracking other people's eye movements more precisely was Alfred L. Yarbus in the 50s and 60s. He developed cumbersome devices that where either directly placed in the eyes (suction caps) or mounted on the head (Yarbus, 1967). In his studies, he provided participants with stationary images and asked them different questions about the content of the images. Depending on which questions he asked, participants attended to different areas of the image, providing for the first time evidence that eye-movements are related to cognitive processes (cf., Eckstein, Guerra-Carrillo, Singley, & Bunge, 2017).

In the 70s several more advanced eye-tracking techniques were developed. Especially interesting in relation to infancy research are electro-oculography (EOG) and corneal-reflection photography (see e.g., Aslin & Murray, 2004; Hunnius, 2007). EOG measures the electrical potential, which is caused by the rotation of the eye (Hunnius, 2007). For this purpose, electrodes need to be fixated on the face of the participants. However, measuring eye-movements via EOG is quite complex as well as time consuming in its handling; thus its application for infants is quite limited (see Aslin & Murray, 2004). More promising is the use of corneal reflection eye-tracking. For this an infrared light is directed towards the eyes and reflected onto the front surface (cornea) of the eye. Additional cameras record this reflection (Hunnius, 2007). Whenever the subject fixates somewhere else, this is mirrored in the change of the corneal reflection. The new position of the corneal reflection relative to the center of the pupil is calculated to determine the new location of the fixation. Importantly, to assess gaze-position, the eye-tracking system has to be calibrated before the measurement of each participant in order to map the system onto the provided stimulus field (Aslin & Murray, 2004). Adults are generally calibrated with a 9-point procedure, whereas for young children and infants mostly 5- or 2-point calibration schemes are used that are less time-consuming (but also less accurate). Over time, corneal reflection eye-tracking systems have become more and more advanced. They are equipped with higher sampling frequencies (up to 1200 Hz) and infant friendly calibration procedures. Newer models also have a higher tolerance for head movements, which enables a more natural testing situation and thus also reduces data loss and attrition rates of young participants (Hunnius, 2007).

In sum eye-tracking techniques have developed tremendously over the last few years, offering a lot of possibilities to consider and answer a wide scope of questions in developmental research. The devices, however, are not limited to the assessment of anticipatory eye-gazes but also enable other measurements such as pupil dilation or eye blink rates to be taken, which seem highly promising for expanding our knowledge about cognitive development (see Eckstein et al., 2017).

1.2 Definition of Relevant Concepts

To situate the present thesis within the research field of the development of action understanding, the previous outlined model of Uithol and Paulus (2014) is used. The three studies of the present thesis investigate the development of action understanding as *target prediction,* one of the four types of action understanding according to the model (Uithol & Paulus, 2014). Thereby various age groups, including infants, children and adults, are assessed by means of eye-tracking experiments to examine social-cognitive mechanisms that underlie the ability of target prediction. Participants' target predictions are primarily operationalized in all three studies via their anticipatory eye-movements, i.e. participant's look towards the target of an action before it is completed.

For the present work, the term *prediction* is used as an umbrella term, based on predictive coding theory (e.g., Clark, 2013a, see also chapter 1.4.4) and describes all forms of predictive processes. Under this term, two different processes are subordinated, namely *verbal prediction* and *anticipation*. Prior studies used the terms action prediction and action anticipation interchangeably. However, for this work the term *verbal prediction* is used when referring to a verbal action prediction, whereas *anticipation* is used when referring to anticipations that are either visual or behavioral (e.g., anticipatory grasping). This differentiation is applied because the word *prediction* originates from the Latin word praedicere, composed of prae which means "before" and dicere meaning "to say" ("Predict", 2019). This implies that a prediction is something verbal, whereas the word *anticipation* (originating from anticipare, anti/ante meaning "before" and capere "to take"; "Anticipation", 2019a) is defined as "the act of looking forward" ("Anticipation", 2019b).

1.3 The Development of Action Anticipation

Target anticipation means that neither the kinematics or the course of the action are anticipated, but the target or the location of the end state (Uithol & Paulus, 2014). In the last few years, research on this topic has grown strongly. A distinction can be made between studies that treat the target as a location, and studies that the treat target as a specific object (cf., Uithol & Paulus, 2014). This distinction is relevant, since different information sources are processed for each of these “types”. This section will give an overview over the current findings considering location and object anticipation, and discuss the distinction between these two processes and their relevance for theories on action anticipation.

A very influential study by Falck-Ytter and colleagues (2006) assessed infants and adults location anticipations: They presented 6-, 12- month-olds and adults with a hand repeatedly reaching for toys and transporting them into a bucket. Whereas 12-month-olds and adults looked at the bucket before the hand arrived there, 6-month-olds observed the action reactively and did not look at the target ahead of time. Interestingly, when the balls were “magically” moving on their own towards the bucket, all age groups observed the action reactively. Since the bucket is always situated at the same location, results of this study imply that infants from 12 months of age onwards anticipate the end location of a reach and grasping action. Falck-Ytter et al. (2006) were the first to demonstrate that infants process simple manual actions predictively and related their findings to infants’ own action experience, as 6-month-olds cannot yet perform a grasp- and transport action themselves, whereas 12-month-olds are already quite experienced with the performance of this type of action. Subsequent studies expanded and replicated the findings of Falck-Ytter et al. (2006). For example, Rosander and von Hofsten (2011) observed that 10-month-olds also anticipate the target of a manual transport action, when provided in a naturalistic setting (Rosander & von Hofsten, 2011). In this context, an infant’s own action experience was related to their action anticipation-ability. Cannon, Woodward, Gredebäck, von Hofsten, and Turek (2012) used the same paradigm from Falck-Ytter et al. (2006), but let 12-month-olds actively engage with the bucket and the toys previous to the eye-tracking task. Those children, who placed more toys into the container themselves, were also better in anticipating the action in the following observation, moreover demonstrating that experience with the execution of an action facilitates action anticipation (see also Melzer, Prinz, & Daum, 2012, for contralateral reach- and transport actions). Besides infants’ own action experience, it has also been demonstrated that specifically salient goal objects seem to enhance action anticipation (e.g., Adam et al., 2016). Henrichs, Elsner, Elsner, and Gredebäck (2012) observed earlier anticipatory gaze shifts within 12-month-olds for a reach-and-grasp action when the goal object was larger compared to when it was smaller. This indicates that salient perceptual cues around the goal object have a facilitating effect on action anticipation.

While there is evidence that infants below 10 months of age fail to anticipate a manual action directed towards a single target (Falck-Ytter et al., 2006; Gredebäck, Stasiewicz, Falck-Ytter, Rosander, & von Hofsten, 2009; Melzer et al., 2012), it has been shown that 6-month-olds anticipate simple actions directed towards another's face (Hunnius & Bekkering, 2010; Kochukhova & Gredebäck, 2010). For example, infants from 6 months of age onwards anticipate that food will be brought to the mouth when observing another person eating (Kochukhova & Gredebäck, 2010) or that phones are brought to ears and cups are brought to the mouth (Hunnius & Bekkering, 2010).

However, these studies do not tell us whether infants already encode the specific goal of an action, or whether they just process the movement trajectories in order to anticipate the end location of an action. Since in the previous outlined studies simple manual transport actions are directed to only one specific goal that is always at the same location, infants' could just rely on the information about the movement in order to anticipate the target. The conclusion that infants are able to anticipate goals cannot be drawn from these experiments. However, this distinction seems relevant since a goal is more general than just a particular action as several actions could lead to the same goal (Thompson et al., 2018). If someone understands that other's act towards goals, one can generalize across different actions to identify the goal (Thompson et al, 2018, p. 107). This definition by Thompson and colleagues (2018) clearly indicates that encoding an action as goal-directed goes beyond the representation of pure physical movements. Thus it has been claimed that the ability to understand other's action goals is quite essential for social-cognitive development (e.g., Woodward, 2005). The ability of goal-understanding has been related to social competencies, such as perspective taking (Krogh-Jespersen, Liberman, & Woodward, 2015) and coordinating one's own actions to those of others (Sebanz, Bekkering, & Knoblich, 2006). For example, in order to establish a joint goal in a situation, it is first essential to identify the goal of the other person and then to plan one's own actions accordingly (Sebanz et al., 2006).

The distinction between goals and movements is also illustrated within a hierarchical representation of actions (e.g. Hamilton, 2009; Hamilton & Grafton, 2006). According to these approaches, action goals can be described on a complex level (e.g., making a tea), a simple level (take cup, put tea bag in it) and on a kinematics level (grab object, lift object, etc.; Hamilton, 2009). This means that an action goal (also referred to a desire on a hierarchically high level) consists of several sub goals on hierarchically different levels.

The distinction between the representation of goals and movements of an action was empirically first addressed by Amanda Woodward (1998), whose study provided one of the key experiments in developmental psychology and was later often referred to as "the Woodward-paradigm" (cf., Paulus, 2019). Woodward (1998) presented 6- and 9-month-olds with two distinct objects placed on a small stage and habituated infants to a human hand that reached for one of these objects repeatedly. After habituation, the positions of the objects were swapped and two test events followed. One event showed the hand reaching for the familiarized object in the now new location and the other event showed the hand reaching for the other object in the same location as in the habituation phase. Only with this change in context, namely the swapping of the objects' position is it possible to distinguish to which aspects of an action infants attend to. Can they generalize the goal across movements? Indeed, results showed that infants looked longer (i.e., showed surprise) when the hand reached for the other object in the old location, instead of when the hand grasped the same object in the new location. This was interpreted by Woodward (1998) that infants from 6 months of age encode an action in relation to its goal-directedness and not in relation to the movement. Interestingly, these differences in looking times were not observed when the action was performed with a rod or claw instead of a human hand, as lifeless objects such as rods cannot "have" a goal.

However, it has been questioned whether broad claims about infants' cognitive abilities can be derived from looking-time paradigms (Haith, 1998). Additionally, they assess infants' post-hoc evaluation of an event and thus it is not clear whether infants also make online action anticipations (see chapter 1.1.2). Therefore Cannon and Woodward (2012) provided a study in which they adapted the Woodward-paradigm (1998) to assess infants' online anticipatory eye-movements via eye-tracking. They presented 11-month-olds with a hand reaching towards one of two objects several times. Then the two objects were swapped and for test trials the hand stopped in the middle without indicting a clear movement direction, and infants' anticipations to either of the two objects were measured. Results revealed that infants anticipated the hand to grasp the familiarized object in the new location, indicating that infants also encoded the goal of the action in this online anticipatory looking-paradigm. In contrast, when the action was performed with a mechanical claw instead of a human hand, 11-month-olds did not provide anticipations directed to the goal.

Notably, Daum and colleagues (2012) modified the paradigm by Cannon and Woodward (2012) by using an animated fish instead of a human hand and obtained different results. They presented 9-month-olds, 12-month-olds, 2-year-olds, 3-year-olds and adults with a fish that repeatedly moved through an occluder to one of two possible goal objects. For test-trials, the goal-objects were swapped and after the fish disappeared behind the occluder without reappearing from it, participant's eye-movements were measured. Interestingly, only 3-year-olds and adults anticipated the action as goal-directed, whereas 9- and 12-month-olds expected the fish to move to the same location. This indicates that younger children encoded the movement path of the action, instead of the goal. The 2-year-olds did not show any preference for either of the targets, implying that they might be in a transition period. The results of Daum et al. (2012) could suggest that rather lower-level cues, such as movement directions, are primarily processed in infancy. Their results challenge the claim that infants from early on process actions in relation to goals (Woodward, 2009a). Thereby it is still an open question whether this difference is due to a different perception of the type of agent. While some claimed that infants attribute goals to any agent-like individual (Leslie, 1995; Luo & Baillargeon, 2005), others proposed that the processing of human actions is easier for infants (e.g., Woodward, 2005).

A group of other studies followed up on the results of Cannon and Woodward (2012), by using a similar paradigm, namely a fully visible human agent sitting at a table and performing grasping actions to one of two toys (Krogh-Jespersen & Woodward, 2014, 2018; Krogh-Jespersen et al., 2015; Krogh-Jespersen, Kaldy, Valadez, Carter, & Woodward, 2018). In all of these studies, participants observed the actor grasping one of the toys once, then the toys changed position and two test trials followed. In test trials, the actor performed an uncompleted reaching action and anticipations were measured. Results showed that 6-month-olds already anticipate the action as goal-directed when they previously engage in grasping-actions themselves (Krogh-Jespersen & Woodward, 2018) and that the ability to anticipate goal-directed is related to 21-month-olds perspective taking competences (Krogh-Jespersen et al., 2015). It was further demonstrated that initiating a goal-directed gaze-shift needs more time than initiating a location-directed gaze-shift, indicating that goal-anticipations demand additional cognitive effort (Krogh-Jespersen & Woodward, 2014). Nevertheless, observations on goal-anticipations were inconsistent for older children in this kind of paradigm. Twenty-one-month-olds anticipated goal-directed in the first test trial but showed chance-performance in the second (Krogh-Jespersen et al., 2015) and 2-year-olds showed chance-performance over both test trials (Krogh-Jespersen et al., 2018). These results together with the studies provided above (Cannon & Woodward, 2012; Daum et al., 2012) illustrate a heterogeneous overall picture of infants' and children's goal-anticipations, leaving an open question of when and under what circumstances infants and children encode movements or goals.

Moreover, others have found that infants primarily base their action anticipations on movement information. Paulus et al. (2011) presented 9-month-olds and adults videos of a cow that repeatedly took a long instead of a short path to reach a goal, as the shorter path was interrupted and thus not passable. However, for test trials the shorter path was passable as well, but still infants anticipated that the cow would continue taking the longer path, even though the shorter path would be more efficient. This suggests that within infants, learning about a movement path and using this information for anticipating an action seems to be more dominant than other factors, such as efficiency considerations (see also chapter 1.4.5). Theoretically also Ruffman et al. (2012) proposed that rather lower-level mechanisms are relevant for infants' processing of other's actions. In contrast to Woodward (2009a), he claims that infants primarily attend to other people and their motions (Ruffman, 2014). With their profound statistical learning skills, infants are able to distinguish patterns in other's behavior and use this knowledge to form expectations about future behaviors (Ruffman et al., 2012; see also chapter 1.4.3).

To sum up, there is an ongoing debate between rich (e.g., Woodward, 1998; 2009a) and lean accounts (e.g., Ruffman et al., 2012) about the social-cognitive mechanisms underlying infants' processing of other's actions. Current empirical evidence also draws an incoherent picture (Cannon & Woodward, 2012; Daum et al., 2012; Krogh-Jespersen et al., 2015, 2018; Paulus et al., 2011).

Furthermore, if infants primarily use lower-level cues, as suggested by Ruffman et al. (2012) and Paulus et al. (2011), it is still an open question regarding how flexible infants can use this information to anticipate other's actions. For example, in the study by Paulus et al. (2011) participants observed the agent repeatedly taking the long instead of the short path. However, for test trials the agent's behavior changed and the cow took the short path for several times. Adults could quickly adjust their anticipations and anticipated the short path after one trial, whereas 9-month-olds kept anticipating the long path for all test trials. Although they observed the changed behavior for several times they could not change their anticipations. This demonstrates that if infants once learned about an agents' behavior, they are not that flexible in changing their expectations about the behavior and indicates that frequency learning seems to be a strong but also inflexible learning mechanism.

So far, a few theoretical positions (e.g., Woodward, 2009a; Ruffman et al., 2012) have already been mentioned. In the next chapter, relevant theoretical perspectives and mechanisms on action anticipation are introduced.

1.4 Theoretical Approaches

The investigation of action understanding and how it develops has long been the focus of developmental psychology. With his theory of Genetic Epistemology, Piaget laid the foundation for many theories of social-cognitive development. Therefore, a brief historical review of his views on the development of action understanding is shortly described, before current theoretical approaches are introduced. More precisely, this thesis concentrates on four current theories: The intentional goal encoding-account (e.g., Woodward, 2009a), the statistical learning-account (e.g., Ruffman et al., 2012), predictive coding theory (e.g., Clark, 2013a) and the teleological stance theory (Gergely & Csibra, 2003).

1.4.1 Historical Excursus – Piaget's Genetic Epistemology

Piaget was driven by the question of how humans gain knowledge about the world (Miller, 2014). He viewed the child as "a scientist" that, instead of passively learning from events, engages actively with the world. Piaget (1952) followed a constructivist approach and claimed that the child actively constructs knowledge by interacting with the environment. Thereby two adaptive processes are used for constructing knowledge, namely assimilation and accommodation. Assimilation involves the incorporation of new elements into already acquired cognitive structures (or schemes), whereas accommodation describes the adjustments of cognitive schemes towards new experiences in the world. When current cognitive structures are not satisfyingly explaining experiences (i.e. when assimilation is not enough), accommodation occurs and new cognitive structures are built.

Importantly, Piaget's approach assumes a stage-wise cognitive development, with different cognitive structures underlying each developmental stage. The basis for cognitive development is thus laid in the first stage, the sensorimotor period (from birth to 2 years; Piaget, 1952). In this stage, infants' cognitive structures are tied to a sensory and motoric representation via sensomotoric schemata (Sodian, 2018). These schemata are structured patterns of behavior that are used for specific interactions with the environment and are further adapted through assimilation and accommodation. For example, in the first stages of the sensorimotor period, schemata, based on inborn reflexes such as sucking and grasping, are modified and become more and more generalized and differentiated. However, in the first two stages, these behavior patterns are mostly focused on the infant's body and not on other objects, whereas in stage 3 (4-8 months) the infant involves external objects in its actions. In this stage, Piaget also observed a first form of a simple coordination between looking and grasping. Importantly in stage 4 (8-12 months), intentional and planning behavior emerges. Infants start to differentiate between means and ends, they combine several schemes to achieve a goal. Furthermore, the schemes are not tied to a specific situation but can be generalized to new situations. Piaget also observed for the first time during a feeding situation, that infants anticipate events, as they open their mouth in anticipation of the arrival of the spoon (Piaget, 1952, p. 249; cf., Miller, 2014). In stage 5 (12-18 months), children start to actively experiment on means to achieve a goal and at stage 6 (18-24 months) children have a mental representation of objects. They can represent objects mentally, even though they do not actively see them.

Piaget also sees a connection between the development of intelligence (as described above) and the development of imitation (Piaget, 1962). For example, children accordingly differentiate in stage 4 between schemes about the means and schemes about the goal of an action when imitating a model. This indicates that the differentiation between means and ends does not only apply for action performance but also when observing others.

To sum up, Piaget's idea was that motor actions of the infant "evolve over the years into abstract thought" (Miller, 2014, p. 651), indicating that understanding of other's actions evolves through first-person agentive experience with the surrounding environment. Thereby infants' knowledge is mentally represented by schemata, which are further adapted through the processes of assimilation and accommodation. Despite the critics and limitations of Piaget's work (for an overview see for example, Miller, 2014; Sodian, 2018), his theory still influences today's theories on social-cognitive development (e.g., Rakison & Woodward, 2008).

1.4.2 Intentional Goal Encoding-Account

The first current theoretical approach assumes that infants represent actions as structured around goals. Woodward (2005, 2009a, 2009b) claims that infants within their first year of life start to perceive other's actions as being organized by goals and "objects of attention" and not as sheer "movements through space" (Woodward, 2009b, p. 228). Adults naturally interpret other's actions as structured by goals, intentions and perceptions and not through mere physical movements. In her view, infants don't seem to understand other's mental lives as adults do, but they "understand intentions as existing independently of particular concrete actions and residing within the individual" (Woodward, 2009a, p. 55; see also Buresh & Woodward, 2007). By her rich definition, a goal is something abstract and intentional, where-as body movements are physical and concrete. Evidence for the claim that infants primarily process action goals and not physical movements came from looking-time studies (Buresh & Woodward, 2007; Guajardo & Woodward, 2004; Luo & Baillargeon, 2005; Sommerville & Woodward, 2005; Woodward, 1998, 1999) and studies that measured visual anticipations (Cannon & Woodward, 2012; Krogh-Jespersen & Woodward, 2014, 2018; Krogh-Jespersen et al., 2015; Krogh-Jespersen et al., 2018). These studies are all based on the "Woodward-paradigm" (as described above in chapter 1.3) and therefore distinguish infants' processing of physical movements from processing the action goal of a manual reach and grasping action. According to Woodward (2009a), lower-level explanations are rather unlikely for explaining the results of her experiments, because infants do not process an action as goal-directed when the hand is not grasping the object but touching it with its back (e.g., Krogh-Jespersen & Woodward, 2014) or when it is performed by an inanimate agent (such as a claw or a rod; e.g., Cannon & Woodward, 2012; Woodward, 1998). Therefore, infants seem to understand the intentional structure of an action. It seems unlikely that, for example, the repeated contact between the agent and the object drew infants' attentional focus towards the goal rather than the movement (Woodward, 2009a), as infants attended towards the goal-object similarly when the action was performed by a claw (Cannon & Woodward, 2012).

One underlying mechanism that has been related to infants' ability to encode the goal of an action could be one's own first-person experience (e.g., Sommerville, Woodward, & Needham, 2005). In line with Piaget (1952), it has been assumed that infants anticipate other's actions, when they are also able to perform the action themselves. Evidence for this has been demonstrated by habituation studies (e.g., Sommerville et al., 2005) and anticipatory looking studies when infants could rely on movement information (e.g., Cannon et al., 2012; Falck-Ytter et al., 2006; Gredebäck & Kochukhova, 2010; Gredebäck & Melinder, 2010; Kanakogi

& Itakura, 2011). For example, by 6 months of age, infants developed the ability to reach for objects themselves and also anticipated the reach and grasping action of a human hand (Kanakogi & Itakura, 2011). More direct evidence for the relation between action execution and action perception was provided by training studies: For example, Sommerville et al. (2005) provided 3-month-olds with sticky mittens that allowed them to perform a goal-directed action. Although 3-month-olds do not show goal-directed behavior yet, they could acquire an object by touching it with the sticky mitten. And indeed, the 3-month-olds who gained active action experience with the sticky mittens before the habituation paradigm, looked longer when the actor reached for the other object in the new location. In contrast, infants who had no prior training with these mittens did not show goal-encoding of the action.

However, it seems that the relation between execution and anticipation is not as simple for flexible goal-anticipations (see also Thompson et al., 2019), as 8-month-olds do not anticipate the specific goal of a reach and grasping action even though they are able to perform the action by themselves (Krogh-Jespersen & Woodward, 2018). Only when they actively engaged in a reaching and grasping action previous to the observation task, were they able to anticipate the action as goal-directed. This indicates that motor priming of the action previous to the observation task seems necessary to elicit flexible goal-anticipations within 8-month-olds.

Theoretically, this relation between action experience and action perception could be due to a common neural representation of the two processes (e.g., Flanagan & Johansson, 2003). More precisely, it has been claimed that through a mirror neuron system (Molenberghs, Cunnington, & Mattingley, 2012), an observed action is mapped onto one’s own motor repertoire and thus enables goal anticipation of another’s action (Falck-Ytter et al., 2006; Gallese, Rochat, Cossu, & Sinigaglia, 2009; Gredebäck & Falck-Ytter, 2015; Kilner, Friston, & Frith, 2007; Rizzolatti, Fogassi, & Gallese, 2001). More simply said, the same brain regions are active during execution of an action and observing someone else perform the same action. By using our own motor knowledge, we can make inferences about other’s goals and intentions (Rizzolatti & Sinigaglia, 2007). However, until today, the precise role of mirror neurons in action anticipation seems to be a matter of debate. While it has been claimed that the mirror neuron system is responsible for goal-encoding (e.g., Rizzolati & Sinigaglia, 2010; Woodward, 2009b), others argued that mirror neurons rather encode lower-level features of an action, such as movement directions, and are therefore “only” involved in the recognition of an action (Cook & Bird, 2013; Cook, Bird, Catmur, Press, & Heyes, 2014; for an overview see also Thompson et al., 2019). On top of that, others doubt the existence of mirror neurons and their role in action understanding altogether (e.g., Hickok, 2009).

1.4.3 Statistical Learning-Account

It has been claimed that the detection of statistical regularities and rules is a very powerful and rapid learning mechanism. Through mere exposure, infants can rapidly detect patterns and distributions in their environment (Aslin, 2017; Aslin & Newport, 2012). Originally, this learning mechanism was investigated in relation to language acquisition (Saffran, Aslin, & Newport, 1996; Saffran, 2003; Smith & Yu, 2008). Thereby it has been observed that 8-month-olds can segment words from a fluid speech stream through the detection of statistical relationships between neighboring speech sounds (Saffran et al., 1996). Importantly, this ability is not limited to auditory stimuli. For instance, it has been shown that infants from 2 months of age can detect and learn the statistical order of a sequence of images (Kirkham, Slemmer, & Johnson, 2002). These and other studies (Fiser & Aslin, 2002; Kudo, Nonaka, Mizuno, Mizuno, & Okanoya, 2011; Lany & Gómez, 2008; Teinonen, Fellman, Näätänen, Alku, & Huotilainen, 2009) provide evidence that this essential learning mechanism is domain general.

It has further been claimed that statistical learning is essential for developing an understanding of other’s actions. Ruffman and colleagues (2012) assume that through their profound statistical learning skills, infants learn about regularities and patterns in other’s actions. These detected and learned regularities are used to form expectations about other’s actions and thus inform anticipations. In his theoretical account, Ruffman proposes that learning about regularities in other’s behavior is the foundation for the development of a Theory of Mind (Ruffman, 2014; Ruffman et al., 2012). Together with infants’ pronounced interest in faces and motion, as well as linguistic maternal input, children slowly start to gain explicit knowledge about mental states. However, before children acquire this explicit mental state understanding, they understand actions on a rather behavioral level and not on a mental state level. In contrast to Woodward (2009a), his account argues for a rather lower-level interpretation of infants' social cognitive abilities. Woodward's results (1998; Cannon & Woodward, 2012) could, therefore, simply be explained through the learning of the association between the agent and the object. Infants' tendency to anticipate other's action goals might be a result of their accumulating life-long experience with observing hands reaching for objects (or generally that agents act towards goals). Likewise, they might not have any experience with claws or rods performing grasping actions, which would make it hard for them to anticipate a goal-directed action performed by a claw.

Several action anticipation-studies provide evidence in support of the claim that infants use prior knowledge to anticipate other's actions. For example, Hunnius and Bekkering (2010) demonstrated that infants from 6 months of age use their knowledge about certain objects to anticipate actions, such as the knowledge that phones are brought to ears and cups to the mouth. It has further been demonstrated that infants use their knowledge about movement extrapolation to anticipate the reappearance of a temporarily occluded rolling ball (Kochukhova & Gredebäck, 2007). Further evidence is provided by Green, Li, Lockman and Gredebäck (2016), who showed that prior cultural experiences influence 8-month-old's anticipation of eating actions. Swedish and Chinese infants observed an actor eating with a spoon or with chopsticks. Results demonstrated that Swedish infants only anticipated the action when performed with the spoon, while Chinese infants only anticipated the action when performed with chopsticks. This indicates that infants' prior visual experience of seeing other's eat with a spoon or chopsticks influences action anticipation thereof.

In addition, it has been shown that infants and adults not only use knowledge that has been gained *before* an experiment, but also acquire new knowledge *within* an experiment and use this knowledge for action anticipation (e.g., Kochukhova & Gredebäck, 2007; Paulus et al., 2011). For instance, Paulus et al. (2011) presented 9-month-olds and adults with a cow that repeatedly took the longer of two paths to reach a goal, since the shorter path was blocked. For test trials both paths were passable and infants and adults anticipated the cow to take the longer path it repeatedly took before. This indicates that infants and adults can learn about the behavior of an agent based on the repeated observation during the experiment. They observed the agent perform an action in a certain way and used this information for action anticipation. This shows that infants and adults can form new knowledge based on an observation within an experiment. Analogously, in a study by Henrichs and colleagues (2014), 12-month-olds anticipated a hand reaching for one of three objects faster, when they observed the hand reaching for this specific object over several trials. This was not observed when infants saw the hand always reaching for a different object. This implies that the statistical regularity of the action helped infants making faster action anticipations (Henrichs et al., 2014). Two recent studies used a more complex setup and provided toddlers and adults with a whole set of action sequences. Toddlers and adults were able to detect statistical regularities within these action sequences and used this information to anticipate those actions (Monroy, Gerson, & Hunnius, 2017; Monroy, Meyer, Gerson, & Hunnius, 2017). This provides even more profound evidence for the presence of a very “powerful statistical learning engine” (Aslin, 2017, p. 4), that seems to be present from birth and plays an essential role for action anticipation.

1.4.4 Predictive Coding Theory

Another theory that originally comes from visual perception is becoming more and more prominent in relation to action anticipation. This account, similar to Ruffman et al. (2012), also relies on human’s sensitivity towards statistical regularities in their environment, but takes a step further in concentrating on its underlying mechanism. According to predictive coding theory (e.g., Clark, 2013a; Friston, 2010; Hohwy, 2012), our perception is not a passive but a rather active process. The brain constantly predicts the causes of sensory input by using a generative model based on Bayesian estimates (Friston, 2012). This generative process works through a bidirectional hierarchically structured system: Relying on prior knowledge (in short “priors”, see e.g., Clark, 2013a; Friston, 2010), hierarchically higher levels in the brain predict the causes of incoming sensory information from lower levels. Further, the amount of sensory input that was not predicted by top-down information results in a prediction error, and is reported backwards (e.g., Clark, 2013a). These prediction errors are especially important, as they provide information about the mismatch between predictions and sensory input, so future predictions can be adjusted and improved. Thereby, according to the free energy principle, the brain constantly aims to minimize its prediction errors, in order to provide the current best estimate of the causes of the sensory input (Clark, 2013a; Friston, 2010).

However, not every prediction error is equally informative for our generative models. Since two experiences are never exactly the same and to some degree prediction errors will always be present, the brain needs to decide which errors to ignore and which errors to take into account for model revisions (Kwisthout, Bekkering, & van Rooij, 2016). This weighing of prediction errors is encoded through "precision" (Friston, 2010). A prediction error with low precision might be a result of our noisy environment and thus needs to be ignored, whereas a prediction error with high precision is very informative and critical for updating a predictive model (van de Cruys et al., 2014). In sum, precision is a very context dependent mechanism of attention that is relevant for our learning processes (Clark, 2016).

So simply said, according to predictive coding, perception is a process "in which we (or rather various parts of our brains) try to guess what is out there" (Clark, 2016, p. 27), by relying on previous knowledge and our assumptions about the world. Thereby, priors can have different levels of abstraction. Priors on a higher level contain more general knowledge and are often also called hyperpriors (e.g., the hyperprior that agents generally act towards goals or that light comes from above; Clark, 2013a; Hohwy, Paton, & Palmer, 2016). Another example was nicely demonstrated by Hohwy, Roepstorff and Friston (2008): In relation to binocular rivalry, a hyperprior would be the knowledge that "only one object can exist in the same place at the same time" (Hohwy et al., 2008; p. 691; cf., Clark, 2013a).

Prediction means on the one hand, guessing the current sensory input, but then can also be used in an anticipatory sense (Friston, Mattout, & Kilner, 2011). For example, Kilner et al. (2007) proposed that the mirror neuron system operates within a predictive coding account, and thus enables anticipation of other's actions. Thereby the mirror neuron system is hierarchically organized, and predicts another's kinematics through one's own action system based on the prior expectations of another's goal. The predicted kinematics are compared with the observed kinematics and result in a prediction error, which lead to updates of the expected action goal.

Theoretically, predictive coding was not only related to action anticipation, but also to motor control (Miall & Wolpert, 1996; Wolpert, Doya, & Kawato, 2003), Theory of Mind (Koster-Hale & Saxe, 2013) and social perception (Bach & Schenke, 2017; Westra, 2019). Besides these expanding theoretical considerations of the predictive processing approach, empirical evidence has grown over the last few decades (e.g., Egner, Monti, & Summerfield, 2010; Rao & Ballard, 1999; Summerfield & de Lange, 2014). A few recent studies with adults provide evidence for predictive processes during social-cognitive processing. By measuring prediction errors, the authors observed that participants showed surprisal when an observed action had an unexpected outcome, demonstrating that predictive coding theory also explains more higher-level social-cognitive processing (Heil, Kwisthout, van Pelt, van Rooij, & Bekkering, 2018; Heil et al., 2019; see also van Pelt et al., 2016). Further evidence for an influence of top-down information on action perception was provided by Hudson, Nicholson, Ellis and Bach (2016).

There are also claims and evidence, that such a predictive system is already present in infants (e.g., Trainor, 2012). For example, Kayhan, Hunnius, O'Reilly and Bekkering (2019) demonstrated with a pupil dilation-paradigm that 9-month-olds can build internal models about their environment and also quickly update these models when necessary. Also, 6-month-olds' ability to anticipate an action was related to their surprisal reactions (measured via pupil dilations) when another's action had an unexpected outcome (Gredebäck, Lindskog, Juvrud, Green, & Marciszko, 2018). This supports the claim that predictive models influence the processing of other's actions in infants.

While predictive coding theory seems to be a promising approach for exploring mechanisms underlying action anticipation, it also has great potential for explaining symptoms of schizophrenia (e.g., Fletcher & Frith, 2009) and autism spectrum disorder (e.g., Pellicano & Burr, 2012; Van de Cruys et al., 2014; see also chapter 1.5.1).

1.4.5 Teleological Stance Theory

Another prominent approach in infancy research is the teleological stance theory (Csibra & Gergely, 1998; Gergely & Cisbra, 2003). This theory assumes that infants do not represent other's actions in relation to mental states but rather through a "reality-based interpretational strategy" (Gergely & Csibra, 2003, p. 290). To use this "strategy", infants rely on three different aspects of an event: The goal state, the action (i.e. the means to acquire the goal) and the situational constraints. These three aspects are related to each other and can be inferred through the rationality principle, i.e. the assumption that goal states are realized through the most rational action given the current situational constraints. By having at least two of the three aspects (goal, action or situational constraints) available, infants can infer the third aspect by assuming that the agent acts in the most efficient manner to reach a goal. Thereby infants can anticipate the goal of an observed action (Gergely & Csibra, 2003). Although the theory assumes that infants do not attribute mental states to others yet, they claim that infants make quite sophisticated assumptions about the rationality of other's actions on a cognitively high level (Paulus & Kiraly, 2013).

While the goal-encoding approach assumes that infants' show goal-understanding for human actions first and expand their knowledge later to other types of agents (e.g., Woodward, Sommerville & Guajardo, 2001), proponents of the teleological stance theory believe that infants attribute goals to human as well as non-human agents from early on (e.g., Gergely, Nadasdy, Csibra, & Biro, 1995; for an overview see also Luo & Baillargeon, 2005). As long as the actions of agents show specific characteristics, such as self-propelledness, equifinal variations or a salient action outcome, infants should not make a difference in perceiving non-human or human actions, according to this account (e.g., Adam, Reitenbach, & Elsner, 2017; Biro & Leslie, 2007; Kamewari et al., 2005).

Most evidence for this theory was provided by habituation based looking-time studies (e.g., Csibra, Biro, Koós, & Gergely, 2003; Csibra, Gergely, Biro, Koós, & Brockbank, 1999; Gergely, et al., 1995; Kamewari et al., 2005). For example, Gergely et al. (1995) habituated 12-month-olds to an agent (a ball) that approached another ball by jumping over a barrier. The barrier was removed in test trials, and infants observed in one test event how the ball directly approached the goal. For the second test event, the ball performed a jumping action as in the habituation phase, but without the barrier. Results implied that infants looked longer when the ball performed a jumping action to reach a goal, instead of taking a direct route. This indicates that infants processed the action in relation to the rationality principle. They showed surprisal when the agent performed an inefficient action (i.e. an unnecessary jump when there is no obstacle).

These looking-time studies were complemented by studies using eye-tracking measures (Biro, 2013; Elsner, Pfeifer, Parker, & Hauf, 2013; Gredebäck & Melinder, 2010; Paulus et al., 2011; Schuwerk & Paulus, 2016). However, whether infants also make use of the principle of rationality for online action anticipation seems to be a matter of debate (e.g., Paulus & Kiraly, 2013; Ruffman et al., 2012). While Biro (2013) reported evidence in support of the rationality principle within infants, other studies reported contradictory findings (Paulus et al., 2011; Schuwerk & Paulus, 2016). Similar to Gergely et al. (1999), Biro (2013) familiarized infants with an animated ball jumping over a barrier to reach a goal. For test trials the barrier was removed and results showed that infants anticipated the goal faster, when the agent approached the goal directly than when making a detour (jumping movement). This indicates that efficiency considerations could play a role in action anticipation (but refer to Ruffman et al., 2012, for an alternative explanation). In contrast, two other studies did not observe anticipations based on efficiency reasoning (Paulus et al., 2011; Schuwerk & Paulus, 2016). For instance, in the study by Schuwerk and Paulus (2016), an agent explicitly stated that it wants to get to its goal as soon as possible and could choose between an efficient and inefficient path. However, none of the age groups (5-year-olds, 15-year-olds and adults) anticipated the agent to take the efficient path. They only anticipated towards the efficient path after they had repeatedly observed the agent taking this path (Schuwerk & Paulus, 2016; see also Paulus et al., 2011). This indicates that even for adolescents and adults, frequency information might be the driving mechanism when anticipating an action, and questions the presence of such high-level cognitive processes within infants (see also Ruffman et al., 2012).

1.4.6 Summary of Current Theoretical Approaches

To summarize, four current theoretical approaches are relevant for this thesis. Two of them assume that rather higher-level cognitive competencies are already present within infants. As described in the intentional goal-encoding account, Woodward (2009a) claims that infants understand other's actions in relation to goals and that this understanding is very likely related to infants' own first-person agentive experience. By her definition, a goal is something abstract and intentional. The teleological stance theory also assumes that infants understand goals, but rather on a behavioral and not on an intentional level. Critically, this theory claims that infants understand actions in relation to an inborn rationality principle and understand other's goals due to efficiency considerations (Gergely & Csibra, 2003). In contrast, the statistical learning account and predictive coding theory assume that rather lower-level processes are responsible for action anticipation abilities. Ruffman et al. (2012) propose that due to sophisticated statistical learning skills, infants detect regularities and patterns in other's actions and use this knowledge to anticipate those actions. According to this account, infants might "understand" goals by forming associations between an agent and a target object (Ruffman et al., 2012). Thus, when anticipating other's actions, more simple information is used. Similarly, predictive coding theory assumes that humans use their prior knowledge to anticipate other's actions (e.g., Clark, 2013a). Through internal forward models, the brain constantly estimates the best fitting predictions of sensory input based on prior knowledge about the world. Through a feedback system, these predictions become more accurate with increasing experience. If infants are able to anticipate actions as goal-directed, this would be due to their acquired knowledge that agents usually act towards goals.

In summation, all four current theoretical approaches assume different mechanisms underlying action anticipation and make different claims about infants' competencies. So far, theories and empirical evidence concentrated on neurotypically developed infants and children. However, most of the mentioned theories also offer explanations for symptoms of Autism spectrum condition. In the next section, abilities of action anticipation within individuals with autism spectrum condition are outlined, as well as the explanatory value of theoretical approaches considering their symptomatology discussed.

1.5 Action Anticipation within Autism Spectrum Condition

Autism spectrum condition (ASC) is a group of neurodevelopmental disorders that begin early in life and last through a lifetime. ASC is characterized by social-communicative difficulties, as well as restrictive and repetitive behaviors and interests (American Psychiatric Association, 2013). It is further related to a high comorbidity rate for other disorders, such as depression, anxiety disorders, or ADHD (Matson & Nebel-Schwalm, 2007). It has been claimed that their social difficulties could be traced back to an inability to anticipate other's actions (e.g., Sinha et al., 2014). Therefore, the next section introduces relevant theories and empirical findings of action anticipation within ASC.

Theories for behavioral symptoms within ASC follow two different directions: Domain specific accounts claim that the core deficit lies specifically in the social domain. In contrast, domain general accounts suggest that general cognitive deficits are the cause for ASC symptomatology. Concerning the domain specific accounts, two theories are especially prominent. First, the *Theory of mind deficit hypothesis* (cf., Schuwerk & Paulus, 2018) claims that individuals with ASC have an inability to attribute intentions and goals to others' behavior (e.g., Frith, 2012; Frith, Morton, & Leslie, 1991). A deficit in Theory of Mind has been claimed to be responsible for social cognitive problems in ASC. According to this theory, individuals with ASC should have problems in anticipating other's actions due to their difficulties in attributing mental states to others and to themselves. Second, the so called *broken mirror theory* claims that individuals with ASC have deficits in their mirror neuron system (e.g., Obermann & Ramachandran, 2017; for an overview see also Hamilton, 2013). This theory is based on the assumption that the mirror neuron system is the driving mechanism behind action anticipation. More precisely, the observed actions are mapped onto one's own motor system and thus enable the anticipation of the action (see also chapter 1.4.2). Individuals with ASC might have problems with this matching process, being the cause for their social deficits.

However, evidence so far is not fully compatible with these domain-specific theories (Dinstein et al., 2010; Hamilton, 2009; Hamilton, 2013). Notably, eye-tracking studies demonstrated that individuals with ASC show no differences to typically developed individuals for motion perception (Cusack, Williams, & Neri, 2015; Murphy, Brady, Fitzgerald, & Troje, 2009; Saygin, Cook, & Blakemore, 2010; von der Lühe et al., 2018) and the anticipation of simple actions (Braukmann et al., 2018; Falck-Ytter, 2010). For instance, in a study by Falck-Ytter (2010), 5-year-olds with ASC as well as comparison participants observed a human hand reaching for an object and placing it into a container. Equivalent to typically developed children and adults, they looked at the container before the hand arrived there, demonstrating no differences between individuals with ASC and comparison participants when anticipating the goal of a simple action. Similarly, 10-month-olds with high familial risk for ASC use object-knowledge for their anticipations, such as that a phone is brought to the ear and cups to the mouth (Braukmann et al., 2018). This indicates that action anticipation is intact within individuals with ASC when actions are simple, and individuals can rely on movement information. The fact that movement information is a strong source of information for individuals with ASC was also observed by Krogh-Jespersen et al. (2018). In their study (based on the Woodward-paradigm), 2-year-old children with ASC observed an actor grasping for one of two objects. In test trials, the objects position swapped and children with ASC anticipated towards the same location and not towards the goal. In contrast, 2-year-olds from the comparison group anticipated towards the goal in the new location. This demonstrates that children with ASC primarily process the movement pattern of the action and not the specific goal.

These results imply that individuals with ASC have difficulties when the specific goal of an action needs to be inferred (Krogh-Jespersen et al., 2018). This is also in line with the observation that adolescences with ASC have problems in sequencing goal-directed actions in a picture story-task (Zalla, Labruyere, & Georgieff, 2006) and make more mistakes when predicting the most likely outcome of an action sequence than comparison participants (Zalla, Labruyère, Clément, & Georgieff, 2010). It seems that when tasks become more complex, individuals with ASC have difficulties in comparison to typically developed participants.

In sum, current evidence on action anticipation within individuals with ASC is mixed. The claim, that individuals with ASC have general deficits in action anticipation cannot be supported. It rather seems that individuals with ASC show deficits under some circumstances (Schuwerk & Paulus, 2018). This indicates that domain specific theories, such as the broken mirror theory and the Theory of mind deficit hypothesis, are no longer tenable (Hamilton, 2009). Rather more fine-grained theories are necessary, that imply a general cognitive deficit (whether social or not), in order to explain the scope of ASC symptomatology. In the following, three relevant domain-general approaches are introduced.

1.5.1 Domain-General Theories of ASC

On the one hand, Ruffman (2014) proposed from a developmental perspective, that individuals with ASC have difficulties with statistical learning. He claims that detecting statistical regularities in our environment is an essential learning mechanism that provides us with the ability to predict other's actions and finally leads to the development of a Theory of Mind (see also chapter 1.4.3). This learning mechanism could be impaired within individuals with ASC, and thus be the cause for their various difficulties, including reduced action anticipation abilities. In line with this, it has been suggested that autism is a "disorder of prediction" (Sinha et al., 2014, p. 15220) because individuals with ASC have problems in estimating conditional probabilities, namely calculating the probability of event B following event A. This might especially affect the interaction with dynamic objects, including the anticipation of other's movements to plan one's own actions (Sinha et al., 2014).

In fact, it has been demonstrated that individuals with ASC have difficulties with the anticipatory timing of their own actions to ongoing events (i.e. motor anticipation). For instance, Brisson, Warreyn, Serres, Foussier, and Adrien-Louis (2012) analyzed feeding situations of infants that were later diagnosed with ASC and observed that they did not open their mouth as regularly as typically developed infants in anticipation of the arrival of the spoon. Similar observations of reduced motor anticipations in other situations were made by others (e.g., Hughes, 1996; Landa, Haworth, & Nebel, 2016; Martineau, Schmitz, Assaiante, Blanc, & Barthélémy, 2004; Schmitz, Martineau, Barthélémy, & Assaiante, 2003), supporting the claim of reduced predictive abilities within ASC (Sinha et al., 2014). Reduced predictions have also been examined in a visual action anticipation task. Schuwerk, Sodian and Paulus (2016) confronted children and adults with and without ASC with movies of an animated agent, who repeatedly took a shorter instead of a longer path to reach a goal. To elicit anticipatory eye-movements, the agent disappeared behind an occluder (which was overlaid on the crossroad where the paths divided into the short and long path) before reappearing on the short path and approaching the goal. During the time the agent disappeared behind the occluder, anticipatory eye-movements were measured and results implied that individuals with ASC made generally less anticipations than comparison participants. This underlines the claim for reduced predictive abilities within ASC (Sinha et al., 2014). On top of that, individuals with ASC did not only make fewer anticipations but also showed less improvement over time (Schuwerk et al., 2016). They could not make use of the repeated observation of the agent always taking the shorter path as good as their comparison participants, which supports the claim for reduced statistical learning abilities within ASC (Ruffman, 2014).

The claim that the detection of statistical regularities in our environment is essential for social cognitive processing finds also attention within predictive coding theories. Over the last few years, this approach has been becoming more and more prominent for explaining ASC-symptomatology. As has been already mentioned in chapter 1.4.4, predictive coding theory suggests that our perception is guided by our expectations about the world (Clark, 2013a). Through a hierarchically structured system, our brain constantly predicts incoming sensory input with top-down predictions (i.e. priors; see also chapter 1.4.4 for detailed explanation). It has been claimed that the use of prior information is attenuated within ASC and they therefore rely much more on bottom-up sensory signals. For example, Pellicano and Burr (2012) stated that individuals with ASC see the world more "as it really is" (p. 504), without the bias of prior knowledge. This explains, for instance, why individuals with ASC are less susceptible to visual illusions. They are less influenced in their perception by their priors. Since lots of sensory information is not explained away by downward predictions, individuals with ASC are constantly flooded with sensory input, resulting in the use of various self-protecting strategies, such as insistence on sameness, repetitive behaviors or insulation (Clark, 2016).

While Pellicano and Burr's approach focuses only on non-social symptoms of ASC, others expanded these claims to social perceptual processes (e.g., Lawson, Rees, & Friston, 2014; Mottron, Dawson, Soulieres, Hubert, & Burack, 2006; Palmer, Lawson, & Howhy, 2017; Van de Cruys et al., 2014). Social situations are complex and many often subtle cues must be interpreted. Thus, we have to rely even more on our prior knowledge (including context information) to anticipate other's actions. When this ability, to adequately use prior knowledge, is impaired, ambiguous situations feel even more unpredictable, which in turn has a significant impact on social life (Clark, 2016).

Accounts following Pellicano and Burr (2012) mostly propose a failure in handling the precision of prediction errors properly (e.g., Lawson et al., 2014; Van de Cruys et al., 2014). They claim that individuals with ASC have problems with their meta-learning, i.e. the ability to distinguish which prediction errors are important for model updates and which are not (e.g., Van de Cruys et al., 2014). Instead of distinguishing mere noise from relevant input, individuals with ASC process all the prediction errors as "important", thus are being constantly flooded with alleged "newsworthy" information.

To directly investigate the influence of priors in a social context, Chambon et al. (2017) tested adults with ASC in an action prediction task. In order to predict an action, they had to infer the intention of one or two actors that manipulated objects. When only one actor was present, participants could rely on visuo-motor information. In the conditions with two actors, they had to rely on prior social beliefs (i.e. the belief that people tend to act reciprocally towards each other) to predict their actions. Results showed that adults with ASC did not have problems in making inferences when they could rely on visuo-motor information. However, when they had to rely on social priors, they showed difficulties in action prediction.

Similarly, von der Lühe et al. (2016) observed that adults with ASC had problems using social priors when predicting actions of two point-light agents. Together with other findings (Amoruso et al., 2018; Król & Król, 2018), these studies provide converging evidence for the claim, that individuals with ASC have problems with using prior information to make action predictions.

To sum up, it seems that these domain-general accounts are better able to explain current evidence on social cognitive processing within individuals with ASC (see also Schuwerk & Paulus, 2018). While children and adults with ASC show no difficulties in anticipating actions in simple situations where only the processing of movement information seems relevant (e.g., Braukmann et al., 2018; Falck-Ytter, 2010), they reveal difficulties when situations get more complex (e.g., Chambon et al., 2017; Krogh-Jespersen et al., 2018; Schuwerk et al., 2016; Zalla et al., 2006). Importantly, studies mostly revealed that individuals with ASC are "only" less sophisticated than comparison participants, but not completely impaired in their ability to use prior information (e.g., Chambon et al., 2017; Schuwerk et al., 2016; cf., Schuwerk & Paulus, 2018). This seems especially relevant, when thinking about practical implications of these findings in relation to suggestions and improvements for the clinical situation of individuals with ASC (see e.g., Haker, Schneebeli, & Stephan, 2016).

1.6 The Current Thesis

1.6.1 Research Questions

The general aim of the current thesis is to find out more about the processes underlying action anticipation early in development. Thereby the focus of the thesis lays on the question of which kind of information infants, children and adults process when making action anticipations. More specifically, how do children use their knowledge about goals and paths for action anticipation and how flexible are they in their use thereof?

As has been outlined in the chapter on the development of action anticipation (chapter 1.3), evidence on infants and children's use of goal- and path-information is inconclusive.

While it has been claimed that already infants process other's actions flexibly in relation to the action goal (e.g., Cannon & Woodward, 2012; Krogh-Jespersen et al., 2018), others have provided evidence against that claim and proposed a later development of flexible goal-anticipations (Daum et al., 2012). These contrasting results rather imply a dominant processing of path and not goal-information within infants (see also Paulus et al., 2011). This contradiction needs further investigation, especially due to its relevance on theories of social-cognitive development. Under which circumstances do infants and children anticipate other's action goals?

Following this overall question based on theories and empirical evidence provided in the previous chapters, the following three research questions were examined in the current work:

(1) The first research question concentrates on infants and children's ability to anticipate an action goal flexibly. Do infants, children and adults anticipate an action in relation to movement information or goal information? Although it has been assumed by the intentional goal-encoding approach (Woodward, 2009a) that infants primarily process action goals, others proposed rather lower-level processes (statistical learning-approach; Ruffman et al., 2012). It is not clear from prior studies at which age children anticipate an action as goal-directed and which factors influence infants and children's goal-anticipations (e.g., whether they distinguish between non-human and human agents).

(2) The second research question investigates whether children and adults anticipate an action goal when they are provided with an additional cue. Can they flexibly use path information in order to encode an action as goal-directed, i.e. when they are confronted with different paths leading to the same goal? Furthermore, this question is also examined in relation to ASC. Are individuals with ASC able to learn about an action goal and use this information for action anticipation? Thus, this research question examines predictive coding theory and the statistical learning approach in relation to ASC.

(3) Last but not least, the third research question focuses further on the ability to use movement-information flexibly and examines teleological stance theory (Gergely & Csibra, 2003) as well as predictive coding accounts (Clark, 2013a). Are children and adults able to change their path-anticipations due to contextual changes?

1.6.2 Outline of the Thesis and Author Contributions

In order to investigate these research questions, three different eye-tracking studies were implemented that included several age groups ranging from infancy to adulthood. All three studies used either a human or an animated animal as the acting agent. The paradigm using the human agent was based on Cannon and Woodward's study (2012) and showed a grasping action towards one of two objects of a human hand. The paradigms containing an animated non-human agent, were based on Daum et al. (2012) and Paulus et al. (2017, 2011). Here the setup showed a path that divided into two different paths. At the crossroad, where the single path divided into the two paths, an occluder was overlaid. When the agent approached the occluder, it disappeared behind it and reappeared on one of the two paths. All paradigms included a familiarization phase at the beginning, to familiarize participants with the setup and the agent. In Study 1 and 3, this was followed by a learning phase, in which participants were confronted with the agent's repeated behavior over several trials. The following test trials comprised an incomplete action of the actor, without the fulfilling of the concrete action goal, and participant's anticipatory eye-movements were measured. In Study 2, participants observed over several trials the complete actions of the agent and learning performance over the trials was assessed.

Study 1 was conducted to answer the first research question and tested the intentional goal encoding approach and the statistical learning account by means of two sub-studies. Study 1a concentrated on the investigation of the factors that might support goal-understanding. Study 1a contains five different experiments that provide a step-by-step approximation from the study of Daum et al. (2012) to the study by Cannon and Woodward (2012), resulting in a replication as close as possible to Cannon and Woodward's study

(2012). This step-by-step approximation should provide information under which circumstances infants show goal anticipations and what caused the different results of Cannon and Woodward (2012) and Daum et al. (2012). Thus, in total 144 12-month-old infants were tested. It was expected that the type of agent (human vs. non-human agent) and the presence of an occluder (Daum et al., 2012) would influence infants' goal-anticipations. Study 1b complemented this investigation and examined the difference of human- and non-human agents systematically and over several age groups. It was further assessed whether the two paradigms measure the same underlying ability. To this end, 34 11-month-olds, 35 32-month-olds and 35 adults observed both a goal-directed human action (based on Cannon & Woodward, 2012) and a non-human action (based on Daum et al., 2012). If the processing of human actions is easier for infants and children, it was hypothesized that goal-directed anticipations are more likely in the hand- than in the path-paradigm. Adults were expected to show goal-anticipations for both paradigms.

Study 2 investigated the second research question and thus also included individuals with ASC, to see whether individuals with ASC have problems in using prior information, as was assumed by the statistical learning account and predictive coding theory (Pellicano & Burr, 2012; Ruffman, 2014). It was assessed whether children, adolescences and adults with and without ASC learn about the goal-directedness of an action when they are provided with an additional cue, and how flexible they are in their use of path-information. Therefore, 71 participants with ASC and 72 without ASC were presented with an animated animal (pig) that repeatedly walked to one of two goal-objects. From time to time the goal-objects changed place, so that participants observed the agent aiming for the same goal independent of its location. Thus, participants also had to rely on information about the goal in order to make correct action anticipations and could not just process the agent's movements. If domain-general theories on ASC are correct, it was expected that individuals with ASC might have problems in learning about the action goal, as they might have difficulties with the use of prior information. It was further hypothesized that individuals without ASC would quickly learn about the goal of an action and show respective action anticipations (following Paulus et al., 2017).

Finally, Study 3 focused on the third research question and investigated whether children and adults adapt their anticipations to contextual changes and are thus flexible in their processing of path-information. Study 3 tested assumptions of teleological stance theory (Gergely & Csibra, 2003) and predictive coding theory (Clark, 2013a). In addition, this study examined this question from a life-span perspective and included older, as well as younger adults. Thus, 2-year-olds (n = 42), 5-year-olds (n = 47), younger (n = 45) and older adults (n = 47) were presented with an animated animal (cow) that repeatedly took one of two paths to reach a goal. Then this path became blocked and was thus not passable. For test trials, only the other path was passable and thus was the only available option for the agent to reach the goal. Due to the fact that 2-year-olds have less developed executive functions and fewer experiences, it was expected that the 5-year-olds might be slightly better in integrating the contextual changes in their action anticipations. It was further hypothesized that flexibility in action anticipation might decline in later adulthood due to a decline in executive functions. However, older adults have more life-long experience which could also lead to an improvement of action anticipation abilities in older ages.

The following table gives an overview of the outlined studies of this thesis and lists the contributions of the author. Importantly, the data of Study 1a was collected by Manja Attig and was used in her dissertation (Attig, 2016). This data was partly reanalyzed by the author of this thesis (see also Table 1) and combined with newly collected data (Study 1b), resulting in a new Study (Study 1).

Table 1. Overview of the studies and author contribution.

	Study 1a	**Study 1b**	**Study 2**	**Study 3**
Design		☑	☑	☑
Data collection		☑		☑
Data analysis	partly	☑	☑	☑
Writing of the manuscript	☑	☑	☑	☑

2 Study 1: Infants' Perception of Goal-Directed Actions: A Multi-Lab Replication Reveals that Infants Anticipate Paths and not Goals

2.1 Abstract

Influential developmental theories claim that infants rely on goals when visually anticipating actions. A widely noticed study suggested that 11-month-olds anticipate that a hand continues to grasp the same object even when it swapped position with another object (Cannon & Woodward, 2012).Yet, other studies found such flexible goal-directed anticipations only from later ages on. Given the theoretical relevance of this phenomenon and given these contradicting findings, the current work investigated in two different studies and labs, whether infants indeed flexibly anticipate an action goal. Study 1a (*N* = 144) investigated by means of five experiments, under which circumstances (e.g., animated agent, human agent) 12-month-olds show flexible goal anticipation abilities. Study 1b (*N* = 104) presented 11-, 32-month-olds and adults both a human grasping action as well as a non-human action. In none of the experiments did infants flexibly anticipate the action based on the goal, but rather on the movement path, irrespective of the type of agent. Although one experiment contained a direct replication of Cannon & Woodward (2012), we were not able to replicate their findings. Overall our work challenges the view that infants are able to flexibly anticipate action goals from early on, but rather rely on movement patterns when processing other's actions.

2.2 Introduction

During the first year of life, infants start to visually anticipate other people's actions (Adam et al., 2016; Ambrosini et al., 2013; Cannon & Woodward, 2012; Daum, Gampe, Wronski, & Attig, 2016; Falck-Ytter et al., 2006). For example, 12-month-olds anticipate the goal of a simple manual reach-and-transport action (Falck-Ytter et al., 2006). However, infants show difficulties in anticipating actions when situations become more complex (Gredebäck, Stasiewicz, et al. 2009). In addition, it has been suggested that action anticipation depends on whether a human or a non-human agent is performing the action (Cannon & Woodward, 2012; Daum et al., 2012; Kanakogi & Itakura, 2011) and that movement characteristics of actions such as distances, durations and velocities have a strong impact on the anticipation of the goal of observed actions (Daum et al., 2016). In this paper we present a series of studies conducted in several laboratories that investigated whether infants and adults are able to visually anticipate an action goal when two goals are available and whether they differentiate between human and non-human (i.e. animated) agents.

Being able to understand that other people have goals is essential for processing social information. Understanding the goal-directedness of human actions has been related to the ability of perspective taking (Krogh-Jespersen et al., 2015) and of coordinating one's own actions with others (Sebanz et al., 2006). Influential developmental theories have therefore stressed the role of goal encoding and anticipation for early social-cognitive development (e.g., Woodward, 2009a). In the study by Falck-Ytter et al. (2006), infants anticipated the action of a hand that placed objects into a container (for a related setup see also Brandone, Horwitz, Wellman, & Aslin, 2014). However, movement path and goal were confounded in this paradigm, and for this reason, no conclusion is possible whether infants' anticipations were based on the information provided by the movement or the information about the action goal. The encoding of an action as goal directed goes beyond the representation of pure physical movements. Accordingly, a study by Cannon and Woodward (2012) presented a manual reaching action with not only one but two possible action goals to infants at the age of 11 months. After being familiarized with the hand always grasping the same of the two objects, the objects' position changed place for the following test trial. During the test trials, the infants observed an uncompleted manual movement where the hand stopped before indicating a clear movement direction. The infants showed anticipations towards the familiarized object in the now new location. This indicates that infants did not just anticipate the mere movement pattern but that they encoded the action as being directed towards a specific goal. This goal attribution served as the basis for the subsequent goal anticipation.

As striking as these results are, different results were obtained by Daum and colleagues (2012). They used a similar methodological approach with a slightly modified paradigm. In their study, participants were familiarized with an animated fish that moved behind an occluder to one of two goal objects. In the test phase, with the location of the two goal objects being swapped, only 3-year-olds and adults anticipated the correct goal. Two-year-olds anticipated both the path and the goal, indicating that they seem to be in a transition phase. In contrast, 9- and 12-month-olds expected the fish continue to move on the movement path as in the familiarization phase. These contradictory findings represent a puzzle, particularly for developmental theories that capitalize on the role of goal understanding in early development.

Notably, a number of studies that used a similar paradigm as Cannon and Woodward (2012) do not give a clear picture either. These studies are different from Cannon and Woodward as the human agent sat at a table and was fully visible to the participants (Krogh-Jespersen & Woodward, 2014; Krogh-Jespersen et al., 2015; Krogh-Jespersen & Woodward, 2018; Krogh-Jespersen et al., 2018; Paulus, 2011). Participants observed an agent grasping one of two objects for once, followed by two consecutive test trials in which the agent performed an uncompleted reaching action. Again, the objects' position was swapped for test trials. Krogh-Jespersen and Woodward (2014) demonstrated with this paradigm that goal-directed fixations of 15-month-olds needed more time to be initialized, indicating additional cognitive effort when taking an action goal into account instead of when the mere movement pattern was anticipated. Interestingly, goal-anticipations were not demonstrated consistently in this paradigm for older children. Two-year-olds anticipated neither the goal nor the previous location systematically (Krogh-Jespersen et al., 2018) and 21-month-olds only made goal-directed anticipations in the first, but demonstrated chance performance in the second test trial (Krogh-Jespersen et al., 2015). Overall, there is a heterogeneous pattern of results on whether or not young children show flexible goal anticipations for a human actor.

Given this evidence it is on the one hand unclear from which age on infants anticipate other's actions as goal-directed and on the other hand, whether they differentiate between non-human and human agents.

Developmental theories claim that one's own experiences are fundamental for understanding others actions. This is also known as the *human-first view* (Luo & Baillargeon, 2005; Meltzoff, 1995; Woodward, 2005). Because a human hand performed the action in the study by Cannon and Woodward (2012), this could have facilitated infants' goal encoding. Some suggest that infants use their own motor abilities when anticipating other's actions (e.g. Kilner et al., 2007; Paulus, 2012). For example Krogh-Jespersen and Woodward (2018) demonstrated that already 8-month-olds anticipate an action goal, but only after they practiced reaching for an object themselves. Others suggest that infants are simply more familiar with human hands than with a non-human agent (Ruffman et al., 2012). This account would imply that infants are more experienced with hands grasping objects than with moving fish, as they have probably not often seen an animated fish before. Indeed, previous studies demonstrated earlier anticipations within infants when actions were more familiar (Cannon & Woodward, 2012; Filippi & Woodward, 2016; Gredebäck & Kochukhova, 2010; Gredebäck & Melinder, 2010; Kanakogi & Itakura, 2011). Cannon and Woodward (2012) showed that infants did not anticipate an action as goal-directed when performed by a mechanical claw (see also Adam et al, 2016; Kanakogi & Itakura, 2011).

In contrast, the so called *all agents-view* (Luo & Baillargeon, 2005) proposes that infants attribute goals to any individual that can be identified as an agent (Leslie, 1995). It has been argued that humans attribute goals to non-human agents as long as they show specific characteristics, like self-propelledness (Luo & Baillargeon, 2005), equifinal variations (Kamewari et al., 2005), or an action outcome produced by the agent (Adam et al., 2017). However, most empirical evidence concerning the *all agents-view* comes from looking-time studies (e.g. Gergely et al., 1995; Luo & Baillargeon, 2005). Thus, it is still an open question whether infants are able to generate online anticipations when perceiving non-human instead of human actions.

However, as it is neither empirically nor theoretically clear when and to what extent infants are able to anticipate an action based on the action goal and not on the movement pattern, we report two studies, assessed in two different labs, that address this question in further detail. Study 1a contains five experiments, which disentangle the precise methodological issues between Cannon and Woodward (2012) and Daum et al. (2012). The goal of the first study was to investigate which aspects are fundamental for infants' goal encoding abilities within 12 months of age. Two major questions guided this research: First, whether infants show goal-directed anticipations for non-human as well as for human actions equally, as proposed by the *all agents-view*, or whether infants are better in anticipating the goal of a human action than the goal of a non-human action, as suggested by the *human-first view*. Second, whether the seemingly contradictory findings of Cannon and Woodward (2012) and Daum et al. (2012) are a result of further methodological differences. In the study by Daum et al. (2012), the agent shortly disappeared behind an opaque occluder. This paradigm was used to trigger participant's eye-movements to the position where they expect the agent to reappear (adapted from Kochukhova and Gredebäck, 2007). However, infants have to maintain the association between the agent and the object when the agent is not visible, which might require additional cognitive capacities, such as memory or attention (Hespos, Gredebäck, von Hofsten, & Spelke, 2009; Jonsson & von Hofsten, 2003). This additional requirement of cognitive resources could be another reason why infants in the Daum et al. study (2012) showed goal-directed anticipations only from later on.

Further, the two studies used different designs in providing the stimuli. Cannon and Woodward (2012) presented infants four blocks, which each contained three familiarization trials, one swap trial (in which the objects position changed place) and one test trial. Daum and colleagues (2012) presented participants eight familiarization trials, one swap trial and two test trials. The more frequent presentation of learning trials in the Daum et al. study (2012) could have increased the attentional focus to the location of the object. As was demonstrated by Paulus and colleagues (2011), already 9-month-olds based their anticipations of an agents' choice for a path on the agent's previous choices. Further, it is also possible that infants encoded both goal and path of the action simultaneously, thus it is unclear which aspect dominates infants visual anticipations.

The following five experiments of Study 1a present a step by step approximation of the paradigm from Daum et al. (2012) to the paradigm of Cannon and Woodward (2012). The last experiment represents a replication as close as possible to the study by Cannon and

Woodward (2012). Initially, we hypothesized that the type of agent and the presence of an occluder influence infants' goal anticipations. Following the *human first-view*, we expected more goal anticipations in the experiments that contain a human agent. In contrast, the *all agents-view* predicts no differences in the goal anticipations between all five experiments, because human and non-human agents are processed equally from early on. We would further assume that infants show more goal-directed anticipations in the experiments without an occluder.

The second study, conducted in a different lab, directly compared the two paradigms in a within-subjects design. That is, Study 1b assessed whether children and adults show systematic differences in their anticipations when observing human and non-human goal-directed actions. A second goal of Study 1b was to answer the question whether the two paradigms assess the same underlying ability regarding their goal anticipations, as proposed by the *all agents-view*. Since non-human agents are widely used in studies on social perception within children (e.g. Hamlin, Wynn, & Bloom, 2007; Kuhlmeier, Wynn, & Bloom, 2003), it is crucial to find out whether they actually perceive animated stimuli in the same way as human stimuli. We tested 11-month-olds as our youngest age group, since this age group showed goal-directed anticipations in the study by Cannon and Woodward (2012). We also included 32-month-olds, because developmental changes of children's goal anticipations for an animated agent between the age of 24 and 36 months were observed by Daum et al. (2012). Developmental changes were also observed by Krogh-Jespersen et al. (2018, 2015), although they found a decrease of goal-directed anticipations for a human agent in toddlers. Given this puzzle, the inclusion of 32-month-olds in Study 1b seems informative. We additionally wanted to clarify whether and how adults differ in their perceptions of the stimulus material presented in the two paradigms. Accordingly, stimulus material was presented in a within design with a human- and a non-human animated agent. One is based on Cannon and Woodward (2012) and contained a human hand grasping one of two objects; the other is based on Paulus et al. (2017) and contained an animated agent walking along a path towards one of two targets (similar to Daum et al., 2012, where an opaque occluder was used). The *human first-view* proposes goal encoding for 11- and 32-month-olds to be more likely in the hand- than in the path-paradigm (Cannon & Woodward, 2012; Daum et al., 2012). In contrast, the *all agents-view* proposes goal anticipations in both paradigms. Either of the theories predicts adults to visually anticipate an action goal for both human- and non-human agents (Daum et al., 2012; Pfundmair, Zwarg, Paulus, & Rimpel, 2017).

The current effort from two labs is a valuable approach with the aim to conceptually and partly even directly replicate a finding that is central in a heated debate in developmental psychology on the early origins of social cognition. It is essential to know in greater detail to which extent the findings by Cannon and Woodward (2012) are replicable before drawing strong theoretical conclusions. Thus, one central point of this endeavor was to examine whether or not we could (conceptually or directly) replicate Cannon and Woodward (2012) and contribute thus to the theoretical debate by examining the robustness of a key finding.

2.3 Study 1a

Study 1a investigates whether 12-month-olds are able to make goal-directed anticipations. Given the contradicting findings of Cannon and Woodward (2012) and Daum et al. (2012), the aim was to test which aspects are relevant for infants' ability to anticipate an action goal. Therefore, the stimuli of Daum et al. (2012) were assimilated step-by-step over five experiments to the stimulus material used by Cannon and Woodward (2012). In Experiment 1 the animated stimuli of Daum et al. (2012) were used but displayed in the same presentation order as in Cannon and Woodward's study (2012). In Experiment 2, the occluder was removed and the action direction was changed from vertical to horizontal, whereas the fish still remained as the agent. In Experiment 3, the fish was replaced by a human hand as the agent. Additional adaptions regarding timing were made in Experiment 4. Finally, Experiment 5 used newly filmed videos, which were designed to be as comparable to the stimuli of Cannon and Woodward (2012) because the original stimulus material was not available. According to the *human first-view*, one would hypothesize to find anticipations towards the previously observed movement path or random gaze behavior in conditions using a non-human agent (Experiment 1 and Experiment 2). In contrast, one would expect anticipations towards the previously observed goal in the conditions in which a human hand served as the agent (Experiment 3, 4 and 5). According to the *all agents-view* infants should demonstrate in all five experiments goal directed anticipations. We further expected that experiments without an occluder would facilitate infants processing of the action, thus we expected to find an increase of goal-directed anticipations in the conditions that did not make use of an occlusion paradigm.

2.3.1 Experiment 1

In the first experiment, the influence of the design of stimuli presentation on infants' encoding of the action was tested. Infants were shown the stimulus material as used by Daum et al. (2012), an animated fish that moved towards one of two goal objects and was briefly occluded. We combined the stimulus material with the procedure used by Cannon and Woodward (2012) where the stimuli were presented in four blocks; each block contained three familiarization trials, one swap-trial, and one test trial. Further some criteria for inclusion (three of four blocks with usable data) and analysis of gaze shifts (gaze shift from the start-AOI to one of the goal-AOIs with 200ms fixation) were the same as in the study by Cannon and Woodward (2012).

2.3.1.1 Method

The preprocessed eye-gaze data of both studies is available at https://osf.io/bucrv/?view_only=fa9e929fe4524755b38383fd223378f5. To protect participants' data privacy, demographic information is not shared in this data set.

Participants

The sample included 24 healthy 12-month-olds (12 girls, mean age = 12 months and 4 days; 11;21-12;15). Ten additional infants had to be excluded due to inattention and restlessness (n = 1), crying (n = 4), technical problems (n = 1) and failure to provide enough eye-tracking data (n = 4; see *measures* section for details).

Stimuli

Participants were presented videos of a red-blue fish, that moved by itself (self-propelledness) on a blue background. At the beginning of the videos, the fish was situated at the bottom in the middle of the screen. The targets were a yellow duck and a colored ball placed on the left and right corner at the top of the screen (see Figure 1). In the middle of the screen was a round occluder in the color of wooden grain.

Infants saw four blocks and each block consisted of three familiarization trials, one swap trial and one test trial. Before each block an attention getter was presented to direct infants' attention to the screen. In the familiarization trial (total duration was 15.12 s) the fish first jumped up and down (accompanied by a sound) for 3 s and then moved towards the occluder (2.44 s). The agent disappeared behind the occluder for 0.92 s and reappeared to aim for one target. At the goal object (after 2.08 s) the fish poked the target for three times (3 s) and the target reacted with small movements, which was combined with a sound. During the swap trial, the two targets changed place (4.96 s) and were shown for another second after the changeover to the infant. In the test trials, the fish again jumped up and down (3 s) before approaching the occluder (2.44 s). The agent stayed behind the occluder for the rest of the trial (another 10.12 s). The total duration of the whole presentation (all four blocks) was 5 minutes and 24 s. Target object as well as the position of the target object was counterbalanced between participants.

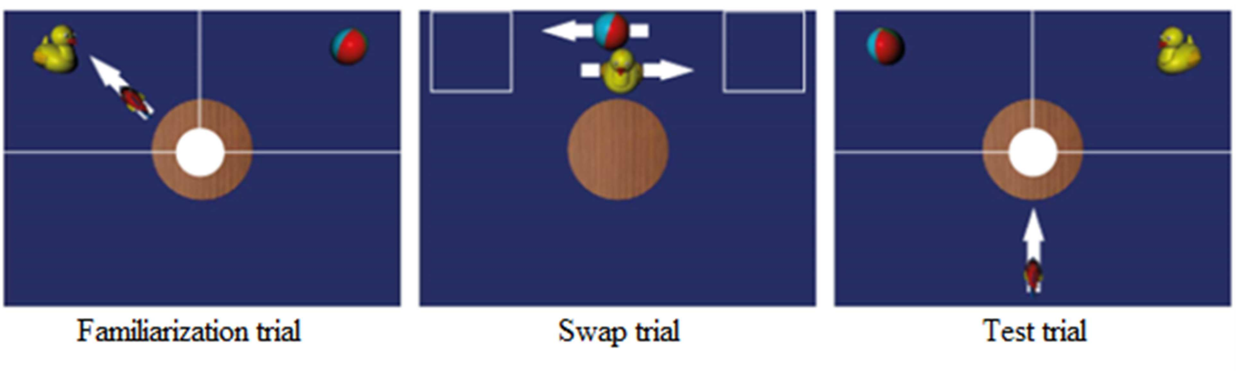


Figure 1. Stimulus material of the familiarization trial, swap- and test trial of Experiment 1. The white arrows represent the movement path of the agent and the targets. The white lines mark the AOIs.

Setting and Procedure

For testing, infants were seated in a car safety seat (Maxi Cosi Cabrio) with a distance of 60 cm between the eye tracker and the child and stimuli were presented on a 17"-monitor (25°x 21°). Gaze was measured through a Tobii 1750 eyetracker (precision: 1°, accuracy: 0.5° and sampling rate: 50Hz) and a nine-point infant calibration was used. The stimuli-presentation was conducted via the software ClearView (version 2.7.1., Tobii).

Measures

To analyze infants' eye-movements, three areas of interest were defined based on Daum et al. (2012, see Figure 1). The lower area was the starting area of the agent, the other two included the two goal objects. For all measures, we analyzed the first fixation participants performed from the start area to one of the goal-AOIs (first look analysis). Infants had to fixate the goal-AOI for 200 ms, within a radius of 50 pixels (based on Cannon &Woodward, 2012). Gaze shifts were categorized as *anticipatory*, when the first fixation was directed in one of the goal-AOIs before the agent reappeared from the occluder during familiarization trials (occlusion-time plus 200 ms). In the test trials, this time interval was extended for another 1000 ms (see Cannon & Woodward, 2012), because the agent did not reappear from behind the occluder (occlusion-time plus 200 ms plus 1000 ms). Gaze shifts were categorized as *reactive*, when fixations to one of the goal-AOIs occurred after the agent reappeared in the familiarization trials. For the test trials, a fixation to one of the goal AOIs after the 2120 ms was categorized as reactive.

First, we calculated the *anticipation rate*, which is the relation of all anticipations to all gaze shifts (anticipatory as well as reactive). This measure indicates how much participants generally perform anticipations; it is not including information to which specific location infants anticipated. To further analyze the type of anticipations, the *accuracy rate* was calculated. For this, the number of anticipations towards the specific target AOI was divided by the total number of gaze shifts (anticipatory and reactive). For this analysis, the number of anticipations was averaged over all familiarization trials and test trials. For familiarization trials the *goal-related accuracy rate* (ratio of goal anticipations and all gaze shifts) and the *non-goal-*

related accuracy rate (ratio of anticipations to the other object and all gaze shifts) were defined. To analyze infants' learning performance in the familiarization phase, two scores were compared (Daum et al., 2012): The accuracy score of the averaged anticipations of the first familiarization trials of all four blocks and the accuracy score of the averaged anticipations of the last familiarization trials of all four blocks. For test trials the *identity-related accuracy rate* (ratio of anticipations to the goal object in the new location and all gaze shifts) and the *location-related accuracy rate* (ratio of anticipations to the other object in the old location and all gaze shifts) were generated. Again, the anticipations were averaged over all four test trials for each score. In sum, for both the familiarization as well as the test phase, each accuracy score consists of four trials. To be included in analysis, infants had to watch the screen at least 200 ms from the start of the movie until the agent disappeared behind the occluder; and 200 ms after disappearance until the end of the movie. Infants were included for final analysis if they had at least three of four test trials that fulfilled these criteria (Cannon & Woodward, 2012). Further they had to look at the swap trial for at least 2000 ms to be included.

In all experiments of Study 1a, we controlled for the possible influence of the type of target and position of target on the number of anticipations for the first four familiarization trials and test trials. As no significant influence could be found in none of the five experiments, the following analysis was averaged over these factors. Further, the anticipation rate of the first four and last four familiarization trials, as well as test trials, were averaged across the four blocks.

2.3.1.2 Results

Anticipation rate. The anticipation rate for the whole experiment was 0.79 (SD = 0.15) and 0.74 (SD = 0.20) for the familiarization phase only. We compared the anticipation rate of the last familiarization trials with anticipation rate of the test trials with a Wilcoxon signed-rank test and found a significant difference. Participants anticipated more in the test trials (M = 0.91, SD = 0.17) than in the last familiarization trials (M = 0.72, SD = 0.30), with z = -2.92, p = .003, r = .42.

Familiarization phase. A Wilcoxon signed-rank test was calculated to compare the goal-related accuracy rate with the non-goal-related accuracy rate in the last familiarization trials. Indeed, children anticipated more to the goal ($M = 0.58$, $SD = 0.34$) than to the non-goal ($M = 0.14$, $SD = 0.25$), with $z = -3.25$, $p = .001$, $r = -.47$. This indicates that the children learned to correctly anticipate the reappearance of the agent from behind the occluder during the familiarization phase. A comparison of the first familiarization trials averaged across the four blocks ($M = 0.51$, $SD = 0.34$) and the last familiarization trials did not show a significant increase of goal-directed anticipations over time, $z = -1.41$, $p = .16$, $r = -.20$.

Test phase. The Wilcoxon signed-rank test demonstrated a higher location-related accuracy rate ($M = 0.60$, $SD = 0.32$) than an identity-related accuracy rate ($M = 0.31$, $SD = 0.31$), $z = -2.14$, $p = .03$, $r = -.31$. Further, a comparison of the goal-related accuracy rate of the last familiarization trials with the identity-related accuracy rate in the test trials showed a significant difference, $z = -2.56$, $p = .01$, $r = -.37$. In contrast, there was no significant difference between the goal-related accuracy rate of the last familiarization trials and the location-related accuracy rate of the test phase, $z = -0.34$, $p = .73$, $r = -.05$.

For the following analysis, only anticipations (and not reactions) were used. A Chi-Square-Test was calculated over the number of identity- and location-related anticipations in test trials. Infants anticipated the reappearance of the agent based on location ($n = 51$) than on identity of the goal object ($n = 28$), $\chi^2(1) = 6.70$, $p = .01$.

Additional analysis. Finally, when interpreting these findings, and comparing them to the original study, one has to consider that the data was differently analyzed than the original study of Cannon and Woodward (2012). The inclusion criteria used are stricter than in the original study by Cannon and Woodward (2012). For example, infants had to look for a specific time at the swap trial or fixate the start area for a certain time before the agent moved behind the occluder, etc. Also, gaze shifts that occurred after a certain time were no longer defined as anticipatory, but as reactive. The resulting scores were calculated different to the original study, which used a proportion score and did not include non-anticipations. Although our use of stricter criteria should result in a more reliable assessment of true goal anticipation, one could argue that the different results are caused by these stricter criteria. To exclude this possibility, we additionally analyzed our data as closely as possible to the approach by Cannon and Woodward (2012; details can be seen in the supplementary material, see chapter 2.4.3). This additional analysis did not change the pattern of results; the mean proportion score of 0.34 (SD = 0.30) was significantly different from chance with $t(23) = -2.64$, $p = .015$, Cohen's $d = 0.54$, indicating a significant looking bias towards the location and not the goal.

2.3.1.3 Discussion

Experiment 1 aimed to examine whether the different findings reported in Cannon and Woodward (2012) and Daum et al. (2012) are the result of differences in the procedure of the stimulus presentation. The findings show that 12-month-olds learned to correctly anticipate the reappearance of the agent by the end of the familiarization phase. However, in the test trials, infants anticipated the action based on the location of the goal object and not on its identity. Therefore, it doesn't seem that the more frequent presentation of the action in Daum et al.'s study (2012) highlighted the path of the action and caused children's location-related anticipations. Ultimately, the divergent findings are not caused by the different presentation order and amount of learning and test trials. The next experiment will test whether the occluder has a significant effect on infants' anticipations.

2.3.2 Experiment 2

In Experiment 2, the animated stimuli were used without an occluder; the agent was visible the whole time. Additionally, the direction of the movement was changed from a vertical to a horizontally movement (as in Cannon & Woodward, 2012). Given the claim that horizontal movements are easier to anticipate for infants (Gredebäck, von Hofsten, & Boudreau, 2002), we intended to facilitate anticipations and to test whether a change of the movement direction increases infants' identity-related anticipations. Also to draw infants' attention to the screen at the beginning of the action, an ostensive cue was integrated (a voice stated "Look").

2.3.2.1 Method

Participants

Again, the sample included 24 healthy 12-month-olds (12 girls, mean age = 12 months and 4 days, 11;20-12;10). Nine additional infants had to be excluded due to inattention and restlessness (n =2), crying (n = 1) or failure to provide enough eye-tracking data (n = 6).

Stimuli and Procedure

The experimental setup was exactly the same as in Experiment 1, only that the targets (duck 3.9° x 4.1°, penguin 3.5° x 4.0°) were now situated in the two corners at the right side of the monitor (see Figure 2). Further the starting point of the agent (1.9° x 4.0°) was close to the left monitor side. No occluder was visible and the background was light blue. Stimuli where similar to Experiment 1 with the exception that in the first two seconds of each movie a voice stated “Look”, to catch infants’ attention. In the familiarization trial the agent jumped up and down (1.96 s, combined with a whistle sound) and started to move towards the target objects. After 4.72 s the agent took a turn to one of the targets, which he reached after another 2.60 s and poked it (see Experiment 1). The whole familiarization trial lasted for 14.92 s. In the swap trial the two objects changed position within 5.96 s and the whole trial lasted for another 5 s. Test trials were similar to Experiment 1, except that the agent, when approaching the target, stopped after 4.72 s just after the middle of the scene and remained there for the rest of the trial (another 4.96 s). The whole presentation time for the movies was 5 minutes and 2 s. Again goal object and position of goal object were counterbalanced between participants.

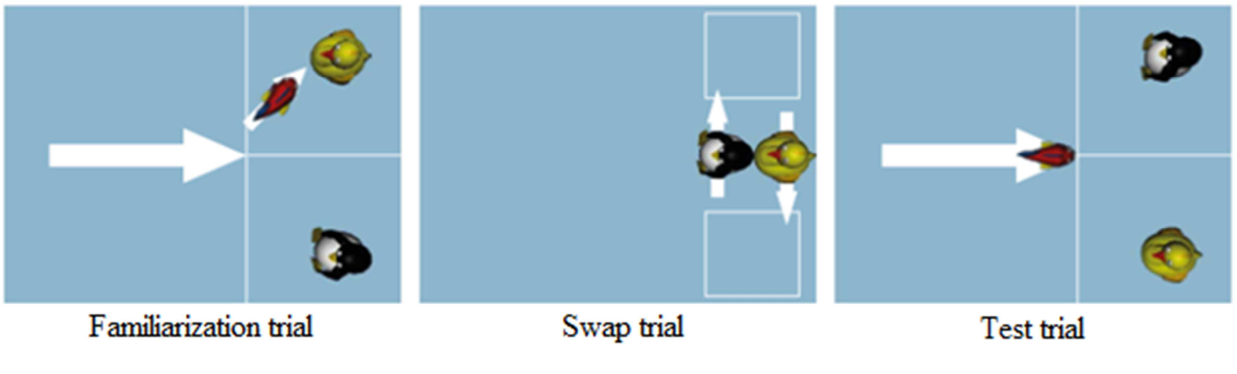


Figure 2. Stimulus material of the familiarization trial, swap- and test trial of Experiment 2. The white arrows represent the movement path of the agent and the targets. The white lines mark the AOIs.

Measures

For Experiment 2 the calculation of the measures followed Experiment 1. Areas of interest can be seen in Figure 2. Gaze shifts were defined as *anticipatory*, if anticipations took place from the beginning of the movement towards the objects until the agent made a turn to one of the targets (for test trials: time of standstill of the agent plus 1000 ms). This results in an anticipatory period of 5720 ms for test trials in total. All gaze shifts that occurred after the turn of the agent were coded as *reactive* (in test trial after the additional 1000 ms).

2.3.2.2 Results

Anticipation rate. For this experiment the anticipation rate was 0.81 (SD = 0.14) for the whole experiment, and 0.76 (SD = 0.19) for the familiarization phase. As in Experiment 1, we found an increase in anticipations in the test trials (M = 0.94, SD = 0.13) compared to the last familiarization trials of all four blocks (M = 0.74, SD = 0.30), with z = -2.62, p = .01, r = -.38.

Familiarization phase. Infants showed in the last familiarization trials more anticipations to the goal (M = 0.60, SD = 0.35) than to the non-goal (M = 0.14, SD = 0.21), z = -3.43, p = .001, r = -.50. The goal-related accuracy rate in the first familiarization trials (M = 0.52, SD = 0.33) was not significantly different from the goal-related accuracy rate in the last familiarization trials (*M* = 0.60, *SD* = 0.35), $z = -0.85$, $p = .40$, $r = -.12$. The infants quickly learned to correctly anticipate the target.

Test phase. The analysis showed no significant difference between the identity-related accuracy rate (*M* = 0.41, *SD* = 0.35) and the location-related accuracy rate (*M* = 0.54, *SD* = 0.33), $z = -1.12$, $p = .26$, $r = -.16$. Further, a comparison between the goal-related accuracy rate in the last familiarization trials (*M* = 0.60, *SD* = 0.35) with the identity-related accuracy rate (*M* = 0.41, *SD* = 0.35), $z = -1.58$, $p = .12$, $r = -.23$, and the location-related accuracy rate (*M* = 0.54, *SD* = 0.33), $z = -0.91$, $p = .36$, $r = -.13$, was not significant. Infants anticipated in the test phase towards the goal as well as to the original location of the object.

Following Experiment 1, only anticipations were analyzed. The Chi-Square test over the four test trials between identity- ($n = 37$) and location-related gaze-shifts ($n = 47$) was not significant, $\chi^2(1) = 1.19$, $p = .28$.

The additional analysis, with the same measure and inclusion criteria as Cannon and Woodward (2012, see Experiment 1 for details) revealed chance performance of the infants' looking behavior, with $t(23) = -.72$, $p = .482$, Cohen's $d = 0.15$, *M* = 0.45, *SD* = 0.33.

2.3.2.3 Discussion

Experiment 2 investigated whether the absence of an occluder and the change in movement direction (from vertical to horizontal) had a facilitating effect on infants' goal encoding abilities. Results of the test trials demonstrated that anticipations of the 12-month-olds were at chance level. They neither showed a significant looking bias towards the goal object, nor to the old location. As they demonstrated goal-directed anticipations at the end of the familiarization phase, problems in learning the association between the agent and the target are not the case. It seems likely that the absence of the occluder facilitated infants' goal anticipations (Hespos et al., 2009; Jonsson & von Hofsten, 2003). It seems easier for infants to encode the goal of an action, when the agent is visible for the whole time. The additional change from a vertical to a horizontal position and the use of a verbal cue at the beginning of the action could have facilitated the task as well. For the next experiment we wanted to see whether the type of agent influences infants' anticipations.

2.3.3 Experiment 3

To test whether infants are more likely to flexibly attribute goal-directed behavior to a human agent, the animated fish was replaced by a human hand that moved to and grasped one of two goal objects. Timing and procedure of the action, as well as size of the targets differed from Cannon and Woodward (2012), as they remained the same as in Experiment 1 and 2.

2.3.3.1 Method

Participants

The final sample included 32 healthy 12-month-olds (16 girls, mean age = 12 months and 1 day, 11;15-12;15). The sample size is larger for this and the following experiments of Study 1a, due to more conditions than in the previous experiments (see section Stimuli and Procedure). Eleven additional infants were tested but excluded due to inattention and restlessness ($n = 4$), crying ($n = 2$), or not enough eye-gaze data ($n = 5$).

Stimuli and Procedure

Stimuli in Experiment 3 are the same as in Experiment 2, except for the following differences: Instead of an animated fish, a human hand (4.6° x 7.6°) was filmed. The two targets (duck 4.8° x 4.9°, penguin 4.5° x 4.8°) still have been animated with CINEMA 4D (Maxon, Version R10). The human hand was inserted in the video via a blue screen method (see Figure 3). For the familiarization trials the human hand started to move its fingers and a whistle sound occurred (1.92 s). Then the hand moved from the left side in the direction of the targets. After 4000 ms the hand crossed the middle and made a turn to one of the targets. The hand reached the target after 2 s, grasped it (1.12 s) and moved it further to the right (action effect plus sound lasted for 0.92 s). The whole familiarization trial took 14 s. The test trials started exactly like the familiarization trials. After the hand started to move towards the middle, it stopped after 4 s for another 5 s. Duration of the test trial was 14.12 s in total. The whole presentation lasted 4 minutes and 48 s.

Type of goal object and position of the object were counterbalanced between participants. Further, the orientation of the hand, that is, thumb pointing towards the goal object, as well as left and right hand were counterbalanced within participants. This led to four different combinations for the blocks, namely 1) familiarization: right hand, test trial: right hand, 2) familiarization: right hand, test trial: left hand, 3) familiarization: left hand, test trial: left hand, 4) familiarization: left hand, test trial: right hand. The order of combination was also counterbalanced.

For analysis the same scores were calculated as in Experiment 1 and 2. Gaze shifts for test trials were defined as *anticipatory* if they occurred within a time period of 5000 ms (from the beginning of the reaching action onwards). Also inclusion criteria remained the same. AOIs were identical to Experiment 2. To control for an influence of hand orientation on the scores, Kruskal-Wallis tests were performed for Experiment 3, 4 and 5 and turned out not significant. Therefore, the following analysis was averaged over this factor.

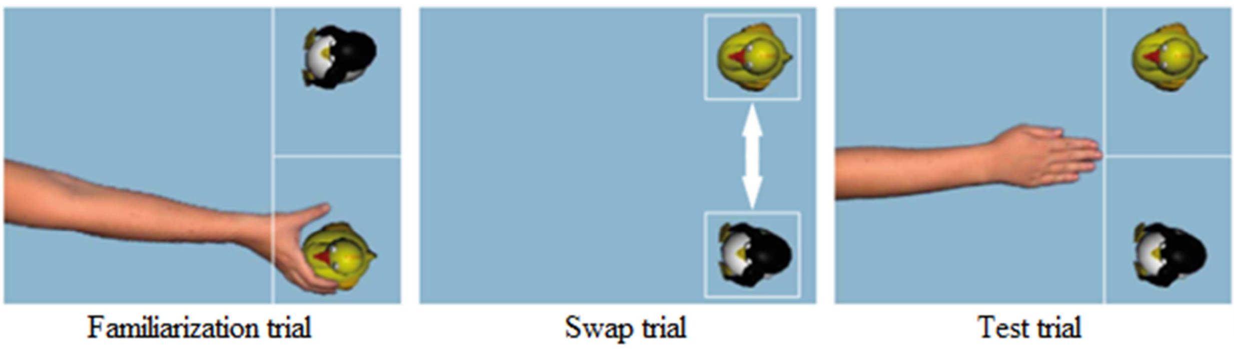


Figure 3. Stimulus material of the familiarization trial, swap- and test trial of Experiment 3. The white arrows represent the movement path of the targets. The white lines mark the AOIs.

2.3.3.2 Results

Anticipation rate. For the whole experiment, the anticipation rate was 0.91 (*SD* = 0.10) and for the familiarization phase 0.89 (*SD* = 0.12). Although participants performed more anticipations in the test trials (*M* = 0.95, *SD* = 0.11) than in the last familiarization trials of all four blocks (*M* = 0.88, *SD* = 0.19), the Wilcoxon-signed rank test was not significant for this experiment, with *z* = -1.86, *p* = .06, *r* = -.23.

Familiarization phase. The Wilcoxon signed-rank test showed that the goal-related accuracy rate in the last familiarization trials (*M* = 0.60, *SD* = 0.34) was significantly higher than the non-goal related accuracy rate of the last familiarization trials (*M* = 0.28, *SD* = 0.31), *z* = -2.58, *p* = .01, *r* = -.32. There was no significant difference between the goal-related accuracy rate of the first familiarization trials (*M* = 0.53, *SD* = 0.27) and the goal-related accuracy rate of the last familiarization trials (*M* = 0.60, *SD* = 0.34), *z* = -1.21, *p* = .23, *r* = -.15.

Test phase. There was no significant difference between infants' identity-related (*M* = 0.40, *SD* = 0.31) and location-related (*M* = 0.55, *SD* = 0.28) accuracy rate, *z* = -1.41, *p* = .16, *r* = -.18. Infants anticipated more to the goal in the familiarization phase (*M* = 0.60, *SD* = 0.34) than to the same goal in the test trials (*M* = 0.40, *SD* = 0.31), *z* = -2.26, *p* = .02, *r* = -.28. In contrast they did not differ in their anticipations to the goal in the last familiarization phase (*M* = 0.60, *SD* = 0.34) and their anticipations to the old location in the test phase (*M* = 0.55, *SD* = 0.28), *z* = -0.74, *p* = .46, *r* = -.09.

A further Chi-Square-Test with the number of anticipations in all four test trials between goal- and identity-related anticipations turned out to be not significant, $\chi^2(1) = 3.64$, *p* = .057, although a tendency towards more location-related (*n* = 65) than identity-related anticipations (*n* = 45) could be observed.

Again, also the additional analysis according to Cannon and Woodward (2012) resulted in chance performance of the infants, with *t*(31) = -1.53, *p* = .137, Cohen's *d* = 0.27, *M* = 0.43, *SD* = 0.27.

2.3.3.3 Discussion

Experiment 3 examined whether the type of agent has an influence on infants' goal anticipations. Therefore, a human hand reaching for one of two objects was presented to 12-month-olds. Results showed that infants did not increase their goal-related anticipations in this experiment. In contrary, they showed the tendency to anticipate the grasping action based on the movement path and not the goal object.

Theoretically this finding speaks against the claim that experience with an action improves infants' anticipations (Cannon & Woodward, 2012; Gredebäck & Melinder, 2010; Kanakogi & Itakura, 2011; Kochukhova & Gredebäck, 2010). Still, it is not clear which factors caused the differences between our experiments with Daum et al's findings (2012) and Cannon and Woodward's (2012). Some differences (timing of the action, start of the presentation, effect of the action, type of goal objects) have remained in the last three experiments. For example, in Experiment 1, 2 and 3, the animated objects visibly swap places in the swap trial and are not presented already in their new position like in Cannon and Woodward's stimuli (2012). It is not clear in what way this could have affected their anticipations. Hence changes in the stimuli material have been made on these factors for the next experiment.

2.3.4 Experiment 4

Because in Experiment 2 and 3, the anticipations were ambivalent, this could be an indication for an increase of identity-related gaze shifts caused by the nature of the agent. To further assess this potential shift of processing caused by the stimulus material, the stimuli have been changed further in Experiment 4 to increase similarity to the stimuli of Cannon and Woodward (2012). Therefore, the timing of the action and the action effect were adapted. Additionally, movements of the hand at the beginning of the trials were removed and the swapping procedure of the target objects was no longer presented. Participants only observed a still frame of the already swapped objects. The rest of the factors, such as blocked design, no occluder, direction of movement, and type of agent stayed the same as in Experiment 3. Differences to Cannon and Woodward (2012) remained regarding the target objects (a duck and a penguin here, a green frog and a red ball in Cannon & Woodward, 2012). Also following Experiment 3, the agent was inserted via a blue screen method and targets were still animated. Further, type and size of targets were different than in the original study.

2.3.4.1 Method

Participants

The sample included 32 healthy 12-month-olds (16 girls, mean age = 11 months and 26 days, 11;12-12;11). Thirteen additional infants were tested but excluded due to inattentiveness and restlessness (*n* =1), crying (*n* = 1), not enough eye-tracking data (*n* = 10) or technical problems (*n* = 1).

Stimuli and Procedure

Movies were similar to Experiment 3 and adapted to the videos of Cannon and Woodward (2012). Each movie started with a black still frame for 0.36 s. After 0.04 s the agent moved into the picture. After another 1.56 s the hand made a turn into the direction of a target. The agent reached the target after 1.04 s. He grasped the object and did not move thereafter (no action effect, only sound; 0.4 s). After 0.52 s the black screen was presented for 0.48 s. One familiarization trial lasted 4.36 s. For the swap trial a still frame with the objects in changed position was presented for 3.56 s. For test trials the agent again moved into the picture after 0.04 s. Then the hand moved in the direction of the targets and stopped after 1.52 s right after the middle of the screen. Movies of test trials lasted each 2.88 s. Presentation time of the whole stimuli material over all four blocks was 1 minute and 33 s.

Goal object, position of goal object, orientation of hand, and the order of presentation was again counterbalanced across the infants. The analysis remained the same as in the previous experiments. However, since the test trial is very short in this experiment, the criteria to treat gaze shifts after the standstill of the hand plus another 1000ms as reactive is no longer applicable. Therefore, all gaze shifts were treated as anticipatory. Inclusion criteria were identical to the other three experiments, except that infants had to watch each movie at least for 100 ms from the start until the turn and again from the turn until the end of the movie. Also they had to look at the swap trial at least for 700 ms.

2.3.4.2 Results

Anticipation rate. The anticipation rate for the whole experiment was 0.74 (SD = 0.18) and 0.65 (SD = 0.24) for all of the 12 familiarization trials. Again, the anticipation rate of the test trials was higher (M = 1.00, SD = 0.00) than in the last familiarization trials of all four blocks (M = 0.61, SD = 0.30), z = -4.32, p < .001, r = -.54.

Familiarization phase. Goal-related accuracy rate of the last familiarization trials (M = 0.49, SD = 0.29) was significantly higher than the non-goal-related accuracy rate of the last familiarization trials (M = 0.12, SD = 0.19), z = -3.98, p < .001, r = -.50. Further the goal-related accuracy rate of the first familiarization trials (M = 0.47, SD = 0.37) was not significantly different from the goal-related accuracy rate of the last familiarization trials (M = 0.49, SD = 0.29), z = -0.53, p = .60, r = -.07.

Test phase. Results revealed that the identity-related accuracy rate (M = 0.30, SD = 0.29) was significantly lower than the location-related accuracy rate (M = 0.70, SD = 0.29) in the test phase, z = -3.23, p = .001, r = -.40. There was also a significant difference between the goal-related accuracy rate in the last familiarization trials (M = 0.49, SD = 0.29) and the identity-related accuracy rate in the test phase (M = 0.30, SD = 0.29), z = -2.14, p = .03, r = -.27. Infants showed more anticipations towards the goal in the familiarization phase than in the test phase. Moreover, another Wilcoxon signed-rank test showed that the location-related accuracy rate in the test phase (M = 0.70, SD = 0.29) was significantly higher than the goal-related accuracy rate in the last familiarization trials (M = 0.49, SD = 0.29), z = -3.04, p = .002, r = -.38.

Again, when only the number of anticipations was included, a Chi-Square test demonstrated that infants anticipated the action more in relation to the location (n = 83) than to the identity of the goal (n = 36), $\chi^2(1)$ = 18.56, p < .001.

The same pattern was observed in the additional analysis according to Cannon and Woodward (2012), in which infants demonstrated a preference for the previous location, with $t(31)$ = -4.05, p < .001, Cohen's d = 0.72, M = 0.29, SD = 0.29.

2.3.4.3 Discussion

In the fourth experiment we wanted to discover, whether the changes of the stimuli in comparison to Experiment 3 would now enable a replication of Cannon and Woodward's results (2012). Findings indicate that 12-month-olds show more anticipations directed towards the location and not the goal object. Even after using stimuli that are highly similar to Cannon and Woodward (2012), we could not replicate their findings. However, our stimuli still contained subtle differences regarding the targets and construction of the stimuli, such as that a human hand was overlaid on the animated background with a blue screen method. Hence, we performed a last experiment that contains a replication as close as possible to the Cannon and Woodward (2012) study.

2.3.5 Experiment 5

To replicate the results of Cannon and Woodward (2012), the stimuli were newly filmed. Direction, timing, and procedure of the action were as close as possible to the original study. The two targets, now also a red ball and a green frog, were at the same position of the screen and had the same size. There should be no to only few differences in the method used between this experiment and Cannon and Woodward (2012).

2.3.5.1 Method

Participants

Thirty-two healthy 12-month-olds were included for the final sample (16 girls, mean-age = 11 months; 27 days, 11;16-12;13). Additionally, 22 infants were tested but excluded due to inattentiveness and restlessness (n = 7), crying (n = 1) or not enough eye-gaze data (n = 14).

Stimuli, Procedure and Analysis

Stimuli were identical to Experiment 4 except that the goal objects were now a green frog (3.4° x 4.4°) and a red ball (4.3° x 4.1°; see Figure 4). For the action the human hand (4.9° x 9.4°) reached from the left to the right side of the screen. No animations were used anymore. Material was edited and cut with Final Cut Pro (Version 7.0.3). To ensure that the action was timed accurately, one movie of Cannon and Woodward (2012) was used as a basis for cutting the stimuli. As already Experiment 4 followed the timing of Cannon and Woodward (2012), there were no other changes made (see Experiment 4 for details).

Goal-object, position of goal-object, hand orientation and order of hand orientation was counterbalanced throughout participants, leading to 16 different combinations. Analysis of the data and inclusion criteria were carried out as in Experiment 4.

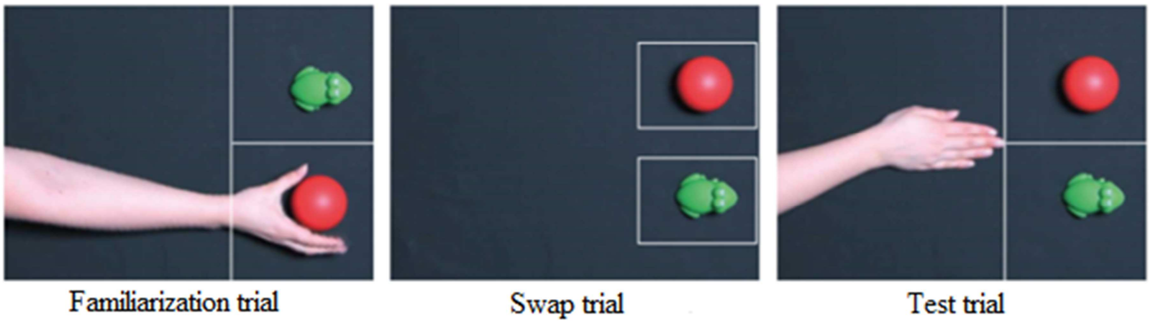


Figure 4. Stimulus material of the familiarization-, swap- and test trial of Experiment 5. The white lines mark the AOIs in Experiment 5. For comparison to the original stimuli, see Cannon and Woodward (2012).

2.3.5.2 Results

Anticipation rate. For the whole experiment, the anticipation rate amounts to 0.74 (SD = 0.14). For the familiarization trials the anticipation rate is 0.65 (SD = 0.18). A Wilcoxon signed-rank test revealed a significant difference between the anticipation rate of the test trials (M = 1.00, SD = 0.00) and the last familiarization trials (M = 0.56, SD = 0.31), with z = -4.40, p < .001, r = -.56.

Familiarization phase. Goal-related accuracy rate in the last familiarization trials (M = 0.39, SD = 0.31) was significantly higher than the non-goal-related accuracy rate of the last familiarization trials (M = 0.18, SD = 0.27), z = -2.03, p = .04, r = -.25. There was no significant difference between the goal-related accuracy rate in the first familiarization trials

(M = 0.50, SD = 0.30) and the goal-related accuracy rate in the last familiarization trials (M = 0.39, SD = 0.31), z = -1.51, p = .13, r = -.19.

Test phase. A Wilcoxon signed-rank test demonstrated no significant difference between the identity-related (M = 0.40, SD = 0.35) and location-related (M = 0.60, SD = 0.35) accuracy rate in the test phase, z = -1.53, p = .13, r = -.19. Also the goal-related accuracy rate in the last familiarization trials (M = 0.39, SD = 0.31) did not differ from the identity-related accuracy rate in the test phase (M = 0.60, SD = 0.35), z = -2.62, p = .009, r = -.23. Nevertheless, the goal-related anticipation rate in the last familiarization trials (M = 0.39, SD = 0.31) was significantly lower than the location-related accuracy rate in the test trials (M = 0.60, SD = 0.35), z = -2.62, p = .009, r = -.23.

A Chi-Square test over the number of anticipations of the test trials showed a significant difference, $\chi^2(1) = 4.40$, p = .036. Infants anticipated more often to the location (n = 66) than to the identity of the goal (n = 44).

The analysis according to Cannon and Woodward (2012) with the same measure and inclusion criteria demonstrated chance level of infants' looking behavior, with $t(30)$ = -0.92, p = .363, Cohen's d = 0.17, M = 0.44, SD = 0.39.

2.3.5.3 Discussion

While the previous experiments 1 to 4 represent conceptual replications of the study by Cannon & Woodward (2012), Experiment 5 represents a direct replication. Because the original stimuli were not available, the stimuli were newly filmed for Experiment 5 and video edited to make them as similar to the original stimuli as possible. Nevertheless, the current findings show that 12-month-olds demonstrated more anticipations to the location than to the goal.

The results of this direct replication are in line with the findings of Experiment 1 to 4 and of Daum et al. (2012). The differing findings between the two paradigms can neither be explained by the presence of an occluder nor by the type of agent. Detailed implications of these findings are discussed in the General Discussion.

2.3.6 Supplemental Material of Study 1a

Additional analysis according to Cannon and Woodward (2012)

For all five experiments of Study 1 we adapted our inclusion criteria to the original study. As the inclusion criteria changed, we carefully checked all children which had to be excluded in the original analysis (for the original study they were replaced for children which met the inclusion criteria) due to the inclusion criteria and included them if they met the "new" inclusion criteria. Over all five experiments, 12 additional infants could be analyzed. To held conditions equally, we dropped later tested children, so that we ended up with the same sample size (except for Experiment 5, where we had to exclude one additional child). The AOIs remained the same to our prior analysis. Only test trials were examined. We measured the first fixation from the start area to one of the goal-AOIs. A fixation towards the goal-AOI had to be 200 ms long within a radius of 50 pixels. To be included into analysis, infants had to show fixations in three or four trials (Cannon & Woodward, 2012). A *Proportion Score* was generated for analysis, with the proportion of goal-directed anticipations in relation to location-directed anticipations (Cannon & Woodward, 2012). For every experiment, one-sample t tests against chance (0.50) were performed.

2.3.7 Discussion Study 1a

The aim of Study 1a was to examine which factors (type of agent, occlusion, order of trials, timing and procedure of the action, movement direction) effect infants' goal encoding and caused the contradictory findings of two previous studies focusing on the same research question (Cannon & Woodward, 2012; Daum et al., 2012). Based on previous findings (Cannon & Woodward, 2012; Hespos et al., 2009; Kanakogi & Itakura, 2011), the hypothesis of Study 1a was that the different results could primarily be attributed to two factors, namely type of agent (human vs. non-human) and differences in the requirement of cognitive resources caused by the use of an occlusion paradigm. For this purpose, these differences were consecutively aligned in Study 1a. In 5 experiments, an agent was presented to 12-month-old infants who moved to one of two goals. Before the test phase, positions of the target objects were swapped. Results over all 5 experiments showed that 12-month-olds learned the association of the agent and the target during familiarization phase already after three trials, thus demonstrating fast learning within infants (Krogh-Jesperson & Woodward, 2014). For test trials, infants showed in four of the five experiments more location- than identity-related anticipations. In one experiment, infants anticipated equally often towards the identity and the location of the target. Over all five experiments, infants demonstrated 311 location-related and 189 identity-related anticipations.

The hypothesis that the different results of the two studies (Cannon & Woodward, 2012; Daum et al., 2012) could be attributed to the type of agent and the occluder was not confirmed. Further, our results are neither in line with the human-first nor with the all agents view, since we did not find goal anticipations in any of the experiments. This finding is not in line with previous studies, which highlight the role of experience (human-first view) for understanding an action as goal-directed in the first year of life (Cannon & Woodward, 2012; Gredebäck & Melinder, 2010; Kanakogi & Itakura, 2011; Krogh-Jesperson & Woodward, 2018). They are in line with findings demonstrating that infants anticipate others' actions based on their previous path (Paulus et al., 2011). However, results are not in line with looking time studies that demonstrated understanding of goal-directed actions of non-human agents already within infants, as stated by the all agents view (e.g. Kamewari et al., 2005; Luo, 2011; Luo & Baillargeon, 2005; Schlottmann & Ray, 2010). Nonetheless, it remains an open question, why infants expected the agent to move to the familiarized location and not to the previous goal.

The assumption, that the occluder could have an influence on infants' anticipations, was not confirmed either in Study 1a. Infants showed location-related anticipations, independent of the presence of an occluder. On the one hand, studies have suggested that the use of an occluder requires extra skills for infants (Hespos et al., 2009; Jonsson & von Hofsten, 2003). On the other hand, previous findings showed that infants in their first year of life are able to anticipate the reappearance of a temporarily occluded object (Gredebäck & von Hofsten, 2004; Gredebäck et al., 2002; Rosander & von Hofsten, 2004). Our results are in line with the latter set of findings.

In sum, the current findings suggest that at the age of 12 months, the ability to flexibly anticipate the actions of others based on goal identity has not yet developed, irrespective of whether the agent was human or not, and therefore, infants have also shown anticipations based on the location. In Study 1b this issue is further addressed in another lab and with different stimuli. The inclusion of older age groups (32-month-olds and adults) in Study 1b will also reveal how stable this effect is over the course of development.

2.4 Study 1b

The second study analyzed whether children and adults show goal encoding for two different paradigms, one using a human hand as an agent (e.g., Cannon and Woodward, 2012) and one a non-human animated animal (e.g., Daum et al., 2012; Paulus et al., 2011). We intended to find out whether infants use similar processing strategies for both paradigms. Thus, both tasks were presented to 11-month-olds, 32-month-olds and adults in a within-subject design. In both paradigms, the agent walked to one of two objects for several times. For test trials the object's position was swapped and participants observed an uncompleted action. The hand paradigm is based on the study by Cannon and Woodward (2012), while the stimuli differed in a few manners. Most notably, the number of trials and the presentation order of learning and test trials were different. Further details are described below in the method section. Moreover, to facilitate infants' encoding of the scenario, we also decided to familiarize participants with the actor and the targets. Goal-directed anticipations from 11 months onward in the hand-paradigm would replicate the findings of Cannon and Woodward (2012). In the path-paradigm, we expected 11-month-olds and 32-month-olds to anticipate the old path, thus the novel goal, as the action is performed by a non-human agent (Daum et al., 2012). We hypothesized to find anticipations towards the familiarized goal within the adult sample in both paradigms (Daum et al., 2012; Pfundmair et al., 2017). A correlational analysis of the anticipatory looking behavior between the two paradigms should further clarify whether the different processing mechanisms assessed by the two paradigms are related to each other. We expected to find at least in the adult sample a positive correlation, because they showed goal anticipations for human and non-human agents in previous studies (Daum et al., 2012; Pfundmair et al., 2017). In case we would find a correlation between the two paradigms within children, as predicted by the *all agents-view*, we wanted to make sure that this relation is not mediated by individual factors of the child (Licata et al., 2014). Hence, we included a measure for temperament (Infant Behavior Questionnaire revised very short form; Putnam, Helbig, Gartstein, Rothbart, & Leerkes, 2013; Early Childhood Behavior Questionnaire very short form; Putnam & Rothbart, 2006) as well as a cognitive measure for pattern recognition. Therefore, items were adapted from the Bayley-Scales (Bayley, 2006; German version by Reuner & Rosenkranz, 2014; see supplemental material of Study 1b) for the 32-month-olds. As there are, to our knowledge, no comparable items for 11-month-olds, a task for working memory (Pelphrey et al., 2004; Reznick, Morrow, Goldman, & Snyder, 2004) was used as an indicator for pattern recognition. In this task infants had to remember in several trials at which of two windows the experimenter appeared beforehand.

2.4.1 Method

Participants

The final sample included 34 11-month-olds (mean age = 11.44 months; *SE* = 0.15; 15 girls), 35 32-month-olds (mean age = 32.11 months; *SE* = .09; 23 girls) and 35 adults (mean age = 23.03 years; *SE* = 1.04; 30 women). Additionally, 8 children were tested but excluded, as they did not want to watch the second movie (*n* = 4), were inattentive (*n* = 2), or because of measurement failure (*n* = 2). Three additional adults had to be excluded due to technical problems. Participants came from a larger city in Germany. The infant population was recruited from local birth records and adult participants were recruited from a student population. Participants or their caregivers gave informed written consent. The study was approved by the local ethics board.

Stimuli and Procedure

Participants were presented with two different paradigms. Both paradigms were shown on a 23-inch monitor, which was attached to a Tobii TX300 corneal reflection eye tracker with a sampling rate of 120 Hz (Tobii Technology, Sweden). Children were either seated on their parent's lap or in a car-safety seat (Chicco) about 60 cm away from the screen. For 11- and 32-month-olds, a 5-point calibration was performed. Adults were calibrated with a 9-point procedure. Data collection and analyzation was carried out with Tobii Studio (Tobii Technology, Sweden). All movies had the size of 1920x1080 pixels.

In the subsequent section, the stimuli for the hand paradigm are described first, the animated path-paradigm second.

Hand-paradigm. The procedure started with a movie, which introduced the agent. The female actor was sitting on a table and waving at the participant (6 s). To familiarize participants with the targets, two pictures were shown (each 2 s). Each showed one of the two targets, a green ball and a blue cube, accompanied by a sound. Next, the learning trials started. Similar to Cannon and Woodward (2012), the movies of the learning trials presented the two targets at the right side of the screen. The ball was situated in the upper position, the cube in the lower position (see Figure 5). The table was light brown. After 0.10 s, the hand reached into the picture (supplemented by a subtle, short sound) from the left side of the screen towards the targets, until just past midline (2.65 s). It then made a curvilinear path towards the ball and grasped it (after another 0.85 s) for 0.40 s combined with a squeak-sound. The whole learning trial lasted for circa 4 s, and was shown for 5 times in a row. Next, participants were presented with the swap trial, which consisted of a picture of the objects in swapped position accompanied by a rattle sound (4 s). Finally, in the test trials the hand reached in from the left (with the same sound as in the familiarization trials) and stopped just past midline (2.80 s). A still-image of the hand in this position was presented for another 6.10 s. A test trial lasted for 8.90 s and was presented for three times in a row. Between each test trial a black screen with an attention-getting sound was presented, to redirect infants' attention to the screen.

Path-paradigm. First, participants were familiarized with the setup using an introductory movie. It showed a horizontal path that led from the right to the left side of the screen. A rabbit was sitting at the right side of the path and a transparent occluder was located in the middle of the path. After 0.2 s the rabbit started to jump up and down, supplemented by a sound. At the same time the occluder turned opaque and the rabbit started to move towards the end of the path through the occluder (6.88 s), turned around and went back towards the starting point. The whole movie lasted for 12.54 s. Afterwards five learning trials were presented. The learning trials contained a path that was leading to two different goals (similar to Paulus et al., 2017); a house that was situated on the upper path and a wood, situated on the lower path (see Figure 5). The occluder was overlaid at the crossroad where the path divided into two options leading to the different goals. The agent was a pig that was located at the left side of the path. At the beginning of the movie the transparent occluder turned opaque (0.44 s). Afterwards the pig started to jump for two times (accompanied by a sound) and moved towards the occluder, until it disappeared for 2.37 s. The pig then reappeared on the upper path and moved towards the house. When it reached the house a bell sound was played. The whole movie took 10.52 s. Following the learning trials, a swap trial was shown (total duration 10.03 s). First a frame of the objects in the old position was presented; after 3 s both targets disappeared with a sound and reappeared in changed position after another 2 s with the same sound. Targets in changed position were presented for 5 more seconds. The pig was situated at the beginning of the path during the whole trial. The following test trials started completely identically to the learning trials, except that the targets were now in changed position and the pig did not reappear from the occluder for 6 s. The duration of one test trial was 11.52 s and test trials were presented three times in a row. Between the three test trials the same black screen with the attention-getting sound was inserted, as was done in the hand-paradigm.

Both paradigms were shown to each participant. Order of paradigms was counterbalanced. Between the two eye-tracking movies 11-month-olds and 32-month-olds did a task for a control measure on the table. A detailed description of control measures can be found in the supplemental material of Study 1b (chapter 2.4.3).

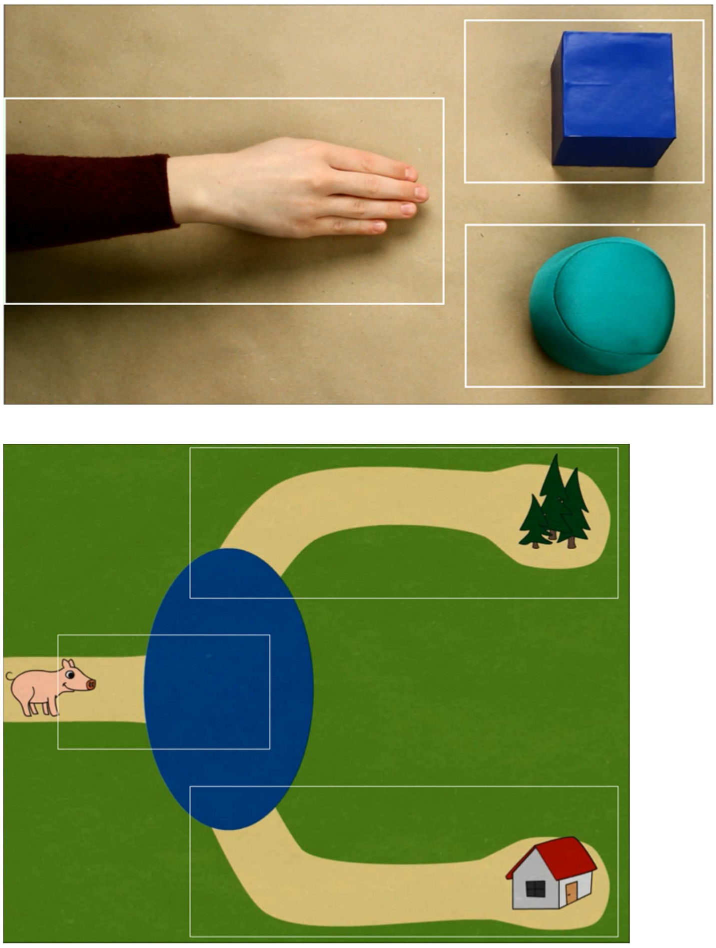


Figure 5. Stimulus material of the test trial of the hand and path paradigm in Study 1b. White boxes indicate the AOIs.

Measures

The Tobii standard fixation filter with a velocity threshold of 35 pixels/window and a distance threshold of 35 pixels was used to define fixations. For the hand paradigm three AOIs were defined: One AOI covered the area of the hand ("starting area", 31.94 %), the other two AOIs covered the targets (each 13.67 %). Participants gaze behavior was measured for the whole test trial. AOIs for the path-paradigm were implemented as followed: The "start-AOI" covered the starting point of the action, namely the first part of the path, which led to the occluder (5.46 %, see Figure 5). The other two AOIs were situated on the area where the paths reappeared from the occluder (each 14.53 %). The "start-AOI" was active for 1.79 s before the agent disappeared behind the occluder. Once the agent disappeared, fixations to the other AOIs were measured. For analysis of participant's gaze behavior, three different measures were used for both paradigms, following previous research (Paulus et al., 2011; Schuwerk & Paulus, 2015). First we assessed whether participants generally anticipated to one of the two targets, irrespective to which one. The second measure assesses participants' expectations based on their first fixations to either of the targets. The third measure assessed looking time durations to both targets. This measure was included to control for corrective eye movements.

Frequency Score. This score assesses whether all three age groups showed an equal amount of general anticipations (irrespective to which of the two targets they fixated) in all three test trials for each paradigm. In the hand-paradigm, a fixation was counted with 1, when participants first fixated the hand and fixated one of the targets after (no matter which of the targets). For the path-paradigm, a fixation was counted with 1, when participants first looked at the path leading to the occluder before the agent disappeared and fixated on one of the target-AOIs after the agent disappeared. A fixation somewhere else or no fixation was coded with 0 (Schuwerk et al., 2016).

First Fixation Score. This score was calculated similar to the Frequency Score, with the only difference that now the type of first fixation, namely to which specific target was fixated, was considered. To be counted as a first fixation for the hand-paradigm, participants had to fixate the hand first and fixate on one of the targets after. In the path-paradigm, first fixations were only included when participants first looked at the path leading to the occluder before the agent disappeared and fixated on one of the other AOIs after the agent disappeared. A fixation from the beginning of the path to the correct path was coded with 1, a fixation to the incorrect, that is, the familiarized path, was coded with -1 and a fixation somewhere else on the screen or no fixation was coded with 0 (Schuwerk & Paulus, 2015). The score was averaged over the three test-trials for analysis. If participants have two or more missing values for test-trials in each paradigm they were excluded for that score. One 32-month-old in the hand-paradigm did not show gaze data for at least two test-trials and one 11-month-old in the path-paradigm.

Differential Looking Score (DLS). A score was calculated that represents the relative amount of time on one AOI in relation to the other. This score was additionally included to control for corrective eye-movements, as participants could fixate first on one AOI but direct most of the following fixations to the other AOI (Schuwerk & Paulus, 2015; Senju, Southgate, White, & Frith, 2009). Therefore the total looking time to the incorrect goal-AOI was subtracted from the total looking time to the correct goal-AOI and divided by the sum of total looking time to both goal-AOIs in that time. This results in scores between -1 and 1; a value towards -1 would indicate a preference for the novel goal, a value towards 1 a preference for the old goal.

2.4.2 Results

Frequency of Anticipations. For the hand-paradigm, participants anticipated in 280 out of 312 trials (9.74 %). For the path-paradigm, participants anticipated in 270 out of 312 trials (6.54 %). A generalized estimating equations model (GEE; Zeger & Liang, 1986) was calculated for each paradigm separately (unstructured working correlation matrix, logit link function, binomial distribution) to see whether age group or test trial (first, second or third trial) or the interaction of age group and test trial had an effect on participants' frequency of anticipatory first fixations. Results can be found in Table 2 and Table 3. For both paradigms, neither of the predictors had a significant influence on the frequency of anticipations. This means that all age groups showed an equal amount of anticipations in all three test trials for both the hand- and path-paradigm.

Table 2. Results of the generalized estimating equations model with the predictors age group, trial and an interaction of age group and trial on the frequency of anticipations in the **hand-paradigm**

Predictor	B	SE	Wald	*df*	*p* value	Exp(B)	95% Confidence interval for Exp(B)	
							Lower	Upper
Age group	0.12	0.69	0.03	1	0.864	1.13	0.30	4.40
Trial	0.99	0.85	1.35	1	0.25	2.68	0.51	14.11
Age group *Trial	-0.52	0.34	2.30	1	0.13	0.60	0.31	1.16

Table 3. Results of the generalized estimating equations model with the predictors age group, trial and an interaction of age group and trial on the frequency of anticipations in the **path-paradigm**

Predictor	B	SE	Wald	*df*	*p* value	Exp(B)	95% Confidence interval for Exp(B)	
							Lower	Upper
Age group	0.37	0.58	0.41	1	0.521	1.45	0.47	4.47
Trial	0.61	0.53	1.34	1	0.247	1.84	0.66	5.19
Age group *Trial	-0.23	0.25	0.86	1	0.353	0.79	0.49	1.29

First Fixation Score. A repeated measures ANOVA with the First Fixation Score was performed with the within-subject factor paradigm (hand vs. path paradigm) and the between-subject factor age group (11-months, 32-months, and adults). No main effect of paradigm was found, $F(1, 99) = 0.64$, $p = .427$; $\eta_p^2 = .01$, but a significant main effect of age group, $F(2, 99) = 6.55$, $p = .002$, $\eta_p^2 = .12$. The interaction of paradigm and age group was also significant, $F(2, 99) = 9.65$, $p < .001$, $\eta_p^2 = .16$. Consequently, a one-way ANOVA with the between subject factor age group was performed for each paradigm separately. Analysis for the hand-paradigm did not reveal significant differences between the age groups, $F(2, 100) = 1.93$, $p = .151$, $\eta_p^2 = .04$, whereas the ANOVA for the path paradigm turned out significant, $F(2, 100) = 13.35$ $p < .001$, $\eta_p^2 = .21$. Bonferroni post-hoc tests showed a significant difference between 11-month-olds ($M = -.34$, $SE = .10$) and adults ($M = .24$, $SE = .10$) with $p < .001$, Cohen's $d = .95$, and 32-month-olds ($M = -.45$, $SE = .10$) and adults, $p < .001$, Cohen's $d = 1.15$. The difference between the two infant groups was not significant, $p = 1.00$, Cohen's $d = .19$.

DLS. Results for the DLS showed a similar pattern. The repeated measures ANOVA with the between subject factor age group and the within subject factor paradigm demonstrated no significant effect of paradigm, $F(1, 100) = .16$, $p = .215$, $\eta_p^2 = .02$, and age group, $F(2, 100) = 1.30$, $p = .277$, $\eta_p^2 = .18$. The interaction effect of paradigm and age group turned out significant, with $F(2, 100) = 10.61$, $p < .001$, $\eta_p^2 = .18$. One-way ANOVAs were performed for each paradigm separately. The ANOVA for the DLS for the hand paradigm was significant, $F(2, 100) = 3.35$, $p = .04$, $\eta_p^2 = .06$. Bonferroni' post-hoc tests showed no significant difference between 11-month-olds ($M = -.05$, $SE = .07$) and 32-month-olds ($M = -.23$, *SE* = .07), with *p* = .23, Cohen's *d* = -.44, and between adults (*M* = -.30, *SE* = .07) and 32-month-olds, *p* = 1.00, Cohen's *d* = -.17. However, comparison between adults and 11-month-olds turned out significant, *p* = .04, Cohen's *d* = -.59. Similarly, analysis for the path-paradigm showed a significant effect with *F*(2, 101) = 6.60, *p* = .002, η_p^2 = .12. Bonferroni' post-hoc tests demonstrated a significant difference between 11-month-olds (*M* = -.27, *SE* = .08) and adults (*M* = .12, *SE* = .08), *p* = .003, Cohen's *d* = .80, and between 32-month-olds (*M* = -.20, *SE* = .08) and adults, *p* = .020, Cohen's *d* = .68. Again the difference between the 11-month-olds and 32-month-olds was not significant, *p* = 1.0, Cohen's *d* = .15.

Comparisons across paradigms per age group. Repeated measures ANOVAs were performed for each age group separately with the within-subject factor paradigm. Analysis of the First Fixation Score for the 11-month-olds revealed no difference in performance for the two paradigms, *F*(1, 32) = 3.41, *p* = .07, η_p^2 = .10, just as for the 32-month-olds, *F*(1, 33) = 0.45, *p* = .51, η_p^2 = .01. In contrast, adults performed in both paradigms differently, with *F*(1, 34) = 16.64, *p* < .001, η_p^2 = .33 (see also Figure 6 for descriptives). Adults showed a looking bias towards the novel object in the old location in the hand-paradigm, but a looking bias towards the goal in the path paradigm. The same pattern was demonstrated for the DLS: No difference was found for the 11-month-olds, *F*(1, 33) = 3.37, *p* = .08, η_p^2 = .09, and 32-month-olds, *F*(1, 33) = 0.04, *p* = .84, η_p^2 = .001. However adults showed a significant difference between the two paradigms, with *F*(1, 34) = 3.01, *p* < .001, η_p^2 = .43, with the same pattern as for the First Fixation Score.

Type of anticipated action. Further to check whether participants showed a significantly different looking bias from chance towards one or the other AOI, one sample *t*-tests against chance level were calculated for each paradigm and each age group separately (indicated by the asterisks in Figure 6). 11-month-olds showed chance performance in the hand paradigm for the First Fixation Score, *t*(33) = -.88, *p* = .39, Cohen's *d* = -.15, and the DLS, *t*(33) = -.73, *p* = .47, Cohen's *d* = -.13. For the path-paradigm they showed a significant looking bias towards the previous path, for the First Fixation Score, *t*(32) = -3.36, *p* = .002, Cohen's *d* = -.58, and the DLS, *t*(33) = -3.30, *p* = .002, Cohen's *d* = -.57. 32-month-olds performed in every paradigm above chance. They anticipated that the hand would grasp the novel object in the old location, indicated by the First Fixation Score, $t(33) = -4.46$, $p < .001$, Cohen's $d = -.77$, and DLS, $t(33) = -3.44$, $p = .002$, Cohen's $d = -.59$; as well as that the agent would reappear on the old path aiming for the novel goal, for First Fixation Score, $t(34) = -4.63$, $p < .001$, Cohen's $d = .78$, and DLS, $t(34) = -2.59$, $p = .014$, Cohen's $d = .44$. Similarly adults anticipated significantly above chance that the hand would grasp the novel object in the old location, with $t(34) = -2.57$, $p = .02$, Cohen's $d = -.44$ for the First Fixation Score, and $t(34) = -4.33$, $p < .001$, Cohen's $d = -.73$ for the DLS. In contrast for the path paradigm, adults anticipated the agent's reappearance on the correct path, with $t(34) = 2.24$, $p = .032$, Cohen's $d = .38$ for the First Fixation Score. Results of the DLS turned out not significant, $t(34) = 1.41$, $p = .167$, Cohen's $d = .24$.

To be able to compare our results better with Cannon and Woodward (2012) we further analyzed only the first test trial of the hand paradigm. As Cannon and Woodward (2012) presented infants four blocks in the design of three learning trials and one test trial per block, and given that we presented participants five learning- and three consecutive test trials, an analyzation of only the first test trial is closer to a replication of the original study (with the difference being that we have five instead of three learning trials). One-sample *t*-test revealed chance performance for the 11-month-olds for the DLS ($M = 0.05$, $SE = 0.11$), $t(32) = .49$, $p = .63$, Cohen's $d = .09$, and a First Fixation Score of $M = -0.12$, $SE = 0.17$. The 32-month-olds showed a significant looking bias towards the old location for the DLS ($M = -0.26$, $SE = 0.08$), $t(33) = -3.18$, $p = .003$, Cohen's $d = -.55$, with also a negative First Fixation Score ($M = -0.53$, $SE = 0.15$). Similarly the *t*-test was also significant for the adults with $t(34) = -4.05$, $p < .001$, Cohen's $d = -.69$, for the DLS ($M = -0.36$, $SE = 0.09$), and a First Fixation Score of $M = -0.37$, $SE = 0.15$, indicating a looking bias towards the location. In sum, even when we only analyzed the first test trial, we did not find goal directed anticipations over all age groups for the hand-paradigm.

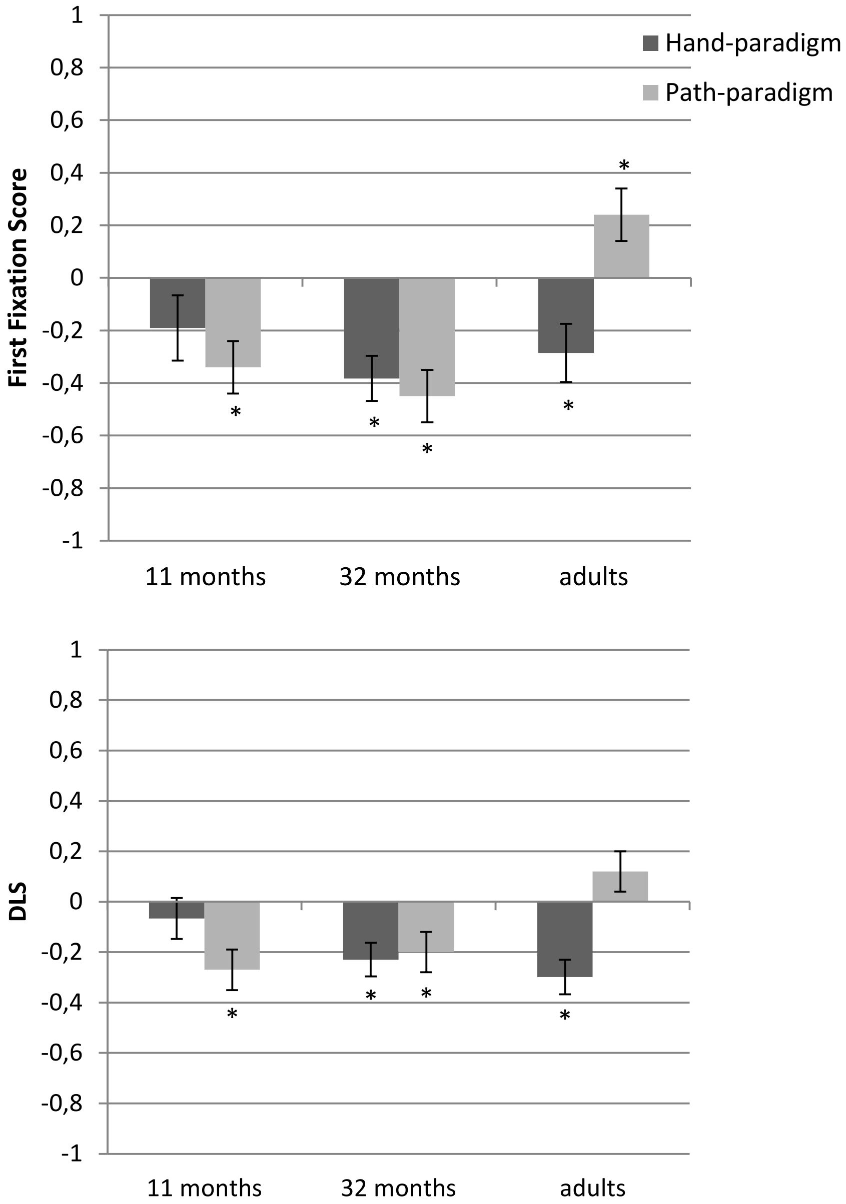


Figure 6. Descriptives of the First Fixation Score and DLS for each paradigm per age group. Error bars mark standard errors of the means. Asterisks indicate a significant difference from chance.

Correlation analysis. For each age group the Spearmen's Roh correlation between scores of the hand- and path paradigm were calculated (see Table 4). All correlations of the control measures can be found in the supplemental material of Study 1b. Analysis of the 11-month-olds and 32-month-olds revealed no significant correlations between the two paradigms. Interestingly, for adults the First Fixation Score did not correlate with each other, whereas the DLS turned out significant.

Table 4. Results of correlation analysis between the two paradigms per age group

	First Fixation Score correlation	**DLS correlation**
11-month-olds	$r_s(33) = .219$	$r_s(34) = -.174$
32-month-olds	$r_s(34) = -.039$	$r_s(34) = .266$
Adults	$r_s(35) = .328$	$r_s(35) = .361$*

Note: DLS = Differential Looking Score; * $p < .05$

Additional analysis. Also Study 1b was additionally analyzed as similar as possible to the study by Cannon and Woodward (2012). Details of analysis and results can be seen in the supplementary material. Results suggest that neither for the hand- nor for the path-paradigm, infants anticipated the action goal-directed. Even when looking at the three test trials separately for the hand-paradigm (see Figure 7), participants' performance was never above chance level.

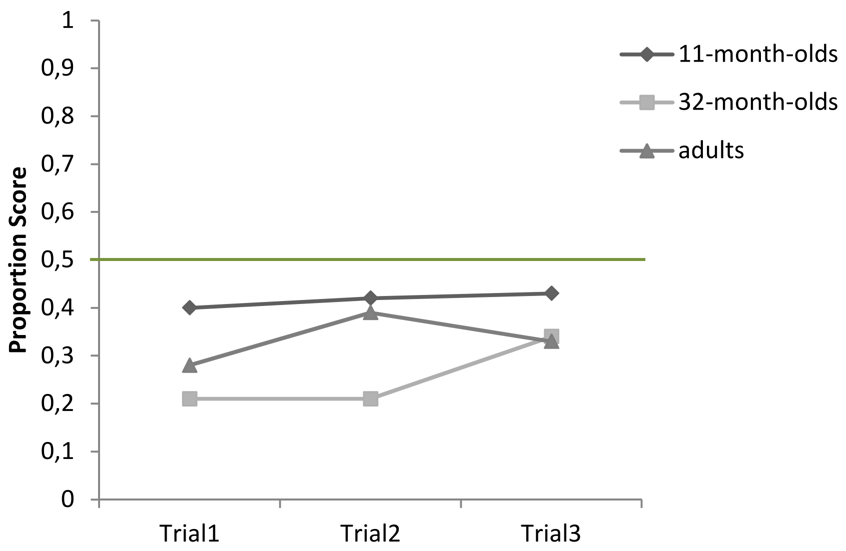


Figure 7. Descriptives for the hand-paradigm of Study 1b for each trial and age group when data was analyzed as similar as possible to Cannon and Woodward (2012).

2.4.3 Supplemental Material of Study 1b

2.4.3.1 Control tasks Study 1b

11-month-olds: To control for 11-month-olds short-term memory ability a task from Reznick et al. (2004) and Pelphrey et al. (2004) was adapted for the current study. Infants were seated on their parent's lap at a table. The experimenter sat across from them. On the table between experimenter and child was a big black frame (86 x 38 cm) with two same sized windows (each 13.5 x 16 cm). Windows were 42 cm apart from each other, center to center. Two white curtains were attached to the back of the frame and covered the two windows. Between the windows in the upper middle of the frame was a small peephole. Infants were recorded with a video camera situated behind the experimenter, another camera recorded the behavior of the experimenter. The procedure was as follows: The experimenter pulled both curtains aside, put her face in one window and drew the infant's attention to herself. After the child got involved, that is, looked at the experimenter, the experimenter disappeared from the window and closed the curtains. In a next step, the experimenter wiggled her fingers at the top center of the whole frame for 2, 6 or 10 s. During that time, she could observe the child through the peephole. All children had to focus at least once at the wiggling finger of the experimenter before continuing. When the time interval (2, 6, or 10 s) was over, the experimenter opened the curtains and waited for 3 s. Afterwards she reappeared again at the previous window and encouraged the child verbally, irrespective of infants' correct or incorrect looking response. The curtains were again closed and after a short pause the next trial started. The whole task included 12 trials combined to four blocks. Each block contained all degrees of delay (2, 6 or 10 s). Order of trials within the blocks was counterbalanced. Also, the location (left or right) of reappearance was counterbalanced. All infants saw the trials in the same order.

Infants' direction of their first gaze within the 3 s following the distraction was assessed. A first gaze to the correct window was coded with 1, a gaze to the incorrect window or no gaze to either of the windows with 0. If the infant did not attend to the task for that trial, it was treated as a missing value (Pelphrey et al., 2004; Reznick et al., 2004). For two infants coding was not possible, as the infant's eyes were not visible due to occlusion by the frame. Another infant was excluded as it did not engage in the task. Two coders coded each 60% of infants looking behavior. For calculation of the interrater-agreement, both coders overlapped in 20% of the cases and agreed in 81% thereof. Disagreement was reviewed by both coders and resolved in consensus. For further analysis a percentage correct score was calculated by dividing the number of correct responses by the number of trials in which a response occurred (Pelphrey et al., 2004). Following Pelphrey and colleagues (2004), infants had to engage in the task for at least 8 trials. If not, infant's score was treated as missing value. Due to this criterion 8 children were eliminated for that task.

To measure infants' temperament, parents filled out a German version of the Infant Behavior Questionnaire revised very short form (IBQ-R; Putnam et al., 2014). The 36 items, which were answered on a 7-level scale, led to three scales, namely Positive Affectivity/Surgency (PAS), Negative Affectivity (NEG) and Orienting/Regulatory Capacity (ORC).

32-month-olds: The ability of recognizing patterns was measured via 3 items of the cognitive scale from the Bayley-III Scales (Bayley, 2006; German version by Reuner & Rosenkranz, 2014), namely "Makes simple patterns" (number 77 from the cognitive scale), "Distinguishes patterns" (number 83) and "Completes patterns" (number 91). The items "Distinguishes patterns" and "Completes patterns" contained each 3 sub-items. For every correct answer to every item and sub-item, participants got a value of 1 and could get in total 7 points for the whole task. For testings, infants were seated on their parent's lap at a table. Across from them sat the experimenter.

For the assessment of children's temperament, parents filled out a German version of the Early Childhood Behavior Questionnaire very short form (ECBQ; Putnam & Rothbart, 2006). Similar to the IBQ-R the version for the older age-group contained 36 items, which resulted in three scales, namely Negative Affect (NEG), Surgency (SURGE) and Effortful Control (EFFCO).

2.4.3.2 Results of the correlational analysis for the control measures

Table 5. Results of correlation analysis per age group

	First Fixation Hand	**DLS Hand**	**First Fixation Path**	**DLS Path**
11-month-olds				
Surgency – IBQ-R	$r_s(32) = .145$	$r_s(32) = .087$	$r_s(31) = .360$*	$r_s(32) = .242$
Effortful Control – IBQ-R	$r_s(30) = -.186$	$r_s(30) = -.291$	$r_s(31) = .304$	$r_s(32) = -.049$
Negativity – IBQ-R	$r_s(30) = .192$	$r_s(30) = -.033$	$r_s(31) = -.069$	$r_s(32) = -.093$
Working Memory	$r_s(21) = .271$	$r_s(21) = .077$	$r_s(23) = .123$	$r_s(23) = -.069$
32-month-olds				
Surgency – ECBQ	$r_s(32) = .090$	$r_s(32) = .110$	$r_s(35) = .138$	$r_s(35) = -.031$
Effortful Control – ECBQ	$r_s(32) = .125$	$r_s(32) = .142$	$r_s(35) = .208$	$r_s(35) = .106$
Negativity – ECBQ	$r_s(32) = -.018$	$r_s(32) = .097$	$r_s(35) = -.195$	$r_s(35) = .170$
Pattern recognition	$r_s(29) = -.073$	$r_s(29) = -.131$	$r_s(32) = -.041$	$r_s(35) = -.197$

Note: DLS = Differential Looking Score; IBQ-R = Infant Behavior Questionnaire revised very short form;
ECBQ = Early Childhood Behavior Questionnaire very short form.
* $p < .05$, ** $p < .0125$

2.4.3.3 Additional analysis according to Cannon and Woodward (2012)

First, for the hand-paradigm the AOI of the hand was made larger (capturing the whole area around the hand, see Figure 8), as was done by Cannon and Woodward (2012). Second, the Tobii Fixation Filter was used (see Krogh-Jespersen & Woodward, 2014) and a fixation had to be at least 200 ms long (following Cannon & Woodward, 2012). A first fixation in the hand-paradigm to either the goal or the other target was counted as such, if participants fixated the hand first and one of the two objects after. For the path-paradigm, participants had to fixate first the path leading to the occluder before the agent's disappearance and then to one of the target-AOI's when the agent was behind the occluder. Only trials, in which the participants showed anticipations were included. They had to demonstrate anticipations in at least two of three test trials. This restriction differs to Cannon and Woodward's criteria

(2012); in their study, infants had to anticipate in at least three of four test trials to be included. Since we presented participants only three consecutive test trials in total, without learning trials in between, we adjusted their inclusion criteria to our design. The same *Proportion Score* was generated for analysis. One-way ANOVAs and one-sample *t*-tests against chance were performed for each paradigm separately, to see whether these criteria might change the pattern for goal-directed anticipations in each age group.

Hand-paradigm: Due to these changes, one additional 11-month-old, one 32-month-old and four adults had to be excluded from the original sample, as they did not show enough anticipations according to the criteria. The included participants did not perform any anticipations in 24 out of 294 trials (8.16 %). A one way ANOVA with the between-subject factor age-group was calculated and revealed no differences between the three age groups, $F(2, 95) = 2.38$, $p = .098$, $\eta_p^2 = .048$. Additionally, one-sample t-tests for each age group against chance level (.50) were calculated to see whether participants performed goal-directed anticipations. The 11-month-olds did not perform significantly different from chance with $t(32) = -1.31$, $p = .199$, Cohen's $d = -.23$, $M = .42$, $SD = .35$. The 32-month-olds showed a looking bias towards the old location significantly different from chance with $t(33) = -5.71$, $p < .001$, Cohen's $d = -.98$, $M = .25$, $SD = .26$; as well as the adults with $t(30) = 2.8$, $p = .009$, Cohen's $d = -.50$, $M = .32$, $SD = .36$. The results suggest that even when the data is analyzed according to Cannon and Woodward (2012), all age groups did not anticipate the action in relation to the goal object. In fact the one-sample *t*-tests suggest the same pattern as with the other inclusion criteria and two scores (First Fixation Score, DLS).

Path-paradigm: According to the different criteria for analysis, additional eleven 11-month-olds, one 32-month-old and nine adults had to be excluded. The one-way ANOVA with the between-subject factor age group was not significant, $F(2, 79) = 2.82$, $p = .065$, $\eta_p^2 = .067$, indicating no differences between age groups. The one-sample *t*-tests against chance (.50) revealed chance performance for the 11-month-olds with $t(22) = -2.00$, $p = .058$, Cohen's $d = -.42$, $M = .35$, $SD = .37$ (while indicating a trend for a looking bias towards the location). The 32-month-olds showed a significant looking bias towards the location with $t(32) = -3.67$, $p = .001$, Cohen's $d = -.64$, $M = .31$, $SD = .30$. Adults performed at chance level with $t(25) = .18$, $p = .86$, Cohen's $d = .04$, $M = .51$, $SD = .36$. In sum, also for the path-paradigm participants did not anticipate the action goal, even when data was analyzed according to Cannon and Woodward (2012).

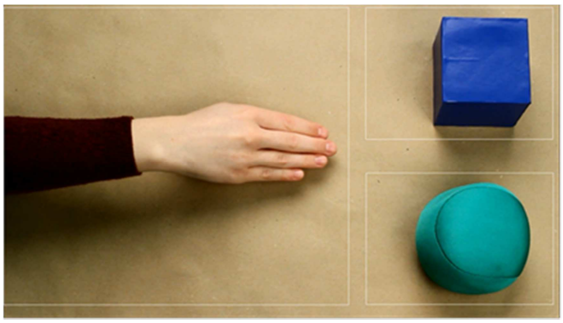


Figure 8. AOIs of the hand-paradigm for the analyzation according to Cannon and Woodward (2012).

2.4.4 Discussion

The second study investigated two questions: (1) Do children and adults anticipate an action of a non-human agent and human agent based on the previously observed goal instead of the previously observed movement path? (2) Do children and adults show similar processing strategies regarding goal encoding for two different paradigms? To this end 11-month-olds, 32-month-olds and adults were presented with two different paradigms. One presented a human hand reaching for one of two objects and the other presented an animated animal walking to one of two goals. Both followed a similar paradigm as described in Study 1a with a previous familiarization phase and a subsequent test phase in which the position of the goal objects were swapped. Results revealed that when the location of targets had changed, 11-month-olds and 32-month-olds did not perform goal-directed anticipations for both types of actions. This is surprising, since we expected goal anticipations for human actions from early on (Cannon & Woodward, 2012; Meltzoff, 1995; Woodward, 2005). Instead we observed for 11-month-olds chance performance when presenting the action performed by the hand. Considering the path paradigm with the animated agent, 11-month-olds looked longer towards the familiarized path leading to the novel goal. Hence results are similar to

Study 1a and Daum et al. (2012). Together with the experiments of Study 1a, our results are not in line with those by Cannon and Woodward (2012) and do not support theoretical claims (e.g., Woodward, 2009a) that the ability to flexibly anticipate other's action goals emerges in infancy. Rather, they support approaches that assume that early action understanding is a multi-faceted construct that involve different kinds of processes and mechanisms (Uithol & Paulus, 2014).

32-month-olds showed a looking bias in both paradigms towards the old path. On the one hand, this is noteworthy, as not even older children visually anticipated the goal of a human action. Yet, even previous research reported a mixed pattern of goal anticipations for human actions in toddlers (Krogh-Jespersen et al., 2015; Krogh-Jespersen et al., 2018). The performance in the path paradigm is in accordance to previous findings (Daum et al., 2012) and our hypothesis. Our results imply that 11-month-olds and 32-month-olds are not able to anticipate goals of non-human actions. This does not support the theoretical claim that infants understand goal-directed actions of non-human actions from early on (Luo & Baillargeon, 2005). The correlational analysis confirmed that children do not use the same processing strategies when observing a human or animated animal, as we didn't find any significant correlations between the paradigms.

In sum, our results cannot confirm the widely made assumption that children perceive human actions based on their goals (Ambrosini et al., 2013; Cannon & Woodward, 2012; Falck-Ytter et al., 2006; Woodward, 1998). Quite the contrary, the findings suggest that infants process actions based on visuo-spatial information and represent actions as movement patterns. Thus, our findings support low-level accounts of social understanding, indicating that infants make use of simple information when they process actions, such as statistical regularities (Daum, Wronski, Harms, & Gredebäck, 2016; Ruffman, 2014; Uithol & Paulus, 2014). Further we did not find any correlations within children between the two paradigms, which speaks against the claim that children process human und non-human actions similarly from early on (Leslie, 1995; Luo & Baillargeon, 2005).

Adults reacted according to our expectations in the path paradigm: They fixated the novel path leading to the familiarized goal first. Surprisingly adults showed contradicting anticipations in the hand-paradigm; they expected the hand to grasp the novel object. Thus, they encoded the movement trajectory instead of the action goal. This is interesting, since the goal of the actor should be clear at least for adults. However, so far there is only one study that tested the paradigm of Cannon and Woodward (2012) in adults. Pfundmair and colleagues (2017) found that adults anticipated the goal of a grasping hand as well as of a grasping claw, which is in contrast to our findings. Given this contradiction and lack of prior studies within adults, further investigation is needed. Maybe this paradigm is not equally suitable for adults as it might be for children (i.e. measuring the same underlying ability).

Interestingly, in our study we found a positive correlation between adults' looking times in the two paradigms, which indicates that they demonstrated related processing strategies for the two types of stimuli. Ramsey and Hamilton (2010) showed in a fMRI-study that adults process goal-directed actions of a triangle similar to goal-directed grasping actions of a human hand. They concluded that the fronto-parietal network, which is often referred to as the human mirror neuron system, actually encodes goals rather than biological motion (Ramsey & Hamilton, 2010). Similar assumptions have been made by Schubotz and Cramon (2004), who found activity in motor areas for abstract, non-human stimuli. One assumption would be that the role of experience influences participants' performance in the two tasks (Ruffman et al., 2012). Adults probably gained more experience with animations and cartoons throughout their life, whereas infants are still not well familiarized with them.

2.5 Meta-Analysis

In the previously described studies, we conducted six similar experiments that measured whether infants between 11- and 12-months of age anticipate the goal of an action instead of the movement path. Infants performed in none of the six experiments visual anticipations towards the goal, questioning the theoretical claim that infants selectively encode and anticipate other's action goals (Cannon & Woodward, 2011; Woodward, 1998). Instead we observed the tendency of infants to anticipate the movement path. In order to produce a more reliable estimate of the observed looking bias towards the location, a meta-analysis was conducted. We wanted to find out whether this effect is significant over all of our six experiments.

2.5.1 Method

Effect sizes. Effect sizes for the meta-analysis were expressed as correlation coefficients, *r*. This metric was chosen, as correlation coefficients are easier to interpret and compared with other metrics (Field, 2001; Rosenthal, 1991). The experiments of Study 1a were treated as single studies for the meta-analysis. As we wanted to see whether the effect of infants making location- instead of goal-directed anticipations is significant over all experiments, we used for each experiment of Study 1a the effect size of the comparison between location and goal-directed anticipations in test-trials. This resulted in five effect sizes for each experiment of Study 1a (see Table 6 for effect- and sample sizes). For Study 1b we used the mean effect size of both paradigms of the First Fixation Score, following Rosenthal's (1991) suggestion for cases when there are more effect sizes within a study. As the effect sizes of Study 1a are based on infants' first fixations, we did not include the Differential Looking Score of Study 1b in this analysis. In Study 1b, the direction of infants' looking bias was measured via one-sample *t*-tests, which is why we used the effect-sizes thereof (see Table 6).

Method of meta-analysis. We assume that our sample sizes come from the same population and expect our sample effect sizes to be homogenous, since all our experiments are similar and collected from similar populations. According to this we decided on a fixed-effects model instead of a random-effects model, as suggested for these circumstances by Field and Gillett (2010). For calculating the fixed-effects model, the approach by Hedges and colleagues (Hedges & Olkin, 1985; Hedges & Vevea, 1998) was used. The analysis was calculated via written syntax for SPSS (see Field & Gillett, 2010).

2.5.2 Results

The mean effect size based on the model was -.24 with a 95% confidence interval (CI_{95}) of -.38 (lower) to -.09 (upper) and a highly significant z score ($z = 3.07$, $p = .002$). According to Cohen's criterion (1988) this is a small to medium effect. A chi-square test of homogeneity of effect sizes was not significant, $\chi^2(5) = 1.51$, $p = .912$. This supports our previous assumption of a low between-study variance indicating that our participants are sampled from the same population.

To illustrate infants' looking bias towards the location instead of the goal over all experiments, the number of anticipations towards the location versus the goal was summed up over all six experiments. From a total of 681 anticipations, infants directed 423 anticipations towards the location whereas 258 anticipations were performed towards the goal.

Table 6. Effect sizes used for meta-analysis and number of participants per experiment

Experiment	Effect-size *r*	Number of participants
Study 1a		
Experiment 1	-.31	24
Experiment 2	-.16	24
Experiment 3	-.18	32
Experiment 4	-.4	32
Experiment 5	-.19	32
Study 1b	-.18	34

2.5.3 Discussion

The meta-analysis aggregated data from178 participants over all six experiments and demonstrated that samples of 11- to 12-month old infants show anticipations directed towards the path of an action and not to its goal, with a small to moderate magnitude. This result underlines the previous findings of Study 1a and Study 1b, and highlights the conclusion of our findings: Through all our 6 experiments we were not able to find a goal-directed looking bias within 11- to 12-month-olds. Rather, we observed anticipations of infants towards the location indicating that infants encode the movement path instead of the goal of an action. This is further discussed in the next section.

2.6 General Discussion

The present work addresses the question of whether and under which circumstances children and adults flexibly anticipate actions as goal-directed. It has been claimed that infants show visual goal anticipations earlier for human than for non-human actions (Meltzoff, 1995; Paulus, 2012; Ruffman et al., 2012; Woodward 2005), whereas others proposed that infants are able to anticipate goals for non-humans equally well as for humans (Leslie, 1995; Luo & Baillargeon, 2005). Cannon and Woodward (2012) demonstrated that 11-month-old infants are able to encode an action of a human hand, but not of a mechanical claw as goal-directed. In contrast, Daum and colleagues (2012) could only find goal-directed anticipations within children from 3 years of age and adults, when using an animated agent instead of a human hand. With the current set of studies, we aimed to contribute to the current debate on infants' goal anticipations by exploring whether infants indeed anticipate actions flexibly based on goals rather than based on movement paths and patterns. Two different labs collaborated over the attempt to replicate both conceptually and directly the findings reported by Cannon and Woodward (2012). We hypothesized that infants understand human actions earlier than actions of a non-human animated agent. Therefore, we expected to replicate the findings of Cannon and Woodward (2012) in our experiments that used a human hand as agent but not necessarily in the experiments that used non-human animated animals as agents.

However, despite our systematic variation of any other factors that could have had an influence on infants' action perception (such as type of agent, presence of an occluder or number of learning- and test trials), we failed to replicate the findings of Cannon and Woodward (2012) across all our experiments and labs. Infants between 11 and 12 months of age did not anticipate an action in relation to its goal, but rather on its movement path. This was observed, irrespective of whether the agent was a human or an animated animal. We even included an experiment that was as close as possible based on the stimuli of Cannon and

Woodward (2012) and were not able to replicate their finding. A meta-analysis aggregated over all of our data emphasizes our result and illustrates a consistent effect for a looking bias towards the location and not the goal within 11- and 12-month-olds.

The finding, that infants base their anticipations on the movement path relates to previous eye-tracking studies (e.g. Paulus et al., 2011; Schuwerk & Paulus, 2015) and further stresses the role of frequency information for infants' action processing. Our results underlie the claim that already infants are able to detect contingencies and regularities in their environment, as supposed to be an important learning mechanism (Kirkham et al., 2002; Ruffman et al., 2012; Smith & Yu, 2008).

Does this mean that infants do never show flexible goal-directed anticipations? It should be noted that the paradigm by Cannon and Woodward (2012) presented participants with a scene of two objects placed on a white background and a hand that appears from the left side to grasp one of them. This scene is filmed from a birds'-eye view and does not include the whole situation, namely an agent sitting on a table in front of two targets. Theoretically, it has been proposed by predictive coding accounts that active perception is informed by environmental features (e.g. Clark, 2013a). Also studies with infants could demonstrate the informative influence of context information on infants' action anticipations (Fawcett & Gredebäck, 2015; Stapel, Hunnius, & Bekkering, 2012). Usual situations in our environment provide us with lots of information that is already there before an action takes place, and thus open room for top-down influence before an action is performed (Clark, 2013a). Thus, it is possible that the situation in the Cannon and Woodward-paradigm (2012), as well as in our experiments, might be too abstract and out of context. The fact that we also couldn't find goal-directed anticipations for adults adds additional concern towards this paradigm. However, adding more ecological cues might help infants. Other studies reported goal anticipations within infants when they were presented with a movie depicting the entire human agent grasping for an object (Kim & Song 2015; Krogh-Jesperson & Woodward, 2014, 2018; Krogh-Jesperson et al., 2015). Furthermore, there are studies demonstrating goal anticipations in infants and toddlers when they had the possibility to learn about the agent's goal (Paulus, 2011; Paulus et al., 2017). For example, in Paulus et al.'s study (2017), children observed an agent walking to a goal for several times whereas the goal's position changed from time to time. This highlighted the goal object on the expense of the movement path (see also Ganglmayer, Schuwerk, Sodian, & Paulus, 2019). In sum these findings suggest that infants might need additional information in order to visually anticipate the goal and not the movement path.

Another possibility relates to cultural factors. While the study of Daum et al. (2012) and the current studies were implemented in Europe, the study of Cannon and Woodward (2012) was conducted in the U.S. A comparison of various studies on children's TV consumption suggests that infants watch more TV in the U.S. than in Europe (Feierabend & Mohr, 2004; Zimmerman, Christakis, & Meltzoff, 2007). In an additional pilot study, we asked 22 parents of 12-month-olds about the average time their infants watch TV. Results showed that only 23% of the 12-month-olds watch TV and for an average time of 4 minutes. In comparison, Zimmerman et al. (2007) reported that infants in the US spend on average an hour per day in front of a TV screen. Given the fact that prior experience with technology and real objects increases learning through TV (Hauf, Aschersleben, & Prinz, 2007; Troseth, Saylor, & Archer, 2006), it is possible that different experiences with TV and screens could be a reason for our diverging findings. Yet, on the other hand, since we did not find goal-related anticipations in 32-month-olds or even adults (Study 1b) who arguably have ample experiences with TV, this factor is rather unlikely to be the central cause underlying our non-replication.

Our work highlights the importance for replication studies in developmental psychology, as recently researchers warned of false positive findings and publication biases. Recent attempts to replicate findings of implicit Theory of Mind tasks turned out difficult as well (e.g. Burnside, Ruel, Azar, & Poulin-Dubois, 2017; Kammermeier & Paulus, 2018; Kulke, Reiß, Krist, & Rakoczy, 2017; Powell, Hobbs, Bardis, Carey, & Saxe, 2017). Some specifically tried and failed to replicate an implicit Theory of Mind task based on anticipatory looking measures, questioning the robustness of these tasks (Kulke, von Duhn, Schneider, & Rakoczy, 2018; Schuwerk, Priewasser, Sodian, & Perner, 2018). One strength of the present manuscript concerns the integration of work conducted at two different labs. Such a collaborative effort is not only in line with suggestions for future best practices (e.g. Frank et al., 2017), but also increases the conclusiveness of our results.

In sum, our findings over various types of stimuli and across two labs suggest that infants around 11 and 12 months of age do not flexibly anticipate an action based on its goal, but primarily use the information about the movement path, when presented with two possible targets that change location for test trials (following Cannon & Woodward, 2012). This indicates that infants base their anticipations on frequency information (similar to Henrichs et al., 2014). When they observe an action performed in a certain way, they use this information to predict that action in the future (Ruffman, 2014). However, infants in their first years of life seem to process this information in relation to movement paths (Paulus et al., 2011). Our findings also imply that we need to reflect on what we exactly mean when we say that infants understand goals, as a goal, in its general meaning, refers to a desire (Ruffman et al., 2012; Uithol & Paulus, 2014). In conclusion, according to our six experiments, infants do not flexibly anticipate action goals around 12 months. Rather, their anticipation of others' actions might rely on more simple heuristics, such as movement trajectories.

3 Study 2: Do Children and Adults with Autism Spectrum Condition Anticipate Other's Actions as Goal-Directed? A Predictive Coding Perspective

3.1 Abstract

An action's end state can be anticipated by considering the agent's goal, or simply by projecting the movement trajectory. Theories suggest that individuals with autism spectrum condition (ASC) have difficulties anticipating other's goal-directed actions, caused by an impairment using prior information. We examined whether children, adolescents and adults with and without ASC visually anticipate another's action based on its goal or movement trajectory by presenting participants an agent repeatedly taking different paths to reach the same of two targets. The ASC group anticipated the goal and not just the movement pattern, but needed more time to perform goal-directed anticipations. Results are in line with predictive coding accounts, claiming that the use of prior information is impaired in ASC.

3.2 Introduction

When we interact with others, we spontaneously respond to their actions. For example, we anticipate who is next to speak in a conversation, or we predict where people are heading when crossing a busy street and move out of their way to avoid a collision. Similarly, we efficiently infer another's action goal. If our counterpart reaches for her cup, we anticipate that she is going to take a sip. A fair amount of research posits that people with autism spectrum condition (ASC) have difficulties making action anticipations and representing goal-directed behaviors (e.g., Chambon et al., 2017; Zalla et al., 2006; for an overview see Schuwerk & Paulus 2018). These difficulties are often linked to core ASC symptoms; some suggested that altered action anticipation is the cause of social interaction and communication deficits in

ASC (Sinha et al., 2014). Here, we investigated these difficulties in action anticipation more profoundly. In particular, we examined whether –and if so, how– individuals with ASC are impaired in their ability to anticipate actions as goal-directed. More specifically, we explored what information they base their anticipations on: Do they learn the specific action goal or do they anticipate the mere spatiotemporal movement trajectories after frequent observation?

Theories regarding anticipatory abilities in ASC follow two different theoretical directions. On the one hand, domain-specific conceptual theories see impairment specifically in the social domain. They argue that an inability to attribute intentional states and goals to others lies at the core of ASC (e.g. Frith et al., 1991). It is claimed that individuals with ASC are impaired in anticipating other's actions, as they have difficulties inferring other people's intentions and goals. However, empirical evidence so far is not fully compatible with this hypothesis (Hamilton, 2009; see also Schuwerk & Paulus 2018), as individuals with ASC perform equally well as typically developed persons on some goal-anticipation tasks (e.g., Falck-Ytter, 2010), but have problems in others (e.g., Zalla et al., 2006). For example, Zalla and colleagues (2006) showed that adolescents with ASC have difficulties sequencing goal-directed actions in a picture-story task. This implies that domain-specific theories cannot explain ASC-symptomatology sufficiently and suggests that subtler domain-general accounts, that imply a general cognitive deficit in predictive abilities, whether social or not, are needed to explain social cognitive characteristics in ASC.

It was recently proposed that individuals with ASC have difficulties with action predictions because they have problems estimating conditional probabilities (e.g., calculating the probability of event B following event A) in their environment (Sinha et al., 2014). This hypothesis is confirmed by findings demonstrating reduced motor anticipations in ASC (Brisson et al., 2012; Hughes, 1996; Schmitz et al., 2003). For example, infants (which were later diagnosed with ASC) did not open their mouth as regularly as comparison participants in anticipation of being spoon-fed (Brisson et al., 2012). However, the picture becomes less clear considering the perception of motion. Empirical findings on whether action anticipation abilities differ between people with and without ASC over various age groups are mixed (Braukmann et al., 2018; Cusack et al., 2015; Murphy et al., 2009; Schuwerk et al., 2016; von Hofsten, Uhlig, Adell, & Kochukhova, 2009).

Complementary to this account, Ruffman (2014) suggested that individuals with ASC have problems with statistical learning. He argues from a developmental perspective and claims, similar to Sinha et al. (2014), that statistical regularities help us to make sense of the world and that they are essential for developing a Theory of Mind; early spontaneous or implicit understanding of others' actions precedes later explicit intention understanding (see also Paulus, 2012). If we see someone performing an action in a certain way, we use this information to anticipate that action in the future. Studies on non-social implicit learning tasks draw an incoherent picture though; some report no difference between people with and without ASC (Barnes et al., 2008; Roser, Aslin, McKenzie, Zahra, & Fiser, 2015), whereas others found weaker implicit learning skills (Kourkoulou, Leekam, & Findlay, 2012; Mostofsky, Goldberg, Landa, & Denckla, 2000).

In an action-anticipation study by Schuwerk and colleagues (2016), individuals with ASC could not make use of the repeated presentation of an agent's behavior when making action anticipations as effectively as typically developed participants. In their study, children and adults were presented with videos of an agent aiming for one of two paths to reach a goal. One path was shorter, the other was longer. At the crossroad, where the path divided into the two possibilities (short vs. long path), an occluder was overlaid to trigger anticipatory eye movements and measure this visual anticipation of the agent's reappearance. Participants saw four repetitions of the agent who always took the short path. Children and adults without ASC increased their correct action anticipations during the repeated presentation of this action. In contrast, children and adults with ASC did not increase their correct anticipations as much, which suggests that the ability to use prior information to anticipate other's actions is attenuated in ASC. However, it remains unclear whether individuals with ASC are generally impaired in statistical learning or whether they just need more repetitions to learn from past experience.

Similarly, predictive coding theories postulate atypical predictive processing in ASC; in accordance with the two approaches described above, they also suggest an inability to use prior information in ASC to make predictions about their environment. While the predictive coding approach has its origins in visual perception, it further differs from the other two accounts (Sinha et al., 2014; Ruffman, 2014) in its proposed underlying mechanism. More precisely, predictive coding theories claim that the perception of one's environment is not only guided by plain sensory input, but also biased by our expectations on what the world looks like (Clark, 2013a). Through a hierarchically structured system, our brain continuously compares incoming sensory information (bottom-up) with downward predictions (top-down). Information that does not match is reported backwards as a prediction error in order to adjust and improve future predictions. Pellicano and Burr (2012) claim that individuals with ASC have problems using prior information for executing downward predictions and that sensory input dominates their perception. Similar suggestions have been made by others (Brock, 2012; Mottron et al., 2006; Van de Cruys et al., 2014). Their claims fit well with observed behaviors in ASC, such as insistence on sameness or repetitive movements. Since individuals with ASC are, according to predictive coding theory, impaired in predicting upcoming events, they need additional exposure to stimuli in order to become comfortable with them. Their desire for sameness could be the result of coping with or avoiding these constant uncertainties. Also, repetitive movements such as finger flipping or rocking might be a result of the drive to minimize uncertainty (Pellicano & Burr, 2012).

The predictive coding account could also explain social interaction problems in ASC. Given that social situations are complex and often uncertain, we have to rely more on our priors when predicting other agents (Lawson et al., 2014). Chambon et al. (2017) found that adults with ASC rely to a lesser extent on prior beliefs, namely the belief that people tend to act reciprocally towards each other; when one acts cooperativelly, the other would too. In this task, participants had to infer the intention of one or two actors that manipulated objects. They could either rely on visuo-motor information (when only one actor was present) or on prior social beliefs (when two actors were present). Individuals with ASC did not have problems making inferences relying on visuo-motor information, but demonstrated difficulties inferring intentions based on prior information that was social (i.e. the two actors acting reciprocal).

However, since most studies on predictive coding in ASC focus mainly on visual perception, empirical findings regarding action processing are rare. Research in this area is also becoming increasingly important for the development of new behavioral and cognitive training programs, as well as for the improvement of diagnostic tests (Haker et al., 2016). The goal of behavioral treatments is to change behavior and improve social and communication skills, as well as fostering a better general functioning (Jensen & Sinclair, 2002). Predictive coding theory offers information on how to gain best improvement within individuals with ASC, for example that it is important during training to keep social situations very simple at the beginning and to expose individuals with many repetitions over a longer period of time. Predictive coding theory could further be a valuable tool for psycho-education within ASD. According to Haker et al. (2016) it already helped their autistic participants to better understand their own symptoms, as the theory explains both behavioral and perceptual aspects. The theory can also help in creating diagnostic tests for ASD that are more sensitive and suitable for adults. So far available tests are often not sensitive enough to diagnose autism in adults, as symptomatology is often concealed by acquired coping strategies. Perceptual peculiarities within adults with ASD may thus not be obvious, which is why more subtle diagnostic tools are necessary (Haker et al., 2016; Van de Cruys et al., 2014). More studies on this issue would be helpful in order to inform recent theories and to improve the current clinical situation for individuals with ASC.

On the basis of these three theories, we examined whether individuals with ASC use prior information as well as typically developed people when making action anticipations. Moreover, we specifically investigated if they encode the particular goal of the action. Since anticipating other's action goals is related to social competencies in typically developed children (Krogh-Jespersen et al., 2015), altered goal understanding in ASC could be a possible cause for social interaction and communication difficulties (Krogh-Jespersen et al., 2018; Zalla et al., 2006; Zalla et al., 2010). These considerations are very well linked to other prominent theories of socio-cognitive deficits in ASC (e.g. Frith et al., 1991). Only a few studies have directly addressed goal anticipation in ASC so far (e.g., Zalla et al., 2006). For example, in an eye-tracking study, two-year-old children with ASC did not anticipate a manual reaching action based on its goal but on its movement path (Krogh-Jespersen et al., 2018). Based on Woodward's (1998) influential looking-time paradigm, children were familiarized with a human actor reaching for one of two objects. In the test trials, the objects' position changed places and participants observed an uncompleted reaching action, as the hand stopped before completing the movement. In contrast to the comparison group, children with ASC anticipated the actor to reach for the other object in the old location. This implies that children with ASC processed the spatiotemporal movement pattern instead of the action goal. When the context changes and participants are confronted with the changed position of the targets in the test trials, individuals with ASC might generate their anticipations based on the spatiotemporal information and not on the goal. The changed position of the objects and the incomplete movement confronts participants with a decision: Is the hand going to take the same path or is it going to reach towards the same goal? What we do not know from this task is whether children did not process the goal of the action at all or whether the information of the movement path dominated over the information of the goal.

Studies using simpler paradigms, which require processing of both types of information simultaneously, report equal performance between individuals with and without ASC (see Hamilton, 2009, for a review). For example, 5-year-olds and adults with ASC accurately anticipated the movements of a hand placing objects into a container (Falck-Ytter, 2010). However, this setup only included one possible action goal. Individuals with ASC could have based their anticipations on the movement of the hand and/or on the goal (container). Thus, conclusions on whether anticipations were based on movement trajectories or the action goal are not possible. Individuals with ASC could have simply relied on the spatiotemporal information.

In sum, these findings suggest that individuals with ASC are able to anticipate an action, when they can rely on movement information or speed, such as transporting balls into a bucket (Falck-Ytter, 2010) or bringing a phone to the ear (Braukmann et al., 2018). As was demonstrated by Krogh-Jespersen et al. (2018), movement information seems to be a strong source of information in ASC when anticipating actions. However, this does not tell us whether individuals with ASC do not process the goal of the action at all. Uithol and Paulus (2014) claimed that anticipating an action is more difficult when two possible goals are available because then additional information is necessary to anticipate the action. Are individuals with ASC able to anticipate an action when they cannot only rely on movement patterns, but have to process the specific action goal? No study has yet investigated whether individuals with ASC anticipate an action as goal-directed in a context in which they are provided with enough cues about the agent's goal and cannot just rely on movement information.

Previously outlined theoretical notions claim that one's own experiences have an impact on anticipating other's actions (Clark, 2013a; Ruffman, 2014). According to that, older participants have more lifelong experience and, under a predictive coding point of view, also more chances to improve their top-down predictions, such as that "agents act towards goals". Empirical evidence so far suggests that individuals with ASC seem to have some basic goal-encoding abilities of other's actions, although these abilities seem to show restrictions when situations become more complex (Hamilton, 2009). Previous studies on goal anticipation in ASC so far mostly include young children ranging from 10 months (Braukmann et al., 2018) to five years of age (Falck-Ytter, 2010). We do not know whether and to what extent these goal-directed anticipatory abilities might still develop throughout adolescence in a more complex setup. It could further be that the ability for statistical learning is still improving between childhood and adulthood in ASC, as is the case for neurotypical individuals (see Schuwerk & Paulus, 2015). Moreover, deficits in Theory of Mind are less evident in older aged individuals with ASC, suggesting improvement of social cognitive abilities over the course of life (Lever & Geurts, 2016). Studies that include a wide age range of individuals with ASC are needed to investigate socio-cognitive developmental changes from childhood into adulthood.

The current study addressed two questions: First, do children, adolescents and adults with ASC anticipate another agent's action in a task which requires goal understanding and cannot be solved by simply anticipating previously observed movement patterns? Second, given the claim that individuals with ASC have problems using prior information (Ruffman, 2014; Pellicano & Burr, 2012) we wanted to investigate whether frequent repetitions of an action lead to an increase in goal-directed action anticipations. When individuals with ASC observe an agent reaching a goal numerous times, are they able to use that information to make action anticipations, indicating statistical learning in the domain of action goals?

The paradigm from Paulus et al. (2017, experiment 3) was employed for the present study, which allowed us to address these questions in a sample of participants with and without ASC. Participants observed an agent always walking to one of two goals, whereas the goal's position varied between trials. If individuals with ASC do consider the agent's goal and do not only rely on spatiotemporal movement information when anticipating actions, we should observe goal-directed action anticipations in participants with ASC. However, according to predictive coding theories (e.g., Pellicano & Burr, 2012) and the statistical learning approach (Ruffman, 2014), we hypothesized that individuals with ASC have problems using prior information and therefore expected that they need more time to learn the action goal than typically developed participants. We further expected higher performance with increased age, since lifelong experience might improve top-down predictions. Given the claim that individuals with ASC generally have problems anticipating other's actions (Schuwerk et al., 2016; Sinha et al., 2014), we predicted that individuals with ASC show less anticipations than typically developed individuals, regardless of whether or not their anticipations were goal-directed.

3.3 Method

The data of the study is available online at the following link, https://osf.io/dqt6w/?view_only=340895d63ba242278f1faf90451772ae. Due to protection of data privacy and to prevent inferences on individual data, demographic information is not shared in this data set. Only preprocessed eye-gaze data is provided.

Participants

The final sample included 143 participants in total. The participants or their caregivers gave informed written consent before starting the procedure. The study was approved by the local ethics board. To be included in the ASC group, participants had to provide a medical certificate containing proof of an ASC diagnosis according to the International Classification of Diseases-10th Revision criteria (World Health Organization, 1993) by a qualified clinical psychologist or psychiatrist. Participants from the ASC group were recruited via local associations, clinics and private-practice physicians. The comparison group was recruited via birth-records or from our lab's participant pool. Participants came from a larger city in Germany. Travel costs were reimbursed. Additionally, adult participants received payment for participation and children received individual presents.

Children and Adolescents. Thirty children with ASC (mean age = 9.73 years, *SD* = 1.86) and 29 comparison children (mean age = 9.34, *SD* = 1.72) took part in the study. Seventeen children from the ASC group were diagnosed with Asperger Syndrome, 6 children with childhood autism, 2 with atypical autism and 5 with high-functioning autism. From the children without ASC, one was diagnosed with an attention-deficit hyperactivity disorder (ADHD), one with an attention deficit disorder and dyslexia, one with specific phobias, one with an adaption disorder and one child was diagnosed with a sensomotoric processing disorder. Since these are all highly comorbid conditions of ASC, children with these conditions were included in the comparison group to guarantee close matching of the participants (Schwartz & Susser, 2011). Choosing a comparison group that only includes healthy individuals (often referred to as "well controls") is not an adequate representation of the general population, leading to bad validity and creating bias (Schwarz & Susser, 2011). Further, preliminary analyses have revealed the same pattern of results for all three age groups, when individuals from the comparison group, who reported such conditions, were excluded.

The adolescent sample comprised 19 participants for the ASC group (mean age = 15.05, *SD* = 1.54) and 19 for the comparison group (mean age = 15.11, *SD* = 1.33). One additional adolescent of the ASC group had to be excluded as no IQ measure could be obtained. Ten of the adolescents with ASC were diagnosed with Asperger Syndrome, five with childhood autism, two with atypical autism, one with high-functioning autism and one with Asperger Syndrome and high functioning autism. For the comparison group, no psychiatric diagnoses were reported.

To assess verbal and nonverbal IQ, children and adolescents were tested with either four subtests of the Wechsler-Intelligence Scale for Children (WISC-IV; Wechsler, 2003; German version by Petermann & Petermann, 2007), or the same subtests of the Wechsler-Intelligence Scale for Adults (WAIS-IV; Wechsler, 2008; German version by Petermann, 2013), namely “vocabulary”, “similarities”, “matrix reasoning” and “picture completion”. These subtests were used as this is the minimum number of subtests necessary to get an estimate of verbal and nonverbal IQ score. For adults, different tests were used as measures for verbal and nonverbal IQ (see below). Additionally, caregivers filled the German adaptions of the Social Responsiveness Scale (SRS), to measure autistic traits (German version by Bölte & Poustka, 2008), and the Social Communication Questionnaire (SCQ), a screening to assess communication skills and social functioning across the whole lifetime (*lifetime form*) and in the most recent 3 months (*current form*; Rutter, Bailey, & Lord, 2001; German version by Bölte & Poustka, 2006). Independent samples *t* tests revealed no group differences in verbal and non-verbal IQ as well as for age. As expected, the groups differed in their SRS and SCQ scores. See Table 7 for descriptives of the measures and detailed results of the group comparison.

Table 7. Mean scores with standard deviations and range in brackets of the demographics and control measures for children, adolescents and adults with ASC and neurotypicals. Independent-groups t tests present comparison between the two groups

	ASC	**NT**	**Group comparison**		
			***t* value**	***p* value**	**Cohen's *d***
Children					
Sample size	*n* = 30	*n* = 29			
Age in years	9.73 (1.86; 5-13)	9.34 (1.72; 5-12)	*t*(57)=0.83	.408	0.22
Verbal IQ (WISC-IV)	109.93 (14.83; 88-152)	105.59 (13.88; 81-136)	*t*(54)=1.13	.263	0.31
Non-verbal IQ (WISC-IV)	104.23 (15.29; 67-131)	111.86 (15.02; 88-147)	*t*(57)=-1.93	.058	0.51
SRS T-Score	84.80 (10.30; 62-100)	47.04 (9.43; 25-70)	*t*(56)=14.53	<.001	3.88
SCQ current form sum score	16.80 (6.19; 3-33)	6.07 (3.85; 0-14)	*t*(49.18)=7.94	<.001	2.26
SCQ lifetime form sum score	23.57 (8.27; 5-38)	6.54 (3.75; 0-14)	*t*(41.04)=10.22	<.001	3.19
Adolescents					
Sample size	*n* =19	*n* = 19			
Age in years	15.05 (1.54; 13-18)	15.11 (1.33; 13-17)	*t*(36)=-0.11	.911	0.04
Verbal-IQ (WISC-IV)	101.79 (21.24; 53-134)	108.05 (12.14; 93-136)	*t*(36)=-1.12	.272	0.37
Non-verbal IQ (WISC-IV)	103.32 (22.12; 45-135)	115.53 (17.32; 90-147)	*t*(36)=-1.90	.066	0.63
SRS T-Score	82.95 (12.41; 59-100)	45.32 (12.58; 23-70)	*t*(36)=9.28	<.001	3.09
SCQ current form sum score	15.00 (8.03; 4-37)	6.89 (3.50; 0-13)	*t*(24.87)=4.02	<.001	1.61
SCQ lifetime form sum score	20.79 (6.48; 10-39)	4.84 (3.22; 0-10)	*t*(36)=9.61	<.001	3.20
Adults					
Sample size	*n* = 22	*n* = 24			
Age in years	33.86 (13.10; 19-63)	38.46 (14.55; 20-67)	*t*(44)=-1.12	.268	0.34
Verbal IQ (MWT-B)	113 (15.18; 75-136)	117.96 (17.42; 92-145)	*t*(44)=-1.03	.311	0.31

Non-verbal IQ (CFT-20-R)	103.14 (21.65; 54-142)	108.25 (14.88; 90-145)	$t(44)=-0.94$	.352	0.28
AQ (short form)	21.41 (7.98; 5-32)	5.67 (3.25; 0-12)	$t(27.31)=8.62$	<.001	3.30

Note:
ASC = Autism Spectrum Condition
NT = Neurotypical comparison group
WISC-IV = Wechsler-Intelligence Scale for children, 4th edition
SRS = Social Responsiveness Scale
SCQ = Social Communication Questionnaire current form / lifetime form
MWT-B = Mehrfachwahl-Wortschatztest (German multiple choice vocabulary test)
CFT-20-R = Culture-Fair Test 20-R (non-verbal IQ regarding general mental capacity)
AQ = Autism-spectrum quotient (short form; cut-off criterion: Score ≥ 17)

Adults. The adult sample comprised 22 participants in the ASC group (mean age = 33.86, *SD* = 13.10) and 24 in the comparison group (mean age = 38.46, *SD* = 14.55). One adult of the comparison group reported a suspected diagnosis of ASC and was therefore excluded. Another two adults of the ASC group were excluded due to missing demographic data and control measures. From the ASC group 18 adults were diagnosed with Asperger Syndrome, three with atypical autism and one with high-functioning autism. One participant from the comparison group was diagnosed with depression and one reported burn-out. As in the children comparison group, these two participants were not excluded from analysis due to better matching of the groups. For an estimation of verbal IQ, a vocabulary test was used (Mehrfachwahl-Wortschatz-Intelligenztest, MWT-B; Lehrl, 2005). For non-verbal IQ the Culture-Fair Test 20-R (CFT-20-R; Weiß, 2006) was implemented. Additionally, adults filled the short form of the autism-spectrum quotient (AQ; with a cut-off criterion of score ≥ 17; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001; German version by Freitag et al., 2007) to evaluate autistic traits. The groups significantly differed in their AQ scores, but not in age or IQ (see Table 7).

Stimuli

The stimulus material included one introductory movie and ten test movies. The movies had the size of 1280x1024 pixels and were created with Adobe CS 5.5 (Adobe Systems Inc., San Jose, CA).

First, an introductory movie was presented to familiarize participants with the setup and the occluder. The movie included a rabbit that was sitting at the end of a horizontal path leading from the right side to the left side of the screen. A transparent occluder was situated in the middle of the path. As the occluder turned opaque, a voice stated “Look, the rabbit” and the rabbit started to move to the other side of the path through the occluder.

The other ten movies contained a path that was leading to two different goals, namely a house and a forest (see also Figure 9). At the crossroad, where the path divided and led to the different goals, an occluder was overlaid. Occluders are often used in action anticipation paradigms as they facilitate anticipatory eye-movements rather than a constant fixation on the agent (cf. Paulus et al., 2011; Schuwerk et al., 2016; von Hofsten, Kochukhova, & Rosander, 2007). The agent, a pig, was situated on the left side of the path. After jumping twice in order to catch the participant's attention, the occluder turned opaque and the pig started to move towards the occluder along the path. The pig disappeared for 3.5 seconds behind the occluder and reappeared on one of the paths to walk to its goal. The movie lasted 17 seconds in total and ended after the pig reached the goal.

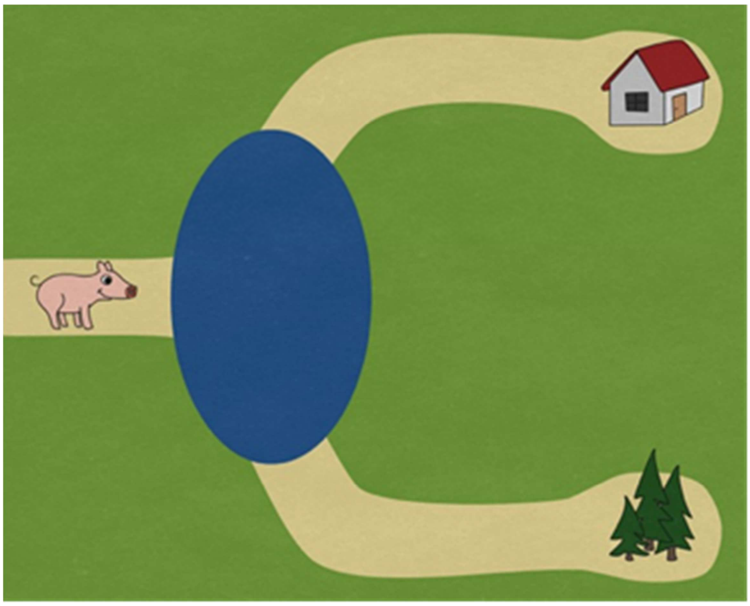


Figure 9. Example of a test movie. The agent is located at the left side of the screen. The opaque occluder overlies the crossroad between both paths. On the right side, two target objects are located.

Setting and Procedure

Participants' eye-gaze was recorded with a corneal reflection eye-tracker (Tobii T60, Tobii Technology, Sweden). Stimuli were presented on a 17-in (43.18 cm) TFT flat-screen monitor and the gaze data was recorded at 60 Hz with an average accuracy of 0.5° visual angle. For movie presentation the software Tobii Studio (Tobii Technology, Sweden) was used.

To familiarize participants with the setup of the occluder, the introductory movie was presented first. Then the ten movies, in which the agent always walked to the same one of the two goals, were shown in a row. Within participants, the position of the target object (lower or upper path) was counterbalanced throughout the ten movies in a fixed order. Thus, participants could not conclude any pattern in the objects' position, disentangling simple path learning from goal anticipations. Additionally, we counterbalanced between participants which of the objects (house or forest) served as the goal.

Measures

To define fixations and saccades, the Tobii Studio standard fixation filter was used with a velocity threshold of 35 pixels/window and a distance threshold of 35 pixels. Following previous research (Paulus et al., 2011; Schuwerk et al., 2016), two areas of interest were situated on the sections where the paths reappeared from the occluder and each occupied 10.13% of the screen. Another AOI covered the whole screen (100%) and was used to control for missing data in the other two AOIs in the test-phase. Participants' gaze behavior was measured during the time period in which the pig disappeared behind the occluder (3.5 seconds). To analyze their gaze behavior, three different measures were used. These are described below. In all three measures, the very first trial was not included into analysis, as participants could not have any expectations of the agents' goal preference for that trial.

Frequency of Action Anticipations. To assess participants' amount of anticipatory fixations over the trials to either the short or long path, irrespective of which one of the two paths they fixated, a score was calculated: A first fixation to either one of the paths was coded with 1; if participants fixated somewhere else on the screen but did not look at either one of the paths during the test phase, this was coded with 0 (Schuwerk et al., 2016).

Type of Anticipation: First Fixation Score. To analyze whether participants fixated either the path leading to the target or the other path, a First Fixation Score was generated (see e.g., Paulus et al., 2011). Therefore, a first anticipatory gaze to the path that led to the goal object was coded with 1 and a first anticipatory gaze to the other path was coded with -1. If none of the two paths were fixated during the anticipatory period (the time the pig was behind the occluder), but fixations were directed somewhere else on the screen, this was coded as 0. No fixations to the screen at all were treated as missing values. For analysis, following Paulus et al. (2017), the nine trials were grouped into three blocks, which contained three trials each (block 1 contained trial 2, 3 and 4; block 2 contained trial 5, 6, 7; block 3 contained trial 8, 9, 10).

A repeated measures ANOVA was performed with the first fixation score as the dependent variable, the within-subject-factor block (first, second, third) and the between-subject-factors age group (children, adolescents, adults) and diagnosis group (ASC, neurotypical).

Type of Anticipation: Differential Looking Score (DLS). In order to control for corrective eye-movements a DLS, which represents the relative amount of time spent on one AOI in relation to the other (see e.g., Senju et al., 2009), was calculated. Hence, the total looking time to the non-goal related AOI was subtracted from the total looking time to the goal related AOI and divided by the sum of overall total looking time to both AOIs. To investigate participants' learning behavior over time more precisely, a regression coefficient analysis was performed with the DLS as the dependent variable (Lorch & Meyers, 1990). Therefore, individual regression slopes for each participant were calculated over the nine trials and regression coefficients (intercept and slope) for each participant were extracted to compute further tests. First, one sample *t* tests were performed for each age and diagnosis group separately, to see whether intercept and slope were significantly different from zero.

For the DLS, in total 3.28% of the gaze data was missing in the experimental group. In the comparison group 1.91% of all trials had missing values. For these cases, the mean of the respective age group and diagnosis group was inserted. For the First Fixation Score, missing values were not replaced, as these scores were averaged over the trials (see results section). In total 17 participants had missing values, with a maximum of three missing trials per participant (n = 1). The other 16 participants had only one or two missing trials.

3.4 Results

Frequency of action anticipations. Individuals with ASC anticipated in 73.08% of the test trials and participants from the comparison group anticipated in 77.62% of trials. To assess participants' overall number of anticipations (irrespective of whether they fixated the path leading to the goal or the other path), a generalized estimating equations model (GEE; Zeger & Liang, 1986) was conducted with an unstructured working correlation matrix, a logit link function and a binomial distribution. Diagnosis group, age, trial and the interaction of diagnosis group with age were inserted as the predictor variables. As can be seen in Table 8, neither one of the predictors had a significant influence on the frequency of action anticipations. That is, individuals with ASC showed equal numbers of action anticipations as did neurotypical individuals.

Table 8. Results of the generalized estimating equations model with the predictors of diagnosis group, age, trial and interaction of diagnosis group and age on the frequency of action anticipations

Predictor	B	SE	Wald	*df*	*p* value	Exp(B)	95% Confidence interval for Exp(B)	
							Lower	Upper
Group	-0.39	0.52	0.55	1	0.460	0.68	0.25	1.89
Age	-0.50	0.45	1.47	1	0.225	0.61	0.27	1.36
Trial	-0.01	0.03	0.08	1	0.777	0.99	0.95	1.04
Group*Age	0.32	0.27	1.40	1	0.236	1.38	0.81	2.34

Type of anticipation: First Fixation Score. The repeated measures ANOVA revealed a significant main effect of diagnosis group, $F(1, 136) = 6.36$, $p = .013$ $\eta_p^2 = .05$, and a main effect of block, with $F(1.98, 269.79) = 10.28$, $p < .001$, $\eta_p^2 = .07$. Overall, the comparison group showed a significantly higher looking bias towards the goal-directed path (M = 0.47, SE = 0.05) than the ASC group (M = 0.31, SE = 0.05). To examine the main effect of block, Bonferroni-adjusted post hoc analysis revealed a significant difference between block one

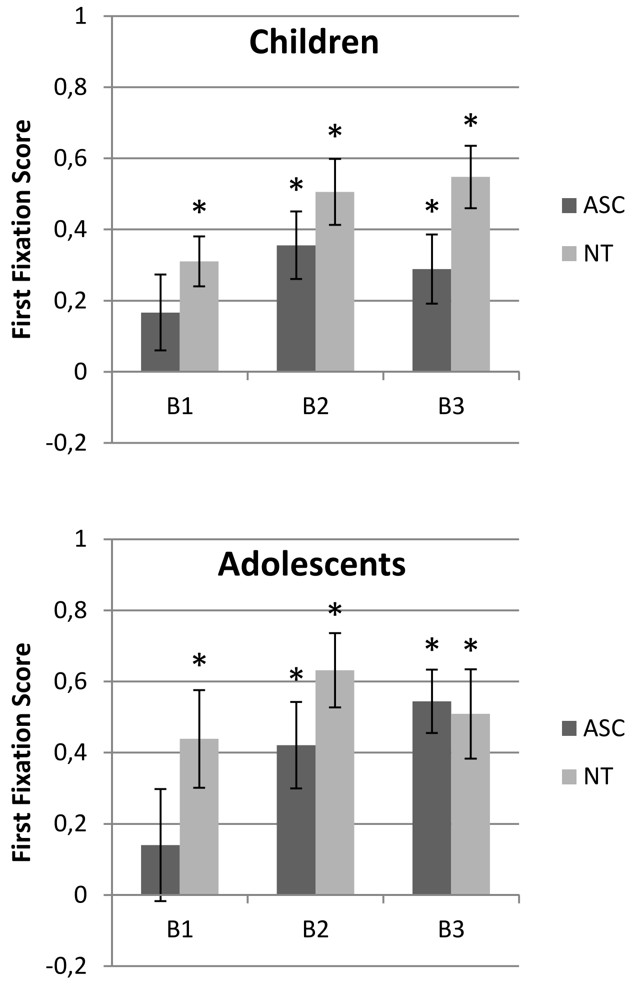
($M = 0.25$, $SD = 0.55$) and two ($M = 0.46$, $SD = 0.52$; $p \leq .001$, Cohen's $d = 0.39$), and between block one and three ($M = 0.44$, $SD = 0.53$; $p = .002$, Cohen's $d = 0.35$). The comparison between block two and three was not significant ($p = 1.000$, Cohen's $d = 0.04$). This indicates an expected learning effect over the three blocks. There was no significant main effect of age, $F(2, 136) = 0.62$, $p = .542$, $\eta_p^2 = .01$, no significant interaction effect of diagnosis group and block, $F(1.98, 269.79) = 0.20$, $p = .82$, $\eta_p^2 = .001$, no interaction effect of age group and block, $F(3.97, 269.79) = .12$, $p = .98$, $\eta_p^2 = .002$, and no significant interaction effect of diagnosis group, age group and block, $F(3.97, 269.79) = 2.04$, $p = .090$, $\eta_p^2 = .03$. Thus, we did not find any differences between age groups, but found that typically developed individuals made more goal-directed anticipations than individuals with ASC.

Following Paulus et al. (2017), one sample *t* tests against chance level were calculated separately for each age group, diagnosis group and block to see whether participants showed a looking bias towards the goal-directed AOI that was significantly different from chance (see in Figure 10).

Children: Results for the children in the comparison group revealed a significant looking bias towards the goal-directed path in block 1, $t(28) = 4.43$, $p < .001$, Cohen's $d = 0.82$, block 2, $t(28) = 5.44$, $p < .001$, Cohen's $d = 1.01$, and block 3, $t(27) = 6.24$, $p < .001$, Cohen's $d = 1.18$. However, the group of children with ASC did not show a goal-directed looking bias in the first block, $t(29) = 1.56$, $p = .13$, Cohen's $d = 0.28$, but in the second, t (29) = 3.76, $p = .001$, Cohen's $d = 0.68$, and third block, $t(29) = 2.98$, $p = .006$, Cohen's $d = 0.54$. This suggests that children with ASC may need more time to learn the action goal.

Adolescents: Similarly, the comparison group of the adolescents anticipated in all blocks goal-directed, Block 1 with $t(18) = 3.19$, $p = .005$, Cohen's $d = 0.73$, Block 2 with $t(18) = 6.03$, $p < .001$, Cohen's $d = 1.38$, and Block 3 with $t(18) = 4.04$, $p = .001$, Cohen's $d = 0.93$. The looking bias of the adolescents with ASC was not significantly different from chance in the first block, $t(18) = .89$, $p = .39$, Cohen's $d = 0.20$, whereas they performed goal-directed anticipations in the second, $t(18) = 3.46$, $p = .003$, Cohen's $d = 0.79$, and third block, $t(18) = 6.12$, $p < .001$, Cohen's $d = 1.40$, indicating slower learning of the action goal in ASC.

Adults: For the adults, one sample *t* tests for the comparison group revealed a significant looking bias towards the goal-directed path in the first block, $t(23) = 2.74$, $p = .012$, Cohen's $d = 0.56$, the second block, $t(23) = 3.87$, $p = .002$, Cohen's $d = 0.79$, and the third block, $t(23) = 5.18$, $p < .001$, Cohen's $d = 1.06$. In comparison, adults with ASC did not show a significant goal-directed looking bias in block 1, $t(21) = 1.82$, $p = .08$, Cohen's $d = 0.39$, but in block 2, $t(21) = 3.74$, $p = .001$, Cohen's $d = 0.80$. In block 3, the looking bias was not significantly different from chance, $t(21) = 1.68$, $p = .108$, Cohen's $d = 0.36$. Performance of adults with ASC declined in the last trials.



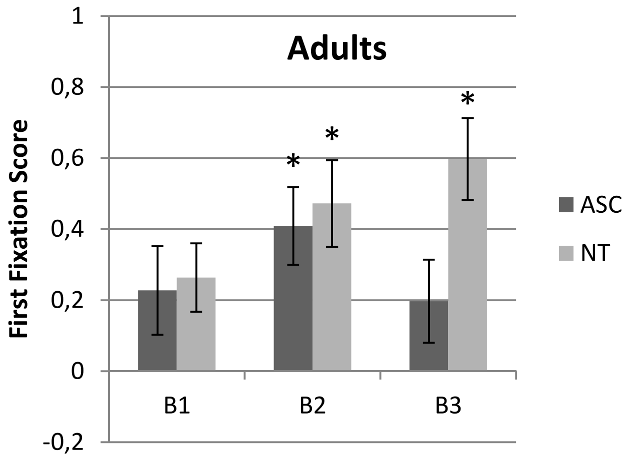


Figure 10. Descriptives of the First Fixation Score per age group and diagnosis group over the three blocks. Stars indicate a significant difference from chance

Type of anticipation: Differential Looking Score. Results can be seen in Table 9. One sample *t* tests showed that the intercept of the children and adolescents was significantly different from chance in each of the groups with the typically developed participants, indicating goal anticipations from early trials on. However, the intercept of children and adolescents with ASC was not significantly different from chance. They did not anticipate the goal in the first test trials. In contrast, the significant results for the slopes of the children and adolescents with ASC suggested an improvement in learning over time. The adults with ASC seemed to show goal encoding from the beginning on, without linear improvement over time, demonstrated by the non-significant result of the *t* test for the slope.

Table 9. Results of the regression coefficient analysis per age group and diagnosis group for the DLS

Age group	**Diagnosis group**	**Intercept**		**Slope**	
		M	*p*	*M*	*p*
Children	ASC	0.16	.095	0.04	.046
	NT	0.25	.001	0.05	.001
Adolescents	ASC	0.10	.446	0.07	< .001
	NT	0.5	.001	0.02	.441
Adults	ASC	0.30	.015	0.01	.569
	NT	0.26	.023	0.04	.038

Note:
ASC = Autism Spectrum Condition
NT = Neurotypical comparison group

3.5 Discussion

The current study examined whether individuals with ASC anticipate another agent's action based on the goal or on the movement pattern and, whether their action anticipations become more accurate over time, which would demonstrate frequency learning of action goals. A third question was concerned with whether there are developmental differences in these abilities. To this end, children, adolescents and adults with and without ASC were presented with an agent that repeatedly walked along several paths towards one of two targets. The target's location was changed in each trial in a randomized order to ensure goal encoding instead of position encoding. Results demonstrated that participants with ASC made less goal-directed anticipations, as they needed more time to encode the goal of the action. This suggests that individuals with ASC have problems using prior information, as proposed by predictive coding theories (Pellicano & Burr, 2012) and the statistical learning approach (Ruffman, 2014). Nevertheless, individuals with ASC anticipated the action of the agent as goal-directed after several trials. Interestingly, there is no evidence that individuals with ASC generally fail to encode someone's action as goal-directed, which is discussed further in the next section.

Individuals with ASC show goal anticipations

According to our results, individuals with ASC anticipate an action as goal-directed to a lesser extent than typically developed people. But, if they are provided with enough opportunities to learn about an agent's goal, they are able to use this information to anticipate future behavior. The current study is, to our knowledge, the first to demonstrate that individuals with ASC do not only base their action anticipations on movement trajectories, but are able to take the specific action goal into account. Due to our results, the claim that individuals with ASC rely only on low-level features when anticipating other's actions (Krogh-Jespersen et al., 2018), cannot be confirmed. Instead, it seems that when individuals with ASC are provided with enough, non-ambiguous cues (i.e. an agent repeatedly takes different paths leading to the same goal), they can rely on hierarchically higher and more abstract information to anticipate future actions.

Our findings are in line with recent accounts that argue against a global impairment in action understanding in ASC, but for social cognitive strategies that are different from the ones used by typically developed individuals (Hamilton, 2009). Also, Uithol and Paulus (2014) stress the need to reflect on the commonly used umbrella term “action understanding”, as this is not something an individual “has” or “doesn’t have”, but rather comprises several different cognitive processes that are involved in action anticipation. This could be even more the case for individuals with social cognitive impairments, such as ASC.

Individuals with ASC show less efficient statistical learning

Interestingly, our results indicate that overall and especially in the first trials, individuals with ASC made less goal-directed anticipations, whereas individuals from the comparison group already anticipated the goal-related path from early trials on. This could be observed for both first anticipations (First Fixation Score) as well as when corrective eye movements were included in the measure (DLS). Given these results it seems that individuals with ASC need more time to learn about the goal of an observed action. Our findings do not indicate that they are not at all able to learn from prior information; it just seems that they need more repetitions. They might consider spatiotemporal features to a greater extent than typically developing persons on the expense of goal-related information, even though they possess basic goal-encoding abilities. The present study is the first to show that individuals with ASC can encode information about the specific goal of an action after frequent observation and anticipate the action accordingly.

Comparable results were reported by Schuwerk and colleagues (2016). They found that individuals with ASC profit less from previous observation when anticipating an agent’s action. In their study, participants observed four repetitions in a similar paradigm and could not improve their anticipations throughout these trials as good as neurotypically developed individuals. Nevertheless, the previous repeated observation, in contrast to efficiency considerations, was the driving mechanism for action anticipations in ASC in their study. Gordon and Stark (2007) reported similar differences from a sequential learning task. In this task, individuals with ASC improved only when receiving specific training trials. Many other studies using implicit learning tests found compatible results (e.g. Kourkoulou et al., 2012; Mostofsky et al., 2000; Scott-Van Zeeland et al., 2010). Our findings contemplate these results and demonstrate that statistical learning is an influential mechanism also in social cognitive processes. The findings of the current study are thus in line with Ruffman's (2014) theoretical claim that individuals with ASC have problems with statistical learning. In particular, he claims that statistical learning abilities are crucial to learn about regularities in our environment and finally, help to combine observed behavior with mental states. Since individuals with ASC have weaker statistical learning skills, this could explain reduced social-cognitive abilities. Further studies could additionally distinguish whether these deficits are limited to the social domain or also affect non-social stimuli, such as learning about machines. This would, in a next step, be informative for the scope and limits of statistical learning abilities in ASC, and thus enrich theoretical accounts.

The present findings also inform recent predictive coding theories. Our findings fit well with the assumption that individuals with ASC have difficulties using sufficient priors and instead rely more on incoming sensory information (Lawson et al., 2014; Pellicano & Burr, 2012; Van de Cruys et al., 2014). Predictive coding theories claim that perception in ASC is less biased by their prior expectations on how the world looks like, so individuals with ASC might perceive sensory information less distorted than typically developed. In our study, individuals with ASC might have had problems in either forming a prior over the trials (i.e. agent walks to goal A) or in using such a prior (in a rather changing context), or even a combination of both. A recent study by Chambon et al. (2017) speaks for problems in forming a prior. In their study, participants with ASC were able to extract statistical regularities from observed behaviors but had problems using social priors. Whereas statistical regularities were inferred from the just observed behavior, social priors are based on their "a priori" experience. In our case, it could be that the prior "agents act towards goals", an assumption that is based on participants prior experience, was not as easily used by individuals with ASC as by typically developed. On the contrary, Van de Cruys et al. (2014) argues for problems in generalizing priors to new situations in ASC. It is further hypothesized that individuals with ASC could have problems in taking contextual information into account (Gomot & Wicker, 2012; Lawson et al., 2014). As stated by Tewolde et al. (2017), it is not clear how broad "prior information" is defined by predictive coding theories. We cannot tell from our study whether the change in context (objects swap position) either helped or hindered forming the prior because of an inability to generalize the prior to a new context.

Interestingly, we did not find general age differences in our study. It seems that the ability for statistical learning in order to make goal-directed anticipations is stable across development in ASC, at least from around 10 years of age onwards. Nevertheless, as compared to the two younger age groups, in our adult sample we did find a slightly different gaze pattern: They showed a looking bias to the goal after several trials, but this bias attenuated with trial repetition. This could be due to boredom or a decline in motivation in ASC. Paulus and colleagues (2017, study 3) reported analogous results.

In sum, our results suggest that individuals with ASC have difficulties integrating previous information into their action anticipations and are thus in line with recent theoretical notions (e.g. Pellicano & Burr, 2012; Ruffman, 2014). Moreover, our results also support recent suggestions for clinical practice. Haker and colleagues (2017) delineated how predictive coding theories can improve diagnosis and treatment of ASC. Our results fit very well with their suggestion to provide individuals with ASC a familiar environment that causes only little surprise. New sensory input should be offered step-by-step and repeatedly over a longer period of time. This might help with learning behavioral strategies and with slowly acquiring varied representations of the world (Haker et al., 2017). Similarly, Van de Cruys and colleagues (2014) emphasized on the role of scaffolding while learning, and state that individuals could learn high-level predictions when being extensively exposed to different situations. Our results not only suggest that individuals with ASC need more repetitions and a changing context to learn such higher-level predictions, they also support the practical suggestion for a gradual exposure from simple to more naturalistic settings (Van de Cruys et al., 2014).

No group difference in overall anticipation rate

We cannot confirm the hypothesis that individuals with ASC have a reduced tendency to engage in action anticipation as compared to typically developed individuals (Sinha et al., 2014). We neither found group differences in the amount of action anticipations, nor did we find a change of the amount of action anticipations throughout the test trials or between age groups. This suggests that already from the second trial onwards, individuals with ASC anticipated the reappearance of the agent. Our findings do not support the assumption that a general impairment in predictive abilities is the cause for social cognitive problems in ASC.

Interestingly, our results are not in line with a recent study by Schuwerk et al. (2016) who reported a weaker tendency to generate action anticipations in 10-year-old children and adults. A reason for our diverging results from Schuwerk and colleagues (2016) could be that in our stimuli the goals (e.g., the house/forest) were visible throughout the entire trial. This could have had an eliciting effect on visual action anticipations. In Schuwerk et al.'s study (2016), the target was only present before the agent started to move and was invisible for most of the time. Analogously, Goldberg and colleagues (2002) showed that individuals with ASC had problems making motion anticipations when targets were not present. Studies from goal perception in typically developing infants also confirmed the facilitating effect of salient targets on anticipatory eye-movements (e.g. Adam et al., 2016; Gredebäck, Stasiewicz, et al., 2009; Henrichs et al., 2012). In sum, it seems that anticipating other's actions might be easier in some situations than in others and that specific situational aspects influence active action processing in ASC. Further examination of anticipatory abilities in ASC by systematically manipulating social contexts is necessary.

Limitations and open questions

In line with previous research on action anticipation (Falck-Ytter, 2010; Schuwerk et al., 2016) we did not find any age differences between individuals with ASC, indicating that the use of prior information to anticipate other's action goals is stable across development, or at least from childhood to adulthood. Nevertheless, little is known about the development of social cognitive abilities in later adulthood in ASC (Lever & Geurts, 2016). Most research on cognitive differences between individuals with and without ASC concentrates on early childhood, but little is known about how these differences manifest in older ages (Powell, Klinger, & Klinger, 2017). Typical aging is associated with a decline in relevant cognitive domains, such as executive functions (e.g. Verhaeghen & Cerella 2002), Theory of Mind (e.g., Charlton, Barrick, Markus, & Morris, 2009), or action anticipation (e.g. Diersch, Jones, & Cross, 2016). For the case of ASC, it was suggested that age-related declines might happen faster in some domains, whereas in other domains similar declines to neurotypically developed are observed; sometimes an ASC-diagnosis even has a “protecting” effect (Geurts & Vissers, 2012; Lever & Geurts, 2016). Given this puzzle, it would be interesting to study action anticipation within older adults with ASC.

Further, although our results suggest that individuals with ASC have difficulties using prior information for their action anticipations, it is still an open question whether they have problems with the acquisition of the information (i.e. that the agent walks to goal A) or with the use of that information in a changing environment. In our study, the context changed as the position of the goals varied. We do not know if individuals with ASC are not that flexible in their use of prior information and thus have difficulties including contextual changes in their action anticipations. We leave it to future studies to disentangle this issue in greater detail.

Conclusion

The current study demonstrates that children, adolescents and adults with ASC anticipate the goal of an action and do not merely process movement information when making action anticipations. However, individuals with ASC needed more time to learn about the goal of an action compared to typically developed individuals, which suggests that the ability to use prior information is attenuated in ASC. This is in line with theories claiming that such an impairment causes social cognitive problems in ASC. In sum, our findings contribute to the understanding of the cognitive mechanisms underlying communication and interaction problems in ASC.

4 Study 3: The Influence of Contextual Information on Action Anticipation across the Life Span

4.1 Abstract

It has been claimed by predictive coding theories, that context information is especially informative and should thus be taken into account when anticipating other's actions. The current study takes a life-span approach and investigates whether humans flexibly integrate contextual changes in their action anticipations. By means of an eye-tracking experiment, 2-year-olds, 5-year-olds, younger and older adults observed an agent repeatedly taking one of two paths to reach a goal. Then, this path became blocked and for test trials only the other path was passable. Results demonstrated that in test trials younger and older adults anticipated towards the continuous path, indicating that they took the contextual changes into account. In contrast, children anticipated towards the blocked path, indicating that they still relied on the agent's previous observed behavior and did not take the contextual change into account. The results highlight developmental changes in human's ability to include contextual information in their visual anticipations. Overall, the study contributes to theories on predictive coding and action processing from a life-span perspective.

4.2 Introduction

We constantly allocate our attention predictively, either when performing our own actions or when observing actions of others (Flanagan & Johannson, 2003). The ability to anticipate others' behavior has been proposed to be a central aspect of human social cognition. For example, it has been suggested that the ability to anticipate others' actions enables efficient interaction, and is thus an essential capacity for everyday social functioning (Sebanz & Knoblich, 2009). Consequently, psychological research aims at understanding the developmental basis and psychological mechanisms that support action anticipation (e.g., Ambrosini, Costantini, & Sinigaglia, 2011; Ambrosini, Pezzulo, & Costantini, 2015; Eshuis, Coventry, & Vulchanova, 2009; Ruffman et al., 2012).

Predictive coding theories have highlighted that contextual information plays an important role in processing information and understanding others' behavior (Clark, 2013a). We live in a social world that is constantly confronting us with changing environmental conditions that determine our possible actions. Information provided by the context is therefore especially informative when processing another's action. Adequate action anticipation thus requires taking context and contextual changes into account. Context information can on the one hand include information about the background, such as the setting (for example, some actions are more likely in an office than in a bathroom context). On the other hand, context can also include information about constraints, such as an obstacle that might block another's way. Situational constraints reduce our action possibilities and make certain actions more likely than others (Van Overwalle, 2010). For example, in case the usual way to the supermarket is blocked due to a construction site, we are able to predict that people will take the alternative route.

While situational constraints are thus an important factor for action anticipation, there is limited evidence on how changes in situational constraints affect action anticipation. The current study aims to investigate the development of the ability to integrate changing context information flexibly into action anticipations across the life span.

According to predictive coding theories, context is especially informative for action anticipation (Clark, 2013a; Kilner et al., 2007). Predictive coding theories claim that a bidirectional hierarchically structured system in the cognitive system constantly compares bottom-up sensory input with top-down predictions (Clark, 2013a). Top-down predictions rely on higher level knowledge, i.e. our concept of what the world "typically" looks like (in short "priors"; Friston, 2010). The amount of sensory input that is not predicted by our priors is reported backwards as a prediction error, in order to improve future top-down predictions. Kilner et al. (2007) proposed that when observing others' actions, the motor system operates within this predictive coding system and thus infers the most likely outcome of an action. The use of prior knowledge to predict incoming input is supposed to facilitate a fast interpretation of events and more accurate responses (Kveraga, Ghuman, & Bar, 2007).

In light of these theoretical considerations, why is context information so relevant for anticipating others' actions? It has been claimed that the perception of contextual information is especially fast (Oliva, 2005). The perceptual and conceptual meaning of a scene, also referred to as the *gist* of a scene, can be recognized within 100 milliseconds (Oliva, 2005). This implies that in most cases, context information is already available before we observe someone's action. That is, a set of context informed priors is already active and "ready" to predict, and thus influences our perception through top-down predictions (Clark, 2013a). In sum, context information is supposed to be highly informative and to constitute an important factor in the processing of others' actions.

The influence of context informed priors can be illustrated by a series of studies on object- and action recognition (e.g. Bar, 2004; Wurm & Schubotz, 2012). Adults recognized actions better when they were provided in their usual setting, such as cracking an egg in a kitchen rather than in an office context (Wurm & Schubotz, 2012, 2016). Similarly 4- to 8-year-old children recognized pantomime actions more easily when the action was compatible with its context (Wurm, Artemenko, Giuliani, & Schubotz, 2017). Further, the detection of objects succeeded better when they were embedded in their typical environment (Bar, 2004). By indicating that specific settings are associated with certain actions and objects, these studies nicely demonstrate the informative power of contextual cues on action recognition.

Yet, less is known on how changes in context lead to flexible action anticipations. Indeed, while there is ample research on action anticipation in infants (e.g., Gampe & Daum, 2014; Gredebäck, Stasiewicz, et al. 2009; Henrichs et al., 2014), children (e.g., Schuwerk & Paulus, 2015), and adults (e.g. Ambrosini et al., 2015; Eshuis et al., 2009), research has hardly focused systematically on how contextual changes affect such action anticipation. One recent study suggested that adults consider contextual changes in verbal action prediction (Stapel et al., 2012). However, recent work indicates differences between time-consuming verbal reasoning and action anticipation (e.g., Apperly & Butterfill, 2009; Schuwerk & Paulus, 2015) so that a direct assessment of visual action anticipations is required.

A few recent studies – although not directly assessing the impact of contextual changes – are indicative of flexibility in action anticipation. For example, it has been shown that children and adults integrate the change of the location of two targets in their action anticipations. Daum et al. (2012) presented children and adults with an agent repeatedly approaching one of two possible goal objects. For test trials the context changed: Goal objects swapped their position. Adults and 3-year-olds (but not younger children) could integrate this information in their anticipations; they anticipated that the agent would approach the object in the new location, indicating a flexible adaptation of their anticipations towards the changed context. Similarly, Ganglmayer, Schuwerk, and colleagues (2019) demonstrated that adults as well as children between 5 and 12 years of age flexibly anticipated an agent's goal in a changing environment. This indicates that children from around three years of age and adults flexibly update information in relation to contextual changes when anticipating another's action. However, there are hints that younger children might be not that flexible (Daum et al., 2012).

It has further been discussed whether infants have an inborn expectation that others act efficiently (Gergely & Csibra, 2003; Ruffman, 2014). If this were true, infants should process situational constraints when anticipating others' actions from early on. Although looking time studies are in line with this proposal (e.g., Gergely et al., 1995), it is unclear whether infants consider contextual changes in their action anticipations. While some evidence supports this claim (e.g., Biro, 2013), other studies have found no evidence for it (e.g., Paulus et al., 2011) and provided alternative explanations (Ruffman, 2014; van Overwalle, 2010). For example, Paulus et al. (2011) presented 9-month-olds and adults with a cow repeatedly taking the longer of two possible paths to reach a goal, as the shorter path was impassable. However, when the context changed and both paths were passable, in the first trial infants and adults still anticipated that the cow would continue taking the longer path, although the shorter one would have been more efficient. This suggests that both adults and infants did not immediately take the contextual changes into account when anticipating the agent's behavior. Although children and adults flexibly adapt their anticipations in relation to contextual changes (Daum et al., 2012; Ganglmayer, Schuwerk, et al., 2019), it is less clear whether also younger children do this. Further, tasks that include changes in the environment require fast and flexible adaptations, based on executive functions. It has been claimed that cognitive flexibility, namely the ability to update and integrate several information sources, still develops into adolescents (Crone, Ridderinkhof, Worm, Somsen, & van der Molen, 2004; Zelazo, 2006). This could imply that younger children might have difficulties in considering context information when anticipating others' actions. Our study also aimed at contributing to this theoretical debate.

Moreover, it is unclear how and to what extent contextual changes influence action anticipation beyond adulthood. From a predictive coding point of view, our top-down predictions should improve through life-long experience (Clark, 2013a). Prediction errors, i.e. the amount of sensory input that was not explained by higher-level predictions, shape our future predictions and are consequently important for learning. Thus, with increasing age we should become better at predicting sensory input through life-long experience. Interestingly, an age-related increase of action anticipation abilities across the life span has indeed been observed by Wermelinger, Gampe, and Daum (2019). However, others suggested a decline of action prediction abilities at older ages (Diersch, Cross, Stadler, Schütz-Bosbach, & Rieger, 2012; Diersch et al., 2016). Such a decrease reported in the latter studies could be related to findings that executive functions, such as inhibition and processing speed, decline in older adults (see for example Gazzaley et al., 2008; Zelazo, Craik, & Booth, 2004). Given such opposing results, it is not clear how well older adults can integrate contextual changes in their action anticipations. Based on the predictive coding theory it could be assumed that the ability to flexibly integrate changes in predictions linearly increases with age, based on the continuously built up experience. However, at older ages, a decline in executive capabilities might increasingly counteract such increase. Taken together, the ability to integrate contextual changes when anticipating others' actions might change across the life span. It might linearly increase with increasing life-long experience, or it might take the form of an inverted u-shaped trajectory due to respective changes in executive functions (see also Zelazo et al., 2004). Thus, an investigation across the life span is necessary in order to empirically test the predictions made by theories on predictive coding and action processing.

The current study

The current study addresses the question of whether participants at different age levels take situational constraints into account when anticipating another's action. Do people flexibly adapt their visual anticipations to sudden contextual changes? And how does this ability develop throughout the life span? Two-year-olds, 5-year-olds, younger and older adults were included in the current eye-tracking study. In order to investigate action processing, we relied on an established paradigm that allows assessing action anticipations already in younger children (Daum et al., 2012; Paulus et al., 2011). Participants repeatedly observed an animated agent taking one of two possible paths to reach a goal, while the agent always took the same path. After several repetitions, this path was blocked and thus impassable. Hence, the agent had to take the other path to reach its' goal. We measured whether participants visually anticipated that the agent would take the other path, as the former was impassable.

We decided to include 2-year-old children, as developmental theories would make different predictions of their performance. This is relevant for developmental theorizing as some theories would assume that they consider contextual changes (Gergely & Csibra, 2003), whereas others would suggest differently (Ruffman, 2014). Further a developmental shift in cognitive flexibility has been reported with three years of age (Blakey, Visser, & Carroll, 2016). The inclusion of 2-year-olds for this study thus seems highly informative. We further included 5-year-olds as cognitive flexibility improves across the preschool period (Zelazo, 2006). If executive functions play a dominant role in the ability to take into account situational constraints in action anticipation, we would expect the 5-year-olds to perform considerably better than 2-year-olds. They further have more experience, and from a predictive coding perspective, should improve their anticipation abilities. We expect 5-year-olds to integrate the contextual changes in their anticipations, but might not perform as well as adults.

To investigate action anticipation abilities across the life span, younger and older adults were also included. Predictive coding theory would assume that life-long experience is beneficial for predictions, and that action anticipation abilities thus improve throughout the life span (Clark, 2013a). If this is true, we would predict a rather linear improvement of action anticipation ability from early childhood into later adulthood. However, if executive functions play a decisive role in integrating contextual changes in their action anticipations, older adults' action anticipation abilities should decrease in comparison to those of younger adults, which would lead to an inverted u-shaped trajectory over the four age groups (Gazzaley et al., 2008; Zelazo et al., 2004).

4.3 Method

The preprocessed eye-gaze data of the study is available at https://osf.io/dpemf/?view_only=dc366915ba724c29922960eea3e2a96f. Demographic information is not included in the data set, due to protection of data privacy and to prevent inferences on individual data.

Participants

The final sample comprised 181 participants. It consisted of 42 2-year-olds (mean age = 24.33 months, *SD* = 0.72, range = 23-26 months), 47 5-year-olds (mean age = 60.87 months, *SD* = 1.26, range = 58 – 66 months), 45 younger adults (mean age = 25.91 years, *SD* = 6.81, range = 18 – 45 years), and 47 older adults (mean age = 71.51 years, *SD* = 4.51, range = 61 – 78 years). Additionally seven 2-year-olds, two 5-year-olds, five younger and three older adults were excluded. Reasons for exclusions were fussiness among the children samples ($n = 4$), problems with eye-tracking or insufficient data ($n = 4$) and experimenter error ($n = 9$). Prior to data acquisition, the sample size was determined based on a power analysis with G*Power 3.1.9.2 (Faul, Erdfelder, Buchner, & Lang, 2009) with $\alpha = 0.05$ and power = 0.80. For the one-way between-subjects' ANOVA with a medium effect size of $f = 0.25$ and four groups, a sample size of 180 participants was estimated.

Informed written consent was given by participants or their caregivers prior to testing. The study was approved by the local ethics board ("Ethikkommission der Fakultät für Psychologie und Pädagogik der Ludwig-Maximilians-Universität München", Title: The development of action anticipation: Children's active perception of others' actions). Adults and children were recruited via birth-records, public announcements, and from participant pools. Travel costs were reimbursed for children and older adults; student participants obtained monetary compensation or course credit. Children also received a small present. All participants came from or around a larger city in Europe.

To control for a possible age-related cognitive impairment indicating first signs of pathological neurodegeneration, the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975; maximum score of 30) was applied in the older adults.

Stimuli

Stimulus material consisted of two introductory movies, five learning movies, a "blocking" movie (in which one of the paths gets interrupted) and three test movies. The movies were created with Adobe Animate CC and Adobe Illustrator (Adobe Systems Inc., San Jose, CA).

Two introductory movies familiarized participants with the setup and presented participants with two equally long paths, leading from the left to the right side of the screen. Both paths merged into one single path at their beginnings and ends (see Figure 11). An occluder overlaid the crossroad on the left side. The occluder was employed to elicit anticipatory eye-movements and to avoid constant fixation on the agent (see Paulus et al., 2011; von Hofsten et al., 2007). At the beginning of the movie, the occluder was transparent and a cow was situated on the far left side of the path. Then the cow jumped up two times. Immediately the transparent occluder turned opaque and the cow started to walk towards the occluder, disappeared behind it for 1.3 seconds, and reappeared on one of the two paths. It then walked towards the far right side and finally left the screen. This sequence lasted for 14 seconds. The video was presented two times, with the cow taking one of the two paths in the first and the other path in the second video. This provided participants with the information that the cow can walk on both paths. The order of which of the paths the cow took first was counterbalanced in randomized order between participants.

The movies of the learning phase contained the same setup as the introductory movie, but additionally a sheep was situated at the far right side of the single path (see Figure 11A).

At the beginning, the cow jumped up twice and a voice stated "Oh a sheep, I want to get to the sheep". Then the sheep wiggled and moved along the path off the screen at the right side. Shortly afterwards, the occluder turned opaque and the cow started to walk towards the sheep, taking one of the two paths.

In the following "blocking" movie the path that was taken by the cow in the learning trials became interrupted. Participants observed the two paths, including the transparent occluder and the cow situated at the far left side of the path. Additionally, a rattle sound played for 3 seconds to attract participants' attention. Afterwards a piece of the path vanished (see Figure 11B). This was accompanied by a triangle sound to draw participants' attention towards the newly appeared gap in the path. To provide participants with the information that the cow was also aware of the newly appeared gap, the voice stated, "Oh what happened there?" after 3 seconds. Then the cow started to move towards the crossroad with the occluder staying transparent. When it reached the crossroad it stopped, looked at the interrupted path and the voice stated, "Ah now it's not passable anymore". This was done in order to make participants aware that the cow cannot walk across the gap. This scene was shown for another 4 seconds. In total, the movie lasted 19.5 seconds.

The test movies started exactly like the movies of the learning trials, except that the familiarized path was now interrupted. The cow jumped up two times and stated again "Oh a sheep, I want to get to the sheep", the occluder turned opaque and the cow started to move towards the occluder, disappeared and did not reappear throughout the rest of the movie (4.5 seconds). The fact that the cow did not reappear from the occluder in the test trials ensured that participants did not learn about any alternative behavior of the cow. One whole test movie lasted a total of 14 seconds.

The stimuli were additionally piloted within a sample (n = 14) of 3- to 6-year-olds (mean age = 4.29) to assess whether children "understand" the stimuli correctly. Children observed the cow once taking the upper path and once taking the lower path to reach the goal. Afterwards, the blocking movie was presented, showing that one of the paths becomes blocked (see description of the "blocking" movie above). Subsequently one test movie was shown (with the corresponding path blocked). After the cow's disappearance behind the occluder during the test trial, children were explicitly asked "Which path can the cow take now?". Almost all of the children (n = 13; 93%) gave correct answers by pointing towards the continuous path or verbally stating so, with $\chi^2(1) = 10.29$, p = .001. Therefore we assume that (at least by the preschool years) children understood the whole setup as well as that the cow could not walk along the interrupted path.

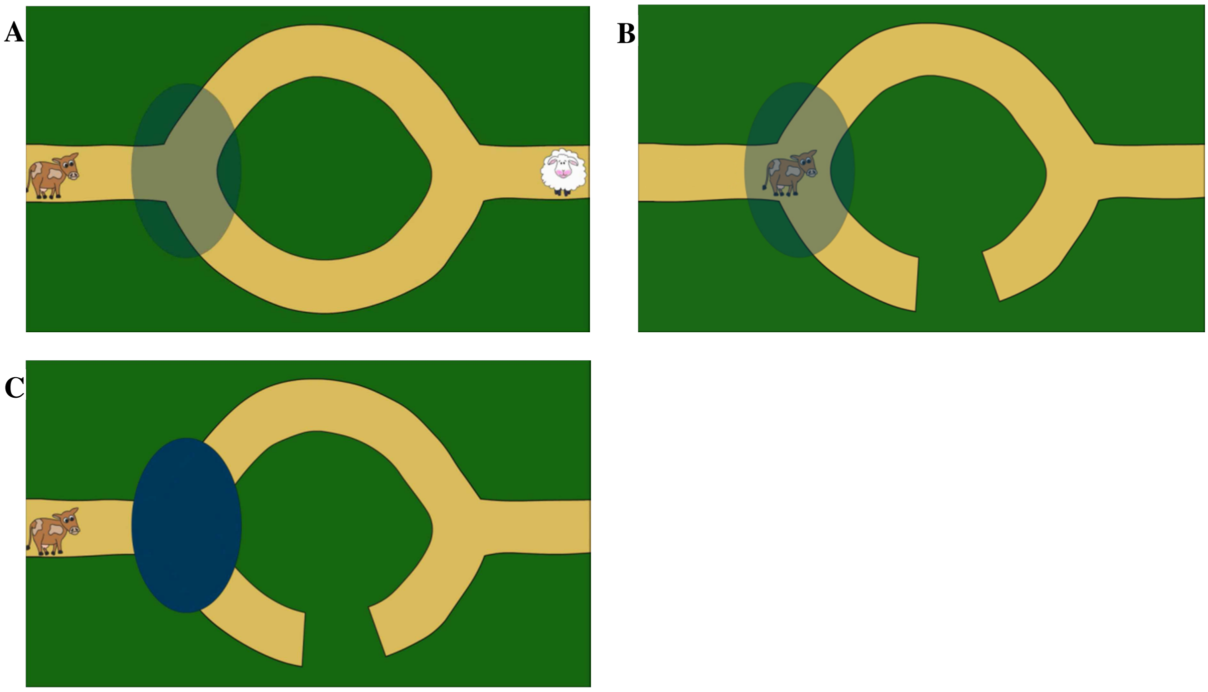


Figure 11. A) Example of a learning movie: The agent (cow) is situated on the left, the goal (sheep) on the right end side of the path. The transparent occluder (which turns opaque before the cow starts to walk) overlies the crossroad of the two paths. B) Example of a "blocking" movie: The lower path has already become interrupted and the cow has reached the crossroad (with the occluder being transparent). C) Example of a test movie: The sheep has already left the scene and the cow is about to start approaching the occluder. For test trials, the cow disappears and does not reappear from behind the occluder.

Setting and Procedure

Two-year-olds were either seated on an age-appropriate car seat (which was attached to a regular chair) or on their parent's lap in case they did not want to sit alone. Five-year-olds, younger and older adults were seated on a regular chair in front of the monitor. For all participants the distance to the monitor was 60-65 cm. For recording participants' eye movements, a corneal reflection eye-tracker (Tobii Pro TX 300, Tobii Technology, Sweden) was used. It recorded eye-gaze data at 120 Hz with an average accuracy of 0.4° visual angle. The software Tobii Studio (Tobii Technology, Sweden) was used for video presentation. For calibration procedure, two-year-olds received a 5-point calibration (due to attention reasons) and 5-year-olds, younger and older adults a 9-point calibration. Three of the 5-year-olds received a 5-point calibration due to experimenter error.

For familiarization with the setup and for providing participants with the information that the cow was able to take both possible paths, the two introductory movies were shown first. Afterwards five learning movies were presented, in which the cow always took the same of the two paths, so participants could learn about the cow's "usual" behavior. Whether the cow was taking the lower or the upper path in the learning trials was counterbalanced between participants. Then the interruption of the respective path was presented, followed by the three test movies.

Measures

The Tobii Studio IV-T fixation filter was used. It consisted of a maximum gap length of 75 ms, eyes' angular velocity within a 20 ms time interval and a velocity threshold of 30 degrees/second. Adjacent fixations were merged to a maximum of 75 ms between fixations and a maximum angle of 0.5 degrees. Minimum fixation duration was 60 ms. In order to analyze participants' eye gazes, and in line with previous research (e.g. Daum et al., 2012; Falck-Ytter et al., 2006), two areas of interest (AOI, each covering 4.54% of the screen) were situated on the sections were the paths reappeared from the occluder. A third AOI covered the whole screen (100%) to control for missing data in the other two AOIs. In test trials participants' gaze behavior was measured from the moment the cow completely disappeared behind the occluder until the end of the movie (4.63 seconds). To be included into analysis, participants had to show eye-gaze data in at least two of the three test trials. In learning trials gaze behavior was measured from the time the cow disappeared behind the occluder until it reappeared (1.29 seconds for condition 1 and 1.49 seconds for condition 2). Two different measures, a First Fixation Score and a Differential Looking Score (DLS) were used to analyze participant's gaze behavior in test trials (see below). For analysis of the learning trials only the Differential Looking Score was used, as it is better suited when looking at individual trials.

First Fixation Score. To assess whether participants fixated first the upper or lower path after the cow's disappearance, a First Fixation Score was generated (see e.g., Paulus et al., 2011). For test trials, participants' gaze behavior was coded with 1 when they fixated the continuous path first and with -1, when they fixated the interrupted path first. If they did not fixate on either of the two AOIs but somewhere else on the screen, their gaze behavior was coded with 0. No fixation to the screen during the anticipatory period was treated as a missing value.

Differential Looking Score (DLS). To investigate whether participants spent more time on one AOI in relation to the other, a DLS was calculated (see e.g., Senju et al., 2009). This score allows controlling for corrective eye movements, as participants could look first to one AOI but fixate the other AOI longer in total. Thus, the total looking time to the AOI of the interrupted path was subtracted by the total looking time to the AOI of the continuous path, divided by the sum of overall total looking time to both AOIs. Similarly, for learning trials, the total looking time to the AOI of the "other path" was subtracted by the total looking time to the AOI of the path the cow always took in the learning trials, divided by the sum of total looking time to both AOIs.

IBM SPSS Statistics 24 (SPSS Inc., Chicago, IL, USA) was used for the statistical analyses. For analysis of the learning phase, the five learning trials were averaged to two blocks separately for both scores (following Paulus et al., 2017). For block one, the mean of the first and second trial was calculated and for block two, the mean of the third, fourth and fifth learning trial was generated. Dependent t-tests between these two blocks were calculated separately for each age group, to see whether participants' learned the agent's path preference over the learning trials.

For analysis of the test trials a mean over the three test trials was generated (e.g., Schuwerk & Paulus, 2015). A one-way ANOVA with the between-subject factor age group

(2-year-olds, 5-year-olds, younger and older adults) was performed with the First Fixation Score and the DLS separately. Further one sample *t*-tests were calculated for each age group separately, to see whether participants' looking bias differed from chance level. We further analyzed whether there were differences between participants' looking behavior for each test trial and age group separately.

4.4 Results

Learning Trials. Results of the dependent *t*-tests revealed a significant difference between block one and two for the 2-year-olds in both scores, with $t(41) = -4.00$, $p < .001$, Hedges' $g = -0.71$ for the First Fixation Score and $t(41) = -3.52$, $p = .001$, Hedges' $g = -0.67$ for the DLS. This indicated a learning effect from the first learning trials to the last trials (see Figure 12 for descriptives of the DLS). Although the descriptive statistics suggest a trend for improvement across the trials in the 5-year-olds, there were no significant effects for the First Fixation Score with $t(46) = -0.81$, $p = .42$, Hedges' $g = -0.16$ and for the DLS with $t(46) = -1.63$, $p = .109$, Hedges' $g = -0.32$. For adults, the *t*-test turned out significant with $t(44) = -4.77$, $p < .001$, Hedges' $g = -0.77$ for the First Fixation Score and $t(44) = -4.59$, $p < .001$, Hedges' $g = -0.79$ for the DLS. Also, older adults show a significant learning effect with $t(46) = -2.70$, $p = .010$, Hedges' $g = -0.41$ for the First Fixation Score and $t(46) = -3.43$, $p = .001$, Hedges' $g = -0.51$ for the DLS. In sum, in all four age groups there was at least a trend for learning the agent's behavior over the five learning trials.

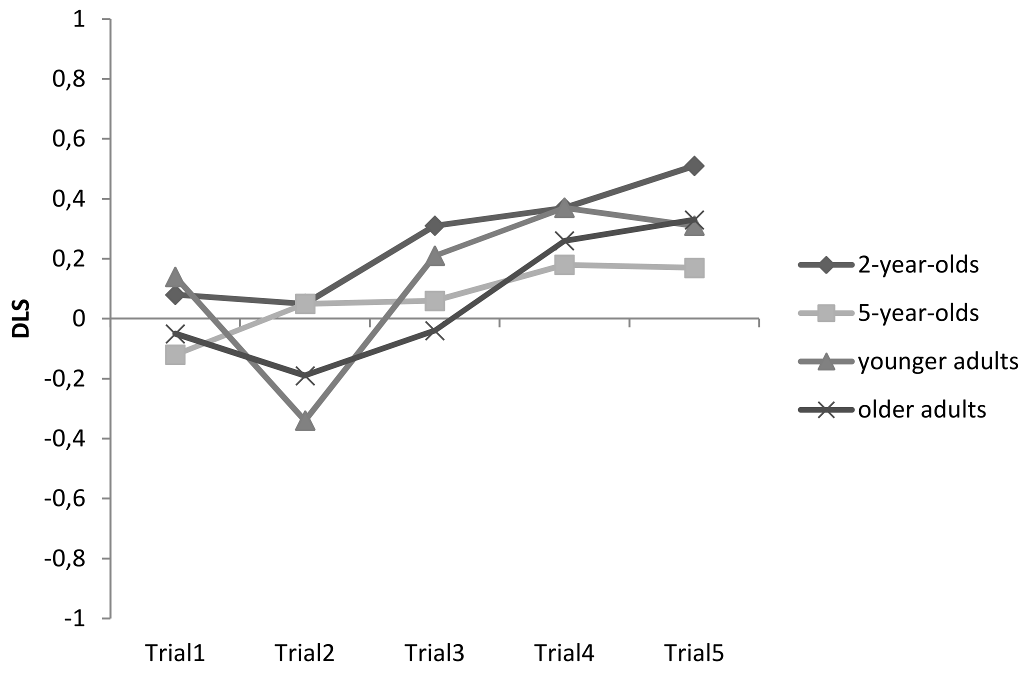


Figure 12. Descriptives of the Differential Looking Score (DLS) for each age group over the five learning trials.

First Fixation Score. The one-way ANOVA revealed a significant effect of age group, with $F(3, 177) = 23.31$, $p < .001$, $\eta_p^2 = .28$. Post-hoc Bonferroni adjusted pairwise comparisons revealed no significant difference between the 2-year-olds (M = -0.43, SE = 0.09) and 5-year-olds (M = -0.33, SD = 0.09), with p = 1.000, Cohen's d = 0.17. As can also be seen in Figure 13, both age groups showed a looking bias towards the interrupted path. There was no significant difference between the younger adults (M = 0.29, SE = 0.09) and older adults (M = 0.39, SE = 0.09), p = 1.000, Cohen's d = 0.17. Younger and older adults anticipated the other, continuous path more often. The 2- and 5-year-olds differed significantly from the younger and older adults, with each $p < .001$. Further, results of the one-sample t-tests revealed a looking bias significantly different from chance level for all age groups (see Table 10 for details). Two- and 5-year-olds fixated first the interrupted path, whereas younger and older adults first fixated the continuous path. This pattern did not change, even when looking at the descriptives of the test trials individually (see Figure 14).

Table 10. Results of the one sample t tests against chance level for First Fixation Score and DLS of each age group.

	2-year-olds	5-year-olds	Younger adults	Older adults
First Fixation Score	$t(41) = -4.84$, $p < .001$	$t(46) = -3.81$, $p < .001$	$t(44) = 3.19$, $p = .003$	$t(46) = 4.84$, $p < .001$
DLS	$t(41) = -4.34$, $p < .001$	$t(46) = -2.42$, $p = .020$	$t(44) = 3.71$, $p = .001$	$t(46) = 6.12$, $p < .001$

Note: DLS = Differential Looking Score

Differential Looking Score (DLS). The one-way ANOVA yielded a significant effect of age group, with $F(3, 177) = 23.98$, $p < .001$, $\eta_p^2 = .29$. Bonferroni adjusted pairwise comparisons resulted in the same pattern as for the First Fixation Score. Two-year-olds ($M = -0.36$, $SE = .08$) and 5-year-olds ($M = -0.18$, $SE = 0.07$) did not significantly differ from each other, with $p = .559$, Cohen's $d = 0.34$. There was also no significant difference between younger ($M = 0.28$, $SE = 0.08$) and older adults ($M = 0.42$, $SE = 0.07$), $p = 1.000$, Cohen's $d = 0.29$. However, both the 2- and 5-year-olds differed from the younger and older adults, all $p < .001$. Further, the means of all age groups were significantly different from chance level (see Table 10), with the 2- and 5-year-olds showing a looking bias towards the interrupted path (see also Figure 13), and the adults and older adults towards the continuous path.

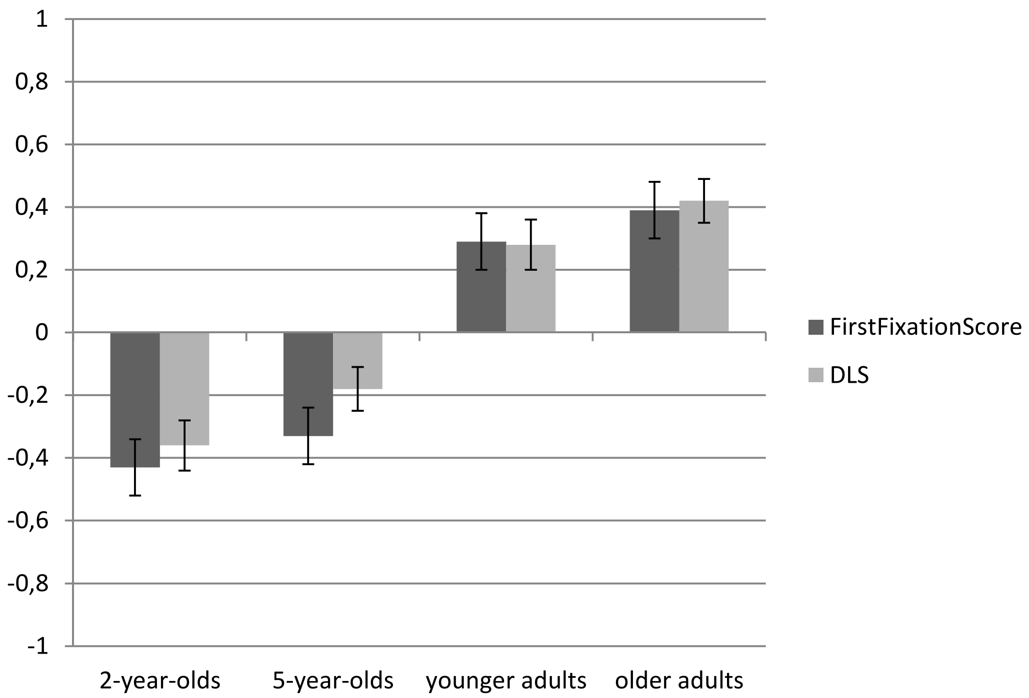


Figure 13. Descriptives for the First Fixation Score and Differential Looking Score (DLS) for each age group. Error bars represent the standard errors of the means.

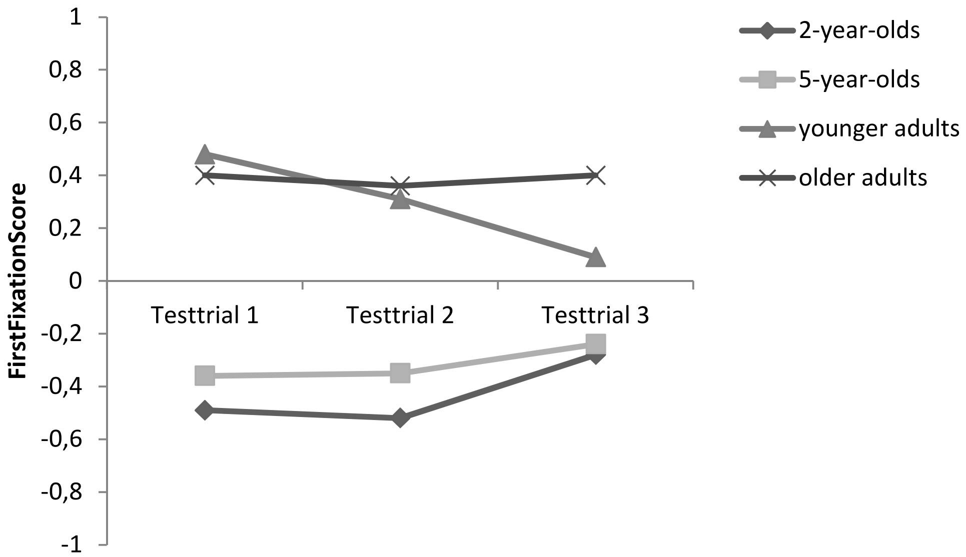


Figure 14. Descriptives of the First Fixation Score for each test trial and age group.

Control Measure - MMSE. We observed no indications of cognitive impairments indicating beginning dementia within the age group of older adults (M = 29.11, SD = 1.10). Further, there were no significant correlations between the MMSE and the First Fixation Score

($r = -.01$, $p = .937$) or the DLS ($r = -.05$, $p = .733$).

Additional analysis 1. So far, results of both scores suggest an age-related change: Children demonstrate a looking bias towards the interrupted path, whereas younger and older adults demonstrate a looking bias towards the continuous path. To see whether there is a significant linear trend over the four age groups, an exploratory trend analysis based on polynomial contrasts was performed for both scores. Results revealed significant linear trends, with $F(1, 177) = 62.19$, $p < .001$ for the First Fixation Score, and $F(1, 177) = 68.43$, $p < .001$ for the DLS. This indicated that from two years of age until later adulthood, participants' ability to integrate contextual changes in their action anticipations might increase linearly with age.

Additional analysis 2. To exclude the possibility that children's looking bias towards the continuous path in test trials is a result of their failure to recognize the gap in the blocking movie, an additional correlational analysis was performed. Correlations between the First Fixation Score resp. DLS of the test trials and participants' looking time towards the interrupted path during the blocking movie were calculated. An AOI was defined around the area of the gap (11.05 %) and the total looking time towards this area was measured from the start of the gap's appearance until the end of the blocking movie (i.e., 16.5 seconds in total). Results yielded no significant correlation between the total looking time towards the gap, and the First Fixation Score and DLS for any of the four age groups (all p's > .151). This indicated that participants' anticipatory looking behavior in test trials was not related to the time they spent looking at the gap during the blocking movie.

4.5 Discussion

The current study investigated whether humans integrate contextual changes flexibly when anticipating others' actions. To this end, 2-year-olds, 5-year-olds, younger and older adults observed an agent repeatedly taking one of two paths to reach a goal. Then, this path became blocked. We assessed by means of eye-tracking whether participants subsequently anticipated the agent to take the other, passable path. This would indicate that participants integrated the contextual changes in their anticipation behavior. Results revealed that younger and older adults integrated the contextual changes flexibly in their action anticipations. This demonstrates the informative power of context information, as suggested by predictive coding theories (Clark, 2013a). Moreover, our analyses revealed clear age-related differences: 2- and 5-year-olds anticipated towards the interrupted path and did not integrate the change in context in their anticipations. Our results suggest this ability develops linearly with increasing age. We discuss these findings further in the next sections.

According to our results, younger and older adults flexibly integrated the contextual changes when anticipating others' actions. This provides evidence for context sensitivity during action anticipation. This is in line with predictive coding theories (Clark, 2013a, 2013b; Kilner et al., 2007). Our results support the assumption that context-informed priors have a significant influence on action processing. Even if adults already have expectations about an agent's behavior based on other priors, they use context information to update these expectations. They have previously learned that an agent performs an action in a certain way (the cow always taking one specific path) and can flexibly change their predictions based on new and more reliable information (i.e., the context change). This suggests that adults integrate multiple information sources when anticipating others' actions and also weigh the information sources in accordance to their reliability (see also Ambrosini et al., 2015).

Within predictive coding theory, the ability to integrate several information sources and to weigh them according to their predictive power is based on so called "hyperpriors" (Ambrosini et al., 2015; Clark, 2013a). Hyperpriors are priors on a higher level of abstraction and include "general knowledge" of the world (e.g., Clark, 2013a; Hohwy et al., 2008); for example the higher level knowledge that people take an alternative route to get to the supermarket, when their usual way is blocked because of a construction site. In the current study, participants are confronted with two different information sources/priors to predict the agent's behavior. One is the agent's previous behavior (it always takes one specific path) and the other one is the change in context (this path becomes blocked and only the other one is passable). Now the two priors have to be integrated and weighted according to their precision: Which one is the most reliable and should thus be used for predictions? It has been claimed that this form of higher level knowledge about the world is not fixed, but must be built and learned through experience (Clark, 2013a).

According to our results, younger and older adults gained enough life-long experience to weigh these two information sources accordingly, whereas 2- and 5-year-olds relied on the agent's previous observed behavior and thus anticipated towards the interrupted path. They did not integrate the contextual information flexibly when anticipating the agent's action. Thus, our results are not in line with claims that children consider contextual changes from early on (Gergely & Csibra, 2013). They rather suggest that a prior, based on the agent's previous observed behavior, dominantly influences children's anticipations (Daum et al., 2012; Ganglmayer, Attig, Daum, & Paulus, 2019). These results also fit well with the observation of Paulus et al. (2011), who showed that infants (in contrast to adults) did not adapt their anticipations towards contextual changes, even after they have repeatedly observed the changed behavior of the agent. So even if infants have seen that the agent performed an alternative behavior due to the context change, they did not change their anticipations. This suggests that, in line with our results, statistical learning is a prevailing mechanism within infants and children when learning about others' actions (Ruffman, 2014).

Furthermore, our results imply a linear increase of the ability to integrate contextual changes when making action anticipations over the four age groups. Again, this supports the claim that life-long experience is important for flexible action anticipation (Clark, 2013a). Our results supplement findings of Wermelinger et al. (2019), who observed an increase of action anticipation frequency from 3 to 80 years of age. In their study, older participants visually anticipated steps of an unfamiliar action more frequently than younger ones. However, in their paradigm context was held constant. Our study thus adds to this line of research by suggesting that people get better with increasing age in considering sudden contextual changes when anticipating others' actions. Notwithstanding these results have to be interpreted cautiously, as they are based on a post-hoc analysis and further studies are needed to investigate this linear increase across the life span more profoundly.

Importantly, in an additional pilot task without any learning phase (see methods section), we also explicitly asked preschool children, which path the agent could take after the gap appeared on one of the paths. Children observed the cow once taking the upper and once taking the lower path before one of the paths became interrupted. Most of the children explicitly referred to the continuous path. We can thus exclude the possibility that young children did not understand the paradigm or that the agent cannot walk across the interrupted path. Furthermore, this indicates that children include contextual information when they are explicitly asked to give a verbal answer about their expectation of the agent's upcoming action. However, on the one hand we do not know whether they flexibly include contextual changes in their verbal predictions if they had previously been presented with a learning phase: If they have previously seen for several times that the agent always takes one instead of the other path before the context changes. On the other hand, there is the assumption that children acquire knowledge first on an explicit level and only later, with increasing automatization, they use this knowledge on an implicit level to visually predict other's actions (Schuwerk & Paulus, 2015; Paulus et al., 2017). Overall, this difference between time-consuming verbal measures and fast visual anticipations relates to proposals on the existence of two systems for the processing of social information and social functioning (Apperly & Butterfill, 2009; Strack & Deutsch, 2004). Further studies are needed to clarify whether this is also the case when flexibly integrating contextual changes in action predictions.

Furthermore, our results revealed that there were no significant relations between the looking time towards the gap and the children's anticipations. Thus, our results do not imply that children simply did not look at the gap long enough to process its appearance and therefore kept anticipating towards the interrupted path. Accordingly it seems very unlikely that children did not recognize the gap or did not understand that the gap is not passable.

Last but not least, analyses of the learning trials suggest learning performance (or at least a trend) over the learning phase in all four age groups. This demonstrates that children learned about the agent's path preference and diminishes the possibility that the differences between the age groups in test trials are based on differences in previous learning performance.

It has been claimed that executive functions in young children are still developing (Blakey et al., 2016; Crone et al., 2004) and abilities, such as inhibition and processing speed decline in healthy older adults (e.g., Gazzaley et al., 2008; Ruiz-Rizzo et al., 2019). This could lead to difficulties in integrating several information sources in order to anticipate other's actions. Given this claim, we would have expected that younger children and older adults might have difficulties in integrating context information flexibly when anticipating other's actions, resulting in an inverted u-shape trajectory over the four age groups. Interestingly, our results did not reveal an inverted u-shape trajectory over the age groups. On the one hand, we observed no significant differences in performance between the 2- and 5-year-olds. This was surprising, since cognitive flexibility improves around the preschool period (Zelazo, 2006) and we thus expected that 5-year-olds would perform better than 2-year-olds. It seems that including context information might be easier for young children in some situations than in others (e.g. Daum et al., 2012; Ganglmayer, Attig, et al., 2019; Kayhan et al., 2019), especially when several information sources have to be taken into account. Thus further examination in different social contexts is necessary. Also, it has been shown that abilities, such as inhibitory control or cognitive flexibility, are still developing into middle childhood (Carver, Livesey, & Charles, 2001; Gupta, Kar, & Srinivasan, 2009) and adolescence (Crone et al., 2004). This suggests that 5-year-olds may not yet have sufficient executive control processes in order to change their expectations of another's behavior due to contextual changes when anticipating other's actions.

On the other hand, our results did not reveal a decrease of anticipation abilities for older adults. Thus our results do not support the claim that action prediction declines at older age (Diersch et al., 2012; Diersch et al., 2016). Although healthy older adults are likely to show declines in several executive functions, their abilities are obviously sufficient to integrate contextual changes in action anticipations for a simple situation as in our task. Our results are also in line with findings that in older adults, some, but not all executive functions and predictive abilities might be reduced (e.g., Haupt, Sorg, Napiórkowski, & Finke, 2018; Verhaeghen, 2011).

Limitations and open questions

Although the age groups included in the current study were selected on the basis of thorough theoretical considerations, future studies could examine further age groups between five years of age and (early) adulthood. This would be helpful to learn more about the underlying mechanisms of the ability to flexibly integrate contextual information into action anticipations.

Also, as described earlier, predictive coding theories distinguish between the integration of several information sources and the weighing of these information sources according to their reliability. In point of this view, it is still not clear whether children have problems with the integration of the information or with the weighing (or both). It could be possible that they have problems with the synchronous integration of the contextual changes and the agent's previous behavior, or that they have problems "deciding" that the change in context is more predictive than the agent's previous behavior. Predictive coding theories do not offer any suggestions concerning the developmental trajectory of a "successful" predictive system. Further theoretical and empirical insights are needed.

In line with this, it would be interesting to assess directly the relationship between the individual capabilities in critical cognitive functions, such as working memory, inhibitory control (inhibiting the prior of the agent's previous behavior in order to make a prediction in relation to the contextual changes) or cognitive flexibility and the ability to flexibly integrate contextual changes in action anticipations. This could improve our knowledge on the contribution of these executive functions in action anticipation.

Conclusion

In sum our results suggest that adults do not only take contextual changes into account when anticipating another's action, but that they also change their previously acquired expectations of another's behavior due to the contextual change. This indicates that context information is taken into account and is thus in line with claims from predictive coding theories (Clark, 2013a). However, 2- and 5-year-olds did not integrate the contextual changes in their anticipations, suggesting that this ability develops later in childhood. Since we observed no decline in flexible anticipation performance in older adults but observed a tendency towards a linear increase over the age groups, it seems likely that life-long experience is essential for flexible action anticipation.

5 General Discussion

5.1 Summary of Findings and Research Questions

The current thesis investigated how infants, children, and adults use information about goals and movements to anticipate other's actions. Do they primarily process movements or goals, and how flexible are humans in using this information? How does this ability change over the course of development?

The ability to understand that other people have action goals has been claimed to be an essential step in the development of an understanding of others. It has been related to the ability of perspective taking (Krogh-Jespersen et al., 2015), and the coordination of one's own actions to those of others (Brownell, Ramani & Zerwas, 2006; Sebanz et al., 2006). Longitudinal studies provided evidence for relations between the ability to encode the goal of an action (using the looking-time based Woodward-paradigm) and later Theory of Mind-abilities (e.g., Aschersleben, Hofer, & Jovanovic, 2008). However, recent eye-tracking studies that measured infants' goal-encoding abilities via anticipatory eye-movements provided a rather mixed overall picture regarding infants' and young children's competencies. Thus, the examined research questions in this thesis aimed to elucidate this current debate.

While there is ample evidence of infant's abilities to anticipate towards a specific end-location of an action (e.g., Cannon et al., 2012; Falck-Ytter et al., 2006; Rosander & von Hofsten, 2011), evidence for infants' abilities to anticipate towards a specific object is less clear (Cannon & Woodward, 2012; Daum et al., 2012). When anticipating the end-location of an action, infants' can simply rely on movement information, since in these designs information about the movement and target object is intermixed. In contrast, when anticipating towards a specific object, infants have to generalize the information about the goal across different movements. Thus, anticipating the specific object of an action goes beyond the representation of mere movements. Setups based on the Woodward-paradigm (1998) are the method of choice to investigate anticipations towards a specific object. Critically, these setups include two possible targets, which change location for test trials. In order to always reach the same goal object, different movement paths have to be taken to account for the change in location. It has been shown that when using this kind of setup, infants anticipated flexibly the specific goal of a manual grasping action (Cannon & Woodward, 2012), whereas they anticipated the action according to the movement information when it was performed by an animated agent (Daum et al., 2012). Only later, from 3 years of age did children anticipate the non-human action as goal-directed (Daum et al., 2012). These contradictory findings require further investigation since the ability of goal understanding is especially relevant for developmental theories. While some claim that infants understand other's goals from early on (e.g., Woodward, 2009a), others propose that rather lower-level mechanisms (such as statistical learning) are pivotal for action anticipation and infants might rather process movements instead of action goals (e.g., Paulus et al., 2011; Ruffman et al., 2012). As a result, three eye-tracking studies were conducted to find out more about how infants and children process action goals and -movements, and how flexible they are in using this information for action anticipations.

Study 1 investigated from which age on infants and children anticipate action goals flexibly and whether the type of agent (human vs. non-human agent) influences their goal-anticipations. Therefore, two different studies were conducted. Study 1a concentrated on the factors that contribute to goal anticipation within 12-month-olds, such as type of agent and the occlusion-based paradigm. Five different experiments were carried out to investigate which factors lead to the conflicting findings of Cannon and Woodward (2012) and Daum et al. (2012). Study 1b investigated the differentiation of human- and non-human goal-directed actions systematically and included more age groups. Eleven-month-olds, 32-month-olds and adults were presented with both human and non-human actions. In both studies, participants repeatedly observed a (human or non-human) goal-directed action towards one of two goals. For test trials, the goals changed position and an incomplete action was presented. Results of Study 1a showed that none of the varying factors (type of agent, occlusion based paradigm, etc.) had an influence on infants' goal-anticipations. Across all five experiments infants showed more anticipations towards the location rather than the goal. This indicates that they processed the movement pattern instead of the goal of the action. Results of Study 1b revealed a similar pattern. Neither 11-month-olds nor 32-month-olds demonstrated goal-anticipations for both paradigms, but rather exhibited a looking-bias towards the location. Adults anticipated towards the goal in the path-paradigm but not in the hand-paradigm. Further analysis revealed that 11-month-olds' and 32-month-olds' anticipatory eye-movements in both paradigms were not related to each other. This implies that human- and non-human actions are not processed similarly in early years. In contrast, results of adults suggest that both action types are processed similarly. In summation, all experiments of Study 1 could not replicate the findings of Cannon and Woodward (2012). Infants and young children failed to flexibly anticipate an action in relation to the goal. In contrast, results showed that they rather encoded an action in relation to the movement pattern, which is in line with findings of Daum et al. (2012; see also Paulus et al., 2011). To conclude, the findings of Study 1 are in line with lower-level accounts of action anticipation (e.g., Ruffman et al., 2012). Moreover, results do not support the claim that one-year-old infants process action goals (e.g., Woodward, 2009a).

Study 2 of this thesis investigated whether children and adults anticipate an action as goal-directed when they are provided with an additional cue. Since Study 1 provided evidence that infants and children primarily process movement paths, the flexibility of children in their processing of movements was further investigated. Therefore, Study 2 assessed whether children ranging from 5 to 12 years of age (mean age = 9 years), adolescences from 13 to 17 years (mean age = 15 years) and adults encode an action as goal-directed when they are provided with an additional cue. This study also included individuals with ASC, to further investigate whether individuals with ASC are impaired in goal-encoding or whether they just have problems in using prior information, as suggested by predictive coding theories. Therefore, participants observed an agent repeatedly approaching one of two goals, while the goal's position changed from time to time. Participants had to be flexible in their processing of path-information, as the agent took different paths to reach the same goal. This further implied that they could not rely only on movement information but had to encode information about the goal. Results showed that all age groups without ASC learned about the action goal only after a few repetitions, whereas individuals with ASC needed more repetitions to encode the goal of the action and to show respective action anticipations. Importantly, individuals with ASC were not completely impaired in anticipating an action goal; they just needed more repetitions. This result is in line with the predictive coding theory (Pellicano & Burr, 2012) and the statistical learning approach (Ruffman, 2014), as they suggest that individuals with ASC have problems in using prior information. To summarize, Study 2 demonstrates that children quickly encode an action as goal-directed when they are provided with an additional cue (see also Paulus et al., 2017). The results of the study further illustrate that children, adolescents, and adults can process information about action movements flexibly.

Study 3 further examined the flexibility in using movement information for action anticipations from a life-span perspective. It was assessed whether children, younger and older adults flexibly integrate contextual changes in their action anticipations once they have previously learned that an agent always takes a specific path to reach a goal. Therefore, 2-year-olds, 5-year-olds, younger and older adults observed an animated animal repeatedly taking one of two paths to reach a goal. Then this path became blocked and no longer passable. In the subsequent test trials only the other path was passable and participants' anticipatory eye-movements were measured. Results displayed that 2- and 5-year-olds anticipated towards the interrupted path, whereas younger and older adults anticipated towards the other, continuous path. This implies that 2- and 5-year-olds still relied on the agent's previous observed behavior and could not include the contextual changes in their action anticipations, which challenges the claims of teleological stance theory (Gergely & Csibra, 2003). It seems that 2- and 5-year-old children cannot flexibly change their expectations about an agent's behavior with respect to contextual changes, once they have learned about an agent's movements. It seems that they rely on the previously learned movement information and indicates that statistical learning of movement patterns is a strong mechanism in early development.

To sum up, the studies of the current thesis provide evidence that mainly statistical learning processes in relation to movement patterns are predominantly utilized for infants' and children's action anticipations (Study 1 and Study 3). In contrast, results are not in line with the claim that infants perceive other's actions as structured around goals (Study 1) or that young children already take situational constraints into account when anticipating other's actions (Study 3). Furthermore, it has been shown that the mechanism of statistical learning seems to be constrained in individuals with ASC (Study 2), which emphasizes even more the importance of this learning mechanism in general. In the next section the contribution of these findings to the research field of action anticipation are further discussed. Lastly, implications for future research and open questions are reflected on.

5.2 Contributions of the Current Work to Action Anticipation

The main aim of the current thesis was to find out more about the ontogeny of action anticipation. More specifically, this research aimed to determine which kind of information (goals versus movements) infants, children and adults use for action anticipation. Then with what degree of flexibility can this information be utilized? The specific contributions of the current work for the research field of the development of action anticipation are discussed in the next sections. What insights does this thesis offer for developmental theories on action understanding?

The findings of this thesis are in accordance with domain-general learning accounts, such as perceptual based frequency learning (Ruffman et al., 2012). Results suggest that when infants and children observe an action several times, they encode the movements of that action and use this information to generate action anticipations. It seems that infants and children are sensitive to the frequent occurrence of patterns in other's behavior and predominantly process these patterns in relation to other's movements (see also Ruffman, 2014). Importantly, the findings of this thesis suggest that infants and children do not process other's actions primarily as structured around goals which challenges theoretical considerations (e.g., Woodward, Sommerville, Gerson, Henderson, & Buresh, 2009; see chapter 1.4.2).

Notably, no evidence was found to support the claim of teleological stance theory that children from early on process situational constraints when anticipating other's actions (Gergely & Csibra, 2003). Teleological stance theory suggests that infants have an inborn expectation that others act efficiently and should thus take situational constraints into account (Gergely & Cisbra, 2003). However, results could not support this claim. Instead, results were rather in line with the statistical learning account, as it was demonstrated that children did not include the contextual changes but instead relied on information about the agent's movements (Paulus et al., 2011; Ruffman et al., 2012). It seems that early in development lower-level processes are predominant for action anticipation and higher-level abilities, such as intentional goal-understanding or efficiency considerations might develop later (e.g., Ruffman et al., 2012).

Results of this thesis are also informative for predictive coding theory. It was proposed by predictive coding theory, that context is especially informative for action anticipation (e.g., Kilner et al., 2007). On the one hand, findings from adults are in line with this claim, as it was demonstrated that adults include contextual changes in their action anticipations. Priors, informed by the context, seem to have a significant influence on action processing. On the other hand, as has already been mentioned above, children based their anticipations on movement information and were not yet able to incorporate contextual changes, indicating that this ability develops later. Based on Gredebäck's and colleagues (2018) first attempts to explain the development of anticipatory processes from a predictive coding perspective, it could be assumed that at first infants and young children rely on statistical regularities and detect primarily movement patterns in other's actions. These movement patterns seem to be a reliable prior in terms of anticipating other's actions in many situations. However, movement information is not always sufficient, especially when situations become more complex or change very quickly. Thus, according to predictive coding theory, feedback loops update the predictive system when prediction errors are high (i.e. when simple movement information is not enough to explain the sensory input). As a result, with increasing experience and maturation, infants and children might slowly get more sensitive towards other, higher-level cues (such as situational constraints or action goals) throughout development and learn that in some situations these higher-level cues are more informative for action anticipation than movement patterns (cf., Gredebäck et al., 2018; see also Kayhan, Meyer, O'Reilly, Hunnius, & Bekkering, 2019). In section 5.2.2, the integration of these other, higher-level cues is further discussed from a predictive coding perspective. In summation, the proposed learning mechanism of predictive coding theory seems to be a promising approach to explain developmental processes of action anticipation.

Furthermore, one study of this thesis included individuals with ASC and corresponding findings contribute to theories on action anticipation within ASC. It has been demonstrated that individuals with ASC do not show a global impairment in understanding other's actions, since they were able to use information about another's action goal for anticipating that action. It rather seems that they have problems with statistical learning, as they could not use prior information as well as neurotypically developed individuals. This finding supports claims from the predictive coding theory (e.g., Pellicano & Burr, 2012) and the statistical learning approach (Ruffman, 2014) in relation to ASC, suggesting that the impairment of using prior information causes social cognitive problems of individuals with ASC.

In the next section, the findings of the thesis are further discussed with regard to the processing of goals. Subsequently, the thesis' findings in relation to the processing of movements will be discussed in further detail.

5.2.1 The processing of goals for action anticipation

Do the results of this thesis (Study 1) indicate that infants and young children never flexibly anticipate an action as goal-directed? Importantly, results suggest that movement information seems to be more *dominant* than goal information in early years. This does not indicate that infants and children never encode the goal of an action. Further evidence of this thesis (Study 3) as well as from other studies (Paulus et al., 2017) suggests that when children are provided with an additional cue that highlights the goal of an action (i.e. when the agent takes different paths to reach the same goal) they anticipate the action according to the goal. For example, Paulus et al. (2017) demonstrated that 2.5-year-olds are able to encode the action goal when they observed an agent taking different paths to reach the same goal.

Moreover, a series of further studies demonstrated flexible goal anticipations within infants when participants had more information about the context of the situation. They used a similar paradigm as Cannon and Woodward (2012) but instead of presenting infants with just the agent's hand performing the action, they provided infants with the entire human agent, sitting at a table and grasping for one of two toys (Krogh-Jespersen & Woodward, 2014, 2018; Krogh-Jespersen et al., 2015; Krogh-Jespersen et al., 2018). Presenting participants with a scene that contains two objects placed on a plain background and a hand that appears to grasp one of them (as in Study 1) could be too abstract and lacking context for infants and children. The scene does not include the whole situation, namely a person sitting at a table in front of two objects, but just provides an enlarged action detail filmed from a birds'-eye view (see also chapter 2.4.4). Infants and children might need further information of the whole situation in order to encode the action in relation to the goal. The fact that not even adults anticipated the goal for this setup (Study 1b) additionally adds concern towards this paradigm. Theoretically, it has also been claimed by predictive coding theory that information provided by the context is especially informative for action perception (e.g., Kilner et al., 2007). Environmental characteristics provide the observer with information before the action takes place, thus leaving room for top-down influences associated with the environment that might be important for goal-directed anticipations. This claim is also supported by evidence from Bello et al. (2014), who showed that children were better in verbally reasoning about why a certain goal-directed action was performed by someone else, when additional contextual cues were presented together with the action.

In light of these considerations, it seems that infants and children primarily process movement patterns and use this information for their action anticipations, especially when situations seem unfamiliar (as in the paradigms using the non-human agent) and ambiguous (as the situation in the Cannon and Woodward-paradigm, which only shows a portion of a situation). It has also been claimed that the processing of movements of an action might be a sufficient and effective strategy for many situations (Daum et al., 2012). However, in order to process the specific goal of an action, infants might need additional cues for goal anticipation (e.g. Krogh-Jespersen & Woodward, 2014; Paulus et al., 2017; Study 2 of this thesis). The processing of goals might be cognitively more demanding (see e.g., Krogh-Jespersen & Woodward, 2014) and therefore requires more information in early development. In line with this, Uithol and Paulus (2014) claimed that action anticipation gets more difficult when two possible targets are available and that additional information is needed to encode the goal. Results of this thesis suggest that this additional information has to go beyond the mere repetition of the same action. Additional cues beyond frequency information seem necessary for goal anticipation within infants and young children.

The findings of the current thesis are also not in line with a large amount of looking-time studies that provide converging evidence for goal-understanding within infants (e.g., Woodward 1998, 1999; Guajardo & Woodward, 2004; Sodian & Thoermer, 2004; Sommerville et al., 2005). These studies do not only include manual grasping actions (e.g., Guajardo & Woodward, 2004; Woodward 1998, 1999), but also the perception of others goal-directed actions such as pointing (e.g., Brune & Woodward, 2007; Woodward & Guajardo, 2002) or gaze direction (e.g., Woodward, 2003). Others demonstrated in longitudinal assessments that goal-encoding abilities in infancy are related to later Theory of mind competences in childhood (e.g., Aschersleben et al., 2008; Sodian et al., 2016), indicating that an early understanding of other's action goals is essential for broader social-cognitive development (Woodward et al., 2009). Now the question arises as to how this converging evidence from looking-time studies, showing that infants do encode action goals, is compatible with the findings of the current thesis? How can these contradicting results be explained?

The observation that infants show indications for certain competences in looking-time measures but not in anticipatory looking measures has also been made by others (e.g., Daum et al., 2012; Paulus et al., 2011) and is thus not a new finding. On the one hand, it has been claimed that the informative value of looking-time studies is limited, and results should be interpreted very cautiously (e.g., Haith, 1998). As has been discussed in chapter 1.1.2, looking-time studies were originally designed to test basic low-level sensory discrimination abilities within infants; therefore, one should be very careful when drawing strong conclusions about higher-level competencies out of these experiments. Recently, even the validity of false-belief looking-time measures has been questioned, since adult participants interpreted the plot of some of the paradigms differently to what researchers intended the plot to be (Low & Edwards, 2018). They presented adults with three scenarios of false-belief looking time tasks and observed whether their verbal interpretations matched with the intended interpretation of the task developers. The results suggest that the adult's interpretations met the intended content in only one out of three tasks. This underlines the suggestion to interpret results of looking-time measures cautiously and adds further concern towards this method. Moreover the measure of looking time is very global, and there is not much control or knowledge about possible perceptual and attentional influences.

On the other hand, despite the critics on the measure per se (e.g., Aslin, 2007; Haith, 1998; Hunnius, 2007), it has been claimed that the two methods differ in terms of cognitive demands on infants, and that this might be the cause of the differing findings (see e.g., Daum et al., 2012). As has been described in chapter 1.1.2, looking-time measures assess infants' expectations about how an action is going to unfold *post-hoc*, namely *after* the action is completed and thus all information about the action is completely provided to the observer when their reactions are assessed. Additionally, infants have more time to process the information. In contrast, anticipatory eye-movements are measured *online*, which means that anticipations are measured *before* the action is completed. Thus, information about the action is incomplete for the observer, and there is less processing time available. A possible explanation for the different findings could be that early in development, infants only process goals post-hoc, when they have enough time and information available, and only later in development do children also process goals more quickly with less available information (Daum et al., 2012).

Another suggestion, also provided by Daum et al. (2012), implies that two different mechanisms, namely two visual pathways (Goodale & Milner, 1992; cf., Daum et al., 2012), are responsible for the different results. The ventral (what) pathway is associated with goal information, whereas the dorsal (where/how) pathway is associated with movement information. It has been claimed that early in development, processing is dominated by the quicker dorsal pathway; whereas the integration of dorsal and ventral information occurs later in development. While this account suggests that the two mechanisms are integrated in later development, Uithol and Paulus (2014) hypothesize that the two approaches (post-hoc versus online measurements) tap into different underlying mechanisms that also have different developmental pathways. In conclusion, future research should not focus on the investigation of whether and at what age infants "understand other's action goals" generally, but instead treat infants' capacities more fine-grained and examine which mechanisms contribute to the various abilities.

5.2.2 The processing of movements for action anticipation

Considering the processing of movements, the findings of the thesis are twofold. On the one hand, there is evidence that children and adults process movements flexibly. Study 2 of this thesis together with Paulus et al. (2017) provide evidence that children from 2.5-years of age process movements flexibly when they observe an agent taking different paths towards the same goal. However, in this paradigm, children are not repeatedly familiarized with a specific movement of the agent (i.e. the agent does not always take one specific movement path but changes its path choice from time to time). The constant information in this paradigm is the goal of the action, as the agent always approaches the same goal. This indicates that information about the goal was highlighted in expense of the information about the movement, which allowed a more flexible movement processing.

On the other hand, the present work provides evidence that when children once learned about an agent's movements (e.g., an agent always taking one specific path), they keep relying on this information, even though contextual changes would lead to a change in movements. When 2- and 5-year-old children observe an agent always taking one specific path to reach a goal and suddenly this path becomes blocked, they still initiate eye-movements towards the blocked path instead of an alternative, continuous path that leads to the goal (Study 3). Similar observations due to infants' inflexibility in updating previously acquired movement information were made by Paulus et al. (2011). In their study, infants observed the agent repeatedly taking a different path than before, but kept anticipating towards the other path the agent repetitively took before. They could not "unlearn" the agent's previous path choice. Correspondingly, the findings of Study 1 may suggest a similar pattern. In this paradigm they were presented with the same action movements several times (i.e. an agent approaching one of two goal objects) until the context changed and the targets swapped positions. Nevertheless, infants' anticipations were based on the previous movement path, as they kept anticipating towards the same location as before. Anticipating towards the goal object in the new location would have required infants to adapt their anticipations.

Together, the studies of this thesis provide evidence that when infants and children once learn about the specific movement of another's action through repeated observation of the action, they have problems in adapting their anticipations to changes in the environment. Importantly, additional experiments and further analyses make it rather unlikely that children did not notice the contextual changes of the scene (see e.g., chapter 2.3.1.1, 4.3 and 4.4). For example in an additional pilot task in Study 3, instead of measuring anticipatory eye-movements, children were explicitly asked which path the agent can take after the gap appeared on one of the paths (without previously familiarizing them with the agent always taking one specific path). Most of the children referred to the continuous path, indicating that they recognized the gap and understood that the agent has to take the other path. In most of the experiments in Study 1, infants' looking towards the changed objects was controlled for, to make sure that infants recognized the change of the location. The question now arises why children do not adapt their anticipations towards contextual changes, once they have learned about an agent's movements?

It could be argued that infants' and children's cognitive flexibility is still developing, which might be a reason why they keep relying on previously learned movement information instead of updating that information due to contextual changes. Cognitive flexibility has been defined as the ability to dynamically activate and modify cognitive processes in response to changing task demands (Déak, 2003, p. 275). Since it has been shown that cognitive abilities, such as inhibitory control and cognitive flexibility continue to develop through middle childhood and adolescence (e.g., Crone et al., 2004; Gupta et al., 2009), it could be argued that this might be a reason for infants' and children's inability to adapt their anticipations towards contextual changes. Related to that suggestion, it could also be assumed that children "automatically" look at the previous location due to their previous learning experience and have thus less control over their eye-movements. Moreover, children in Study 3 referred to the continuous path when they were explicitly asked to, indicating that they have knowledge about the agent's possibilities. The claim that infants and children might have less control over their automatic eye-movements is also in line with studies showing that the ability to control for saccadic eye-movements still develops into adolescence and has been referred to prefrontal maturation as well as “the ability to inhibit prepotent but incorrect responses” (Kramer, de Sather, & Cassavaugh, 2005, p. 761; see also Klein & Foerster, 2001). However, no action anticipation study has yet directly assessed the relation between flexible action anticipation abilities and executive control abilities, such as inhibitory control and cognitive flexibility. Thus further studies are needed to see whether and how executive control processes might influence the flexible processing of movement information for action anticipation.

Another reason for infants’ and children’s inflexible use of movement information could be that infants and children weigh information about the movement more strongly than information about the change in context. Here, predictive coding theory offers a plausible approach: It has been claimed that the ability to integrate several information sources and to weigh them according to their predictive power is based on “hyperpriors” (Clark, 2013a). As described in chapter 1.4.4, hyperpriors are priors that include general knowledge about the world, namely knowledge on a more abstract level, such as that people take an alternative way to approach their goal when their usual route is blocked, or that people usually tend to act in a goal-directed manner. For the situations in the current studies (Study 1 and Study 3), participants have to integrate two possible priors and weigh them according to their predictive power. One prior is based on the previous experience, namely the observation of the movement, whereas the other prior includes the contextual changes. The knowledge about which prior has more predictive power and should be used for top-down predictions is based on the hyperprior (e.g., to know that the information about a blocked path is more reliable for prediction than the previous movement). It has been argued by predictive coding theory that these hyperpriors have to be built and learned through experience. It might be possible, that infants’ and children’s hyperpriors in relation to the situations in the current studies are not yet sufficiently developed. Thereby, not only the decision of which information source is the more reliable one, but also the integration of several information sources might be difficult for young children. In sum, when argued from a predictive coding point of view, the results of the current studies suggest that infants and children weigh priors that are based on movement information with a high predictive power. Thereby it remains to be an open question whether the reliance on that prior is due to problems with the integration of an additional information source or whether the weighing of the predictive power of those two sources is still not adequate within children.

5.3 Theoretical Conclusion

In summation, results of the studies of the present thesis are informative in relation to the provided theories of action anticipation (see chapter 1.4). Particularly, results challenge domain-specific theories of action anticipation, such as the intentional goal-encoding approach of Woodward (2009a) and the teleological stance theory by Gergely and Csibra (2003). Domain-general approaches such as the statistical learning-account as well as predictive coding theory, however, seem more fruitful in explaining action anticipation abilities in the course of development. In addition, the two domain-general approaches have been valuable to explain differences in action anticipation between individuals with ASC and comparison participants, which even more support their broad explanatory power.

5.4 Future Directions and Open Questions

In light of the findings of this thesis and the previously outlined gained insights for the development of action anticipation, new questions arise that are relevant for future research.

One of the main findings of this thesis concerns infants' anticipation of action goals. It has been observed that infants and young children do not anticipate other's action goals flexibly. Results of an influential study (Cannon & Woodward, 2012) could not be replicated in this thesis, thus questioning the claim that infants process other's actions in relation to goals. With that in mind, further research is necessary to find out more about infants' goal anticipation abilities. I have suggested already in chapter 2.6 and 5.2.1 that infants might need additional cues in order to process the goal of the action. It has also been shown that highlighting the action goal facilitates action anticipation (Adam et al., 2016; Henrichs et al., 2012). Future research could investigate which cues are needed by infants to encode the action goal. For example, a paradigm similar to Study 2 could be suitable to see whether highlighting the goal would result in goal-anticipations within infants. In a future study, infants could be presented with a hand always grasping the same of two objects whereas the objects' position changes from time to time. Infants would observe the hand taking different movement paths to always grasp the same object. In order to make adequate action anticipations, infants would have to rely on the information about the goal. Paulus et al. (2017) showed that 2.5-year-olds could anticipate the action as goal-directed in this paradigm; however, it remains an open question whether younger children are able to do so as well.

To present participants with just an enlarged detail of an action, such as a human hand grasping for objects without providing details of the whole situation, has the advantage of having more control over possible distracting and influencing factors. Furthermore, studies could show that in their daily life, infants start from around their first birthday to focus more on hands than faces in their observation of others (Fausey, Javaraman, & Smith, 2016; cf., Smith, Jayaraman, Clerkin, & Yu, 2018). This indicates that the observation of a hand grasping for an object, even though it is just an enlarged action detail, might not be that unusual for infants. Nevertheless, it could also be argued that for encoding an action as goal directed, infants might need additional information about the context of an action. For example, in Study 1 and Cannon and Woodward's study (2012), information about the setting in which the action takes place or about the person who performs the grasping action is not provided to participants when the action is presented. Eye-tracking stimuli, which present participants with segmented action details might seem abstract and artificial to the observer. It has also been claimed by predictive coding theory that the environment constantly provides the observer with lots of valuable information (Clark, 2013a). Thus it might be interesting, to study infants' goal anticipations in more naturalistic settings. The use of more naturalistic settings might not only provide the observing child with more information about the context but would also result in a more ecologically valid assessment. On the one hand, this could be realized by creating more naturalistic eye-tracking stimuli that do not only contain enlarged action details but the whole situation in which the action is performed (for example similar to the paradigm of

Krogh-Jespersen & Woodward, 2018). Whereas on the other hand, instead of placing infants in front of a screen and showing them movies of other's actions, infants' action anticipations could also be directly investigated in an interactive situation with another person. This would create a more naturalistic environment that is closer to infants' daily interactions with others. To my knowledge, no published study has investigated infants' goal anticipations during a live interaction with another person. Previous so called "ego-centric vision studies" from various research areas could show that observations from naturalistic contexts often revealed different results than observations from structured, experimental settings (e.g., Foulsham, Walker, & Kingstone, 2011; Tamis-LeMonda, Kuchirko, Luo, Escobar, & Bornstein, 2017; cf., Smith, Jayaraman, Clerkin, & Yu, 2018). This underlines the importance of studying infants' anticipation abilities in naturalistic environments. Technical advances, such as head-mounted eye tracking, offer new possibilities to examine infants' action anticipations in "the wild" (e.g., Slone et al., 2018).

Another point that could shed more light on infants and children's goal anticipation abilities considers the relation of explicit and implicit information processing. It has been claimed that social information is processed via two distinct systems, namely an explicit and an implicit system (Apperly & Butterfill, 2009; see also chapter 1.1.1). The explicit system is based on language, is more effortful but highly flexible. The implicit system is not tied to language and is more efficient but less flexible. The two-systems-account suggests that implicit information processing develops earlier than explicit processing. However, recent studies observed that knowledge about other's actions could also be acquired first on an explicit level and then later on an implicit one (e.g., Schuwerk & Paulus, 2016). Results of Study 3 of this thesis indicate a development in a similar direction, when children have to consider sudden situational constraints. Since the studies of this thesis focused on infants' and children's implicit goal processing, it would be revealing to investigate goal processing on an explicit level as well, in order to gain a better overall understanding about young children's goal understanding. Do young children predict another's action in relation to the goal when they need to verbally reason about the action outcome? Maybe the processing of action goals is cognitively too demanding and effortful and is therefore processed first on an explicit level before it becomes more automatic and enables a faster, implicit processing later in development (cf., Schuwerk & Paulus, 2016). This would be also in line with the observations of Schuwerk and Paulus (2016), who demonstrated that 5-year-old children based their action predictions on efficiency considerations when they were explicitly asked, whereas their visual anticipations did not reflect this pattern. Maybe the processing of other's action goals follows a similar developmental pathway. Future studies could present young children from around 2 years of age with the paradigms of Study 1, and instead of measuring anticipatory eye-movements, experimenters should explicitly ask them in test trials which goal object the agent is going to approach. The inclusion of an adult population would be interesting as well, since results of this thesis showed that their anticipatory behavior in relation to action goals was surprisingly inconclusive in one paradigm (Study 1b).

It has been proposed in previous chapters of this thesis that executive functions might play a role for action anticipation. So far, previous studies and theories have rarely discussed a possible relation between executive functions and action anticipations. Cannon and Woodward (2012) suggested that the ability to anticipate action goals could be related to general cognitive capacities such as working memory. Similarly, Study 3 of this thesis discussed a likely relation between executive functions, especially inhibitory processes, and the ability to include contextual changes in action anticipations. Zelazo (2015) claimed that executive functions "provide an important foundation for learning and adaptation across a wide range of contexts" (Zelazo, 2015, p. 56). Generally, research has shown that executive functions develop over a very wide age span. First abilities emerge around the second half of the first year of life (e.g., Pelphrey et al., 2014). Between 2 and 5 years of age, further important developmental changes take place (cf., Zelazo & Müller, 2014; Zelazo, 2006). At around 12 years of age, children's performance on many executive functions tasks reach adult-level, while performance on some tasks continue to change until young adulthood or beyond older adulthood (e.g., Gazzaley et al., 2008; Zelazo et al., 2004; cf., Zelazo & Müller, 2014). Executive functions might play a significant role for the ability to change anticipations due to contextual changes. Here, especially inhibitory processes and cognitive flexibility might be an essential capacity. In relation to the ability to anticipate action goals in the Woodward-paradigm, it could be suggested that inhibitory control processes play a significant role for successful goal anticipation. One could assume that infants and young children could not inhibit the previously learned movement of the action after the two objects changed place, and thus kept anticipating towards the same location as before. One study already demonstrated that infants needed more time to initiate saccades towards the goal than when they anticipated towards the location (Krogh-Jespersen & Woodward, 2014). This could be an indication that inhibitory processes play a role in flexible goal-anticipations. Similarly, it has been discussed in relation to Study 3 (see chapter 4.5) that children might not have been able to inhibit the previously learned movement, in order to adapt their anticipations to the change in context. Thus, future studies could investigate a possible direct relationship between abilities in executive functions and the ability to integrate contextual changes in action anticipations. This would improve our knowledge about possible underlying mechanisms of action anticipation.

6 References

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7 Appendices

A. Paper by Ganglmayer, Attig, Daum and Paulus (2019), published in Infant Behavior and Development, based on data presented in this thesis

Ganglmayer, K., Attig, M., Daum, M. M., & Paulus, M. (2019). Infants' perception of goal-directed actions: A multi-lab replication reveals that infants anticipate paths and not goals. *Infant Behavior and Development, 57,* 101340. https://doi.org/10.1016/j.infbeh.2019.101340

B. Paper by Ganglmayer, Schuwerk, Sodian and Paulus (2019), published in Journal of Autism and Developmental Disorders, based on data presented in this thesis

Ganglmayer, K., Schuwerk, T., Sodian, B., & Paulus, M. (2019). Do children and adults with autism spectrum condition anticipate others' actions as goal-directed? A predictive coding perspective. *Journal of Autism and Developmental Disorders*. https://doi.org/10.1007/s10803-019-03964-8

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Eidesstattliche Versicherung

Statement of Scientific Integrity

Ganglmayer Kerstin

Name, Vorname

Last name, first name

Ich versichere, dass ich die an der Fakultät für Psychologie und Pädagogik der Ludwig-Maximilians-Universität München zur Dissertation eingereichte Arbeit mit dem Titel:

I assert that the thesis I submitted to the Faculty of Psychology and Pedagogy of the Ludwig-Maximilian-Universität München under the title:

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I assert I have not applied anywhere else for a doctoral degree nor have I obtained a doctor title on the basis of my present studies or failed a doctoral examination.

München, 15.07.2020

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Place, Date

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