

Object-Directed Action Experiences and their Effect on Cognitive and Social

Development

by

Klaus Libertus

Department of Psychology & Neuroscience
Duke University

Date: _____

Approved:

Amy Needham, Co-Chair

Amy S. Joh, Co-Chair

Jennifer M. Groh

Leonard E. White

Stephen R. Mitroff

Dissertation submitted in partial fulfillment of
the requirements for the degree of Doctor
of Philosophy in the Department of
Psychology & Neuroscience in the Graduate School
of Duke University

2010

ABSTRACT

Object-Directed Action Experiences and their Effect on Cognitive and Social

Development

by

Klaus Libertus

Department of Psychology & Neuroscience
Duke University

Date: _____

Approved:

Amy Needham, Co-Chair

Amy S. Joh, Co-Chair

Jennifer M. Groh

Leonard E. White

Stephen R. Mitroff

An abstract of a dissertation submitted in partial
fulfillment of the requirements for the degree
of Doctor of Philosophy in the Department of
Psychology & Neuroscience in the Graduate School
of Duke University

2010

Copyright by
Klaus Libertus
2010

Abstract

Reaching is an important and early emerging motor skill that allows infants to interact with the physical and social world (e.g., when sharing objects). Despite the importance of motor experiences in early infancy, few studies have considered the influence of reaching behavior on cognitive, social, and motor development. In this dissertation, reaching behavior was selectively manipulated in 73 non-reaching three-month-old infants using four different training interventions. Infants' reaching and social cognition skills were assessed and compared, and the long-term effects of one particular training intervention were explored.

Of the four training interventions used here, one procedure—referred to as active training—facilitated domain-specific development (reaching and grasping behavior) and increased infants' preferential orienting towards faces in a visual-preference task (face preference). None of the remaining three training interventions facilitated motor development and only one increased face-preference behavior. However, a relation between face-preference behavior and motor experience was present in all trained infants as well as in three- to 11-month-old untrained infants. In untrained infants, face-preference behavior was the earliest social-cognition skill to emerge and was related to later emerging skills such as gaze following. Therefore, a preference for faces may be an important basic social-cognition skill that influences future social development.

Additionally, the long-term effects of the active-training procedure were assessed in 14 infants who were tested one year after they had participated in the active-training intervention. Even after one year, converging evidence showed advanced manual exploration and object-engagement skills in trained compared to untrained infants.

The studies described in this dissertation attempt to systematically investigate the role of early reaching experiences on subsequent development of motor and social cognition behaviors. The present findings demonstrate the importance of self-produced motor experiences on the development of social cognition and have implications for our understanding of typical development and the etiology of developmental disorders in social cognition.

Dedication

To my family, thank you for your love and support throughout the years.

Contents

Abstract.....	iv
List of Tables.....	xi
List of Figures.....	xii
Acknowledgements.....	xiv
1. Introduction.....	1
1.1 Motor development as catalyst for change.....	3
1.2 Direct manipulations of action experience.....	6
1.3 The development of reaching.....	7
1.4 The development of social orienting towards faces.....	9
1.5 Dissertation outline.....	11
2. General Methods.....	13
2.1 Participants.....	13
2.2 Reaching Assessment.....	13
2.3. Analysis of manual exploration data.....	15
2.4 Eye-Tracking Procedure.....	16
3. Experiment 1: The influences of simulated reaching experience on motor and social development.....	17
3.1 Introduction.....	17
3.2 Method.....	21
3.2.1 Participants.....	21
3.2.2 Apparatus.....	23
3.2.3 Measures.....	24
3.2.4 Procedure.....	27

3.2.5 Coding and Reliability	30
3.3 Results	31
3.3.1 Manual-exploration assessment.....	31
3.3.2 Visual-preference task	36
3.3.3 Regression model	39
3.4 Discussion.....	41
4. Experiment 2: Relations between basic social cognition skills during the first year and influences of infants' overall activity level.....	48
4.1 Introduction.....	48
4.2 Method	53
4.2.1 Participants.....	53
4.2.2 Apparatus.....	54
4.2.3 Measures.....	54
4.3 Results	58
4.3.1 HSF preference.....	59
4.3.2 Face preference	60
4.3.3 Gaze following.....	63
4.3.4 Anticipation of actions.....	64
4.3.5 Regression models on motor activity and face preference.....	66
4.3.6 Correlations among social cognition behaviors.....	68
4.4 Discussion.....	70
4.4.1 Activity level and face-preference behavior.....	70
4.4.2 Face-preference behavior and its relation to other social cognition abilities....	72
4.4.3 Gaze-following behavior	75
4.4.4 Action anticipation.....	76

5. Experiment 3: Influences of external encouragement and first-hand experiences on infants' motor and social development	80
5.1 Introduction.....	80
5.2 Method	85
5.2.1 Participants.....	85
5.2.2 Procedure.....	87
5.2.3 Measures.....	89
5.3 Results	90
5.3.1 Manual exploration	90
5.3.2 Eye-tracking tasks.....	94
5.3.3 Correlations between demographic, social cognition, and manual measures.	98
5.4 Discussion.....	100
6. Experiment 4: Long-term effects of simulated reaching experience	107
6.1 Introduction.....	107
6.2 Method	110
6.2.1 Participants.....	110
6.2.2 Apparatus	111
6.2.3 Measures	111
6.2.4 Coding and Reliability	116
6.2.5 Data Analysis	117
6.3 Results	119
6.3.1 Perspective-taking task.....	119
6.3.2 Sustained-exploration task.....	120
6.3.3 Novel object exploration task	123
6.3.4 Temperament questionnaire.....	126

6.3.5 Correlations between measures	127
6.4 Discussion.....	128
7. General Discussion	136
7.1 Why does motor training affect development?.....	137
7.2 What experiences encourage face-preference behavior?	140
7.3 How are motor abilities and social cognition related?.....	143
7.4 How long lasting are the effects of early motor training?	146
8. Future directions	148
References.....	152
Biography	167
Publications	167
Scholarships and Awards.....	167
Memberships in Honorary Societies.....	167

List of Tables

Table 1: Experiment 1, participant characteristics.....	23
Table 2: Experiment 1, measures completed by participants	27
Table 3: Experiment 1, within-group analyses of the manual-exploration task	36
Table 4: Experiment 2, participant characteristics.....	53
Table 5: Experiment 2, correlations between social cognition measures for 3-5-month-old infants	68
Table 6: Experiment 2, correlations between social cognition measures for 9-11-month-old infants.....	70
Table 7: Experiment 3, participant characteristics.....	87
Table 8: Experiment 3, within-group comparisons of face-preference behavior.....	96
Table 9: Experiment 3, correlations among demographic, social cognition and manual-exploration measures.....	100
Table 10: Experiment 4, participant characteristics.....	110
Table 11: Experiment 4, temperament differences	126
Table 12: Experiment 4, correlations between measures.....	128

List of Figures

Figure 1: Schematic of the four-step reaching assessment.	15
Figure 2: Experiment 1, example of the Active- and Passive-Training procedures.	29
Figure 3: Experiment 1, outline of assessment and training schedule.	30
Figure 4: Experiment 1, manual-exploration results.	33
Figure 5: Experiment 1, face-preference behavior results.	38
Figure 6: Experiment 1, relationship between manual object contact and face preference.	41
Figure 7: Experiment 2, measures of the eye-tracking battery.	58
Figure 8: Experiment 2, HSF preference and face preference results.	60
Figure 9: Experiment 2, horizontal eye-gaze position during face-preference task.	62
Figure 10: Experiment 2, results of gaze-follow task.	64
Figure 11: Experiment 2, results of the action anticipation tasks.	66
Figure 12: Experiment 3, outline of assessment and training schedule.	86
Figure 13: Experiment 3, examples of training procedures.	89
Figure 14: Experiment 3, manual-exploration results.	93
Figure 15: Experiment 3, combined face-preference results for Experiments 1-3.	94
Figure 16: Experiment 3, results of anticipation tasks by training condition.	97
Figure 17: Experiment 4, bird-eye schematic of perspective-taking task.	113
Figure 18: Experiment 4, objects used in a) sustained-exploration task and b) novel-object exploration task.	116
Figure 19: Experiment 4, results of the perspective-taking task.	119
Figure 20: Experiment 4, results of the sustained-exploration task.	122
Figure 21: Experiment 4, results of the novel object exploration task.	125

Figure 22: Face-preference scores by amount of manual control and attention drawn to objects during the training experiences. 142

Acknowledgements

This dissertation would not have been possible without the guidance and support of my advisor, Dr. Amy Needham, who continuously encouraged me in my own research endeavors. I am also grateful to Dr. Amy Joh for her comments and insights on my work and ideas. By sharing her knowledge with me she has influenced many aspects of my research and career. I am thankful to Dr. Kevin Pelphrey who introduced me to research on social cognition and to eye tracking with infants. Furthermore, I wish to thank Dr. Leonard White for his challenging questions and for expanding my scientific horizon, Dr. Jennifer Groh for welcoming me to her lab and demonstrating how to enjoy teaching, and to Dr. Stephen Mitroff who in addition to scientific advice also provided data for my studies.

The research described in this dissertation would not have been possible without the many members of the Infant Perception Lab and their assistance in participant recruitment, data collection, and data analysis. In particular, I would like to thank Stephanie DiGuseppi, Dr. Marissa Greif, Jennifer Gibson, and my VIP students Megan Kuhfeld, Jessie O'Connor, Katherine Rief, and Addie Price. Finally, I would like to thank all the parents who participated in my studies and allowed me to visit their homes and work with their children.

1. Introduction

Among the first challenges an infant faces are learning to interact with the physical world and to coordinate her own limbs. Simultaneously, infants also have to learn how to behave in a complex social world. Navigating the social world can be a daunting task even for experienced adults. Nevertheless, with just a few months of experience, infants seem to be able to handle these two concurrent challenges.

Researchers in Developmental Psychology often assumed that motor and social development are two separate processes and that infants tackle each challenge independently. Motor development is seen as a growth process that originates from within the infant and is independent from the social environment. A more extreme position suggested that motor abilities are unfolding with age and are solely dependent upon maturational constraints. The maturational position dates back to observations that restricting motor activity in tadpoles (Carmichael, 1926)¹ or human infants (e.g., Dennis, 1935; Dennis & Dennis, 1940) had relatively little impact on the emergence of future motor skills. Several shortcomings of the maturational view have since been identified. More recent views acknowledge maturational constraints (e.g., physical growth) but emphasize the role of learning and experiences in motor development (e.g., Adolph & Joh, 2009). Nevertheless, motor development is still regarded as a process that is largely independent from the social world. In contrast, social development is seen as more dependent on experiences with a social partner. While some rudimentary social interaction abilities such as imitation of facial expressions seem to be present at birth in several primate species (Ferrari, et al., 2006; Meltzoff & Moore, 1977; Myowa-

¹ Note that Carmichael (1926) did not interpret his findings in this manner and instead argued for an interaction between environment and heredity.

Yamakoshi, Tomonaga, Tanaka, & Matsuzawaz, 2004), social behaviors more broadly are defined as *“elicited by the presence of another human and terminated by the departure of that human”* (Bower, 1982, p. 256). Therefore, social development clearly requires environmental stimulation.

For infants, however, motor and social development may not present separate and unrelated challenges. Interacting with the physical world does not happen in isolation but in the context of social situations such as play or exploration. Similarly, social engagement with another person involves moving the limbs and controlling muscles. Hence, one cannot separate social from motor development. Embodied views of development also emphasize the mind-body coupling by pointing out that we cannot separate motor from social or cognitive development (Corbetta, 2009; Smith & Gasser, 2005). Further, there are parallels in the domains of motor and social development. For example, orienting to faces and rudimentary reaching attempts are present in newborns, both behaviors disappear around two months of age and re-emerge around 4-5 months of age (Johnson, Dziurawiec, Ellis, & Morton, 1991; Keller & Boigs, 1991; Maurer, 1985; von Hofsten, 1984). It is unknown whether concurrent developmental patterns in the motor and social domain are a coincidental reflection of unrelated parallel processes or an indication of a deeper connection between motor and social development.

In my dissertation research, I investigated the influences of motor experiences on subsequent development in both motor and social domains. Few studies have investigated the effects of active, self-produced motor experiences on cognitive and social development in human infants by examining reaching behavior—a very early emerging motor skill. To what extent does reaching experience influence social development, and what is the relationship between the two areas of development? I

addressed these questions in four experiments. In Experiment 1, I investigated the effects of simulated reaching experience (see Needham, Barrett, & Peterman, 2002) on motor and social development. To examine how motor experiences shape development, I compared the effects of active and passive training procedures on behavior. In Experiment 2, I further examined the link between motor and social behaviors and developed a new measure to explore the development of social cognition skills during the first year of life. In Experiment 3, I returned to the issues raised in Experiment 1 and examined how different aspects of the simulated reaching experience affect motor behavior and social cognition abilities as measured using the assessment developed in Experiment 2. Finally, in Experiment 4, I investigated the long-term effects of early motor experiences on infants' subsequent motor abilities, social skills, and temperament.

1.1 Motor development as catalyst for change

The emergence of coordinated body movements and motor skills are an important part of typical, healthy development in infants. Gross-motor skills are relatively easy to observe, allowing for the compilation of approximate developmental timetables (de Onis, 2006). It is expected that most typically developing infants would begin to sit up without support around 6 months of age, engage in crawling around 8 months of age, and begin to walk alone around 12 months of age (de Onis, 2006; Rosenblith, 1992). However, the importance of motor development goes beyond the attainment of new skills. Several researchers have noted that motor development serves as a precursor or prerequisite to cognitive, perceptual, social, and emotional development in infancy (e.g., Bushnell & Boudreau, 1993; Campos, et al., 2000; Gibson, 1988; Woodward, 2009). Learning occurs in a context of active exploration and new

motor skills open up novel opportunities for learning about the environment and about our own bodies.

For example, the degree to which an infant engages in active grasping and exploring of an object determines the kind of information (e.g., shape, texture, or weight) that can be obtained about the object (Bushnell & Boudreau, 1993). Attainment of new motor skills opens up new opportunities for learning about object properties, object boundaries, and function of objects. Infants with advanced manual exploration skills show increased attention towards properties of objects (such as when an object makes a sound) that may guide their own future actions (Eppler, 1995). Similarly, infants engaging in active manual object exploration show more advanced object segregation abilities, possibly because active infants explore objects more thoroughly and therefore identify features of objects that are helpful for object segregation (Needham, 2000). Further, grasping infants use exploratory strategies that match the properties of the explored object or surface. For example, soft objects are squeezed more than hard object and flexible surfaces are pressed more than rigid ones. As infants become older, the relation between object and surface properties are increasingly considered when choosing exploration strategies (Bourgeois, Khawar, Neal, & Lockman, 2005). Thus, active exploration appears to provide infants with opportunities to learn about object properties, object boundaries, object functions, surface properties and, over time, also about the relation between object and surface properties.

In addition to learning about the physical world, motor development also influences infants' learning about the social world. For example, as infants acquire better postural control abilities and engage in independent reaching they begin to shift from face-to-face interactions with their caregivers to interactions with their caregiver about

objects (Fogel, Dedo, & McEwen, 1992; Fogel, Messinger, Dickson, & Hsu, 1999).

Independent reaching experiences make objects more interesting and salient and allow infants to incorporate objects into their social interactions with others. Slightly later, the onset of upright locomotor activity increases both infants' positive and negative (e.g., testing of wills) exchanges with their mothers (Biringen, Emde, Campos, & Appelbaum, 1995). Further, independent walking experiences encourage infants to actively initiate social interactions with others (Clearfield, Osborne, & Mullen, 2008). Thus, the attainment of new motor skills changes how infants interact with the environment and with others.

The studies reviewed above suggest connections between motor, cognitive, and social domains of development. However, how the different domains are related remains unclear. Does motor development *cause* changes in cognitive and social development, or does it merely co-occur with them? Do infants engage more with objects because they learned how to sit independently (freeing their hands for exploration) or are they encouraged to learn how to sit independently because of their motivation to act on objects and sitting is a necessary step to achieve this goal? Similarly, do infants initiate more social interactions because they learned how to locomote or does a growing desire to interact with others encourage them to learn how to locomote? Findings from the studies reviewed above only showed correlations and cannot answer these questions because they tested different groups of infants at different ages. Direct manipulations of motor ability are necessary to identify the causes that underlie developmental transitions.

1.2 Direct manipulations of action experience

Perhaps the earliest direct evidence for the relationship between motor and perceptual development comes from an animal study in which motor experience was directly manipulated (Held & Hein, 1963). In this classic study, kittens were raised in the dark except for brief episodes inside a patterned carousel apparatus. Inside the carousel, one group of kittens was allowed to move around independently—the visual input they received was contingent on their movements. In contrast, a second group of kittens sat passively inside a sled that was pulled by a kitten from the active group—the visual input they received was not contingent on their own movements. Subsequently, the kittens behavior was tested on a visual cliff (Gibson & Walk, 1960), an apparatus which has a shallow and a deep end and creates the visual impression of a steep drop-off going from the shallow to the deep side, but both sides provide support for walking. When placed on the visual cliff, only the kittens with active experience avoided deep side of the drop off, suggesting that actively obtained visual experience shaped kittens' interpretation of the visual world and their visually-guided behaviors.

Experiments manipulating motor experience are rare in human infants because of ethical issues related to depriving infants of necessary experiences (but see Dennis, 1935). Exceptions are experiments that enable infants to practice a new motor skill before they would typically attain it on their own (e.g., McGraw, 1935). In one study on the effects of self-produced locomotion, pre-crawling infants experienced about 40 hours of independent locomotion using infant walkers in their homes (Bertenthal, Campos, & Kermoian, 1994). When subsequently tested on the visual cliff, the trained infants avoided the deep side of the visual cliff and showed an increase in heart rate when placed on the deep side. Untrained comparison groups did not show these effects,

suggesting that, like the kittens in Held and Hein's (1963) study, experience with self-produced locomotion changed the way infants perceived the visual cliff (Bertenthal, et al., 1994).

Similarly, studies on infants' visually-guided reaching behavior showed that self-produced reaching experience alters both infants' motor abilities and their perception of others' actions. Non-reaching infants were trained using "sticky mittens" that enabled them to pick up objects just by swiping at them. Following the training experience, infants showed increased visual and manual exploration of objects and perceived actions by others as goal directed (Needham, et al., 2002; Sommerville, Woodward, & Needham, 2005).

Together, the studies reviewed above suggest that passive observation alone may not be sufficient for the development of complex visually guided behaviors. Instead, learning and growth occurs during the active interaction of the infant with the environment (Gibson & Pick, 2000). Of particular interest for the investigations presented in this dissertation are the kinds of developmental changes associated with infants' improved reaching skills.

1.3 The development of reaching

Reaching skills are attained earlier than locomotor skills and are among the earliest motor abilities that enable infants to actively interact with the physical world. Therefore, the onset of independent reaching may be one of the first important steps for infants' learning and development. Most components necessary for independent reaching can be seen already during fetal development. Isolated arm movements of the fetus start around nine weeks gestational age (GA) and by 12 weeks GA extension of the arm is often accompanied by an extension of the fingers (de Vries & Fong, 2006).

Prenatal arm movements can be directed towards objects inside the uterus such as the uterine wall or umbilical cord or they can be directed towards the fetus's own body (Arabin, Bos, Rijlaarsdam, Mohnhaupt, & vanEyck, 1996; Habek, et al., 2006). In the latter case, the fetus shows anticipation of the expected outcome of the movement. For example, opening the mouth in anticipation of the hand traveling towards it has been observed in fetuses as young as 19 weeks GA (Myowa-Yamakoshi & Takeshita, 2006). By 22 weeks GA, kinematics of hand-to-face movements show smooth trajectories with seemingly planned acceleration and deceleration phases depending on the target of the movement (Zoia, et al., 2007). These patterns suggest that the fetus may be capable of prospective and intentional actions. Indeed, it has been argued that all components necessary for reaching and grasping can be elicited in a fetus by 16 weeks GA (Bower, 1982).

Fetal grasping behavior stands in contrast to newborns' inability to reach and obtain objects. Despite earlier reports of reaching in newborns (Bower, Broughton, & Moore, 1970), most of the time newborns do not succeed in contacting or obtaining objects with their "prereaching" attempts (von Hofsten, 1982). Therefore, it has been suggested that the primary function of prereaching behavior is to guide visual attention to objects and not to manually explore them (Campos, et al., 2008; von Hofsten, 1982). Successful independent reaching does not emerge until about four to five months after birth (Pomerleau & Malcuit, 1980; von Hofsten & Ronnqvist, 1988). The development of reaching seems regressive and follows an U-shaped developmental trajectory: Reaching behavior is present prenatally, newborns show unsuccessful reaching attempts, subsequently reaching behaviors disappear, and eventually successful reaching re-emerges around five months of age.

Regressive events are common in development and the questions of whether and how early and later emerging skills are related to each other is an ongoing topic of debate (Campos, et al., 2008). For example, it is unclear whether early and later emerging skills are supported by the same mechanism and whether early behaviors are unrelated reflexes or precursors of the later emerging skills. Apart from reaching behavior, there are several other examples of regressive events in development. For example, the emergence of infants' preference for faces also shows an U-shaped pattern of development that seems parallel to the development of reaching behavior.

1.4 The development of social orienting towards faces

A preference for faces has been observed in newborn humans and also monkeys, suggesting a biological predisposition for this behavior (Goren, Sarty, & Wu, 1975; Johnson, et al., 1991; Sugita, 2008, 2009). In humans, newborns' face preference seems to decrease around the second month and, depending on test procedure and stimuli, two- to three-month-old infants show no clear preference for faces over scrambled faces or checkerboard patterns (Johnson, et al., 1991; Keller & Boigs, 1991; Maurer, 1985). It has been argued that sufficient exposure to faces early in life is required for typical development of face processing skills later in life, and that initially face preference is driven by sub-cortical mechanisms while subsequent, more complex face-processing skills are driven by cortical mechanisms (Johnson, 2005). Face-preference responses decline as face processing becomes increasingly controlled by cortical mechanisms (Johnson & Morton, 1991). Supporting this idea is the observation that the cortical Fusiform Face Area (FFA) seems to be involved in processing of not only faces but also other objects with which the observer has high levels of expertise (Gauthier & Nelson,

2001). Thus, while early face preference may be necessary for later face-processing abilities, the two seem to be supported by different mechanisms.

It is interesting to note that the developmental trajectories of both reaching and face preference are strikingly similar: Both decrease around two months of age only to reappear in a more mature form around 4-5 months of age (Keller & Boigs, 1991; Maurer, 1985; von Hofsten, 1984). Similarly to face-processing abilities, it is also possible that newborns' reaching experiences may be important for the emergence of later reaching but could be driven by different (e.g., sub-cortical) mechanisms. Do similar developmental trajectories of reaching and face-preference behavior suggest a relation between reaching and face-preference behavior? Or has the brain just matured enough to allow several unrelated mechanisms to begin to function around four months of age? One previous study on face-to-face interactions between mother and infant supports a relation between reaching behavior and face-preference behavior and indicates a *decrease* in face-preference behavior following onset of independent reaching (Fogel, et al., 1992). No other studies have since investigated the relation between reaching and face-preference behavior.

In summary, face-preference responses may be infants' first step towards engaging in social interactions and may be an important part of early social development. Attending to faces provides infants with opportunities for social exchanges and with exposure to the social cues present in a face. A relationship between reaching and face-preference behavior would have implications for our understanding of overall social development, especially processing of faces and other's intentions.

1.5 Dissertation outline

In the following sections, I will begin by describing the general procedures and methods that were used throughout my dissertation research. Then, I will describe four experiments on the effects of object-directed action experiences on cognitive and social development.

Experiment 1 examined how simulated reaching experience (Needham, et al., 2002) shapes infants' reaching, grasping and face-preference behavior. The effects of an active-training condition were compared to a passive-observation condition. Infants' behaviors were sampled repeatedly over a two-week period using a microgenetic approach with a short sampling interval of every 2-4 days (Adolph, Young, Robinson, & Gill-Alvarez, 2008; Kuhn, 1995; Siegler & Crowley, 1991).

Experiment 2 developed a novel social cognition assessment for infants during their first year of life. In addition, I explored the relationship between face-preference behavior and overall motor-activity level in untrained, naïve infants and whether face-preference behavior is related to other social cognition skills.

Experiment 3 investigated which factors were essential for the active-training paradigm of Experiment 1 to encourage reaching, grasping, and face-preference behavior. Two novel motor-training procedures were developed to isolate aspects of the active-training procedure from Experiment 1 and to determine their independent influences on reaching, grasping, face-preference behavior, and other social cognition skills investigated in Experiment 2. The results of Experiment 3 were directly compared to those from Experiments 1 and 2.

Finally, Experiment 4 explored the long-term social and motor effects of early motor training. Infants who participated in the active-training procedure of Experiment

1 were tested again at 14 months of age. Experiment 4 addressed the issue whether the benefits of simulated reaching training were transient or long lasting and whether they extended into different domains of development (social, motor, temperament).

Results from all four experiments are discussed in the context of their theoretical, practical, and clinical implications.

2. General Methods

2.1 Participants

All participants were recruited from public birth records published in Wake, Orange, and Durham Counties in North Carolina. The Duke University Institutional Review Board approved the research protocol. Informed consent was obtained from a parent or legal guardian before experiments were conducted. Infants were eligible for participation in the experiments reported here only if they were born at term (after at least 37 weeks of gestation) and had no known motor or visual deficits.

Different age groups were selected based on the hypotheses of the specific study. In general, to study the effect of reaching experience on cognitive and social development, infants who did not yet show independent reaching were tested and infants who already engaged in reaching behavior were used as comparison groups. Typically, infants do not show independent reaching between two to three months of age (Needham, et al., 2002) and independent reaching emerges between four to five months of age (Pomerleau & Malcuit, 1980; von Hofsten & Ronnqvist, 1988).

Infants' age in relation to their expected due date (in the following referred to as corrected age) has been found to be a good predictor for reaching behavior (van der Fits, Klip, van Eykern, & Hadders-Algra, 1999). Infants are rarely born on their due date and, especially early in life, this small variation may have an impact on behavior. Therefore, infants' corrected age was used in all studies.

2.2 Reaching Assessment

A sequential four-step reaching assessment was developed to measure infants' exploratory and grasping behavior. The four steps of the reaching assessment revealed

influences of the reaching context on behavior and it could be administered together with other measures during one visit to our lab. The assessment was conducted with the infant sitting on her parent's lap at a table with a semicircle cut out on the infant's side to surround the infant with the table. A reaching tray with a similar semicircle cut out was used when assessments were conducted at infants' homes (see Figure 1). A colorful rattle toy (0.8 × 6.4 × 11.5 cm, H×W×D) that was easily graspable for an infant was used in this assessment.

The steps of the assessment were based on previous findings that older infants alter their behavior depending on whether an object is placed near to them or far away: Starting at five months of age, infants show more reaching attempts when an object is placed easily within reach than when the same object is placed clearly beyond reach. In contrast, the toy's distance does not affect reaching behavior of younger, less experienced infants in the same way (Fetters & Todd, 1987; Yonas & Hartman, 1993).

The four-step reaching assessment systematically varies the distance between the toy and the infant in four sequential steps (see Figure 1):

- I. A small toy rattle is placed clearly beyond the infant's reach.
- II. The toy is moved within reach at midline but still far from the infant's hand (to contact the object the infant has to stretch out one arm and bring it to midline).
- III. The toy is placed next to one of the infant's hands so that the infant only needs to move the hand slightly to contact the toy. Placement is first attempted near the more active hand but the toy is moved over to the other hand if no grasping attempts are made within 15 seconds.
- IV. Finally, the toy is inserted into the infant's hand and the fingers and thumb are closed around the handle of the toy. If the infant drops the toy immediately,

further attempts are made to place the toy into the infant's hand but once the infant holds the toy for about 15 seconds, the toy is not replaced into the infant's hand when dropped.

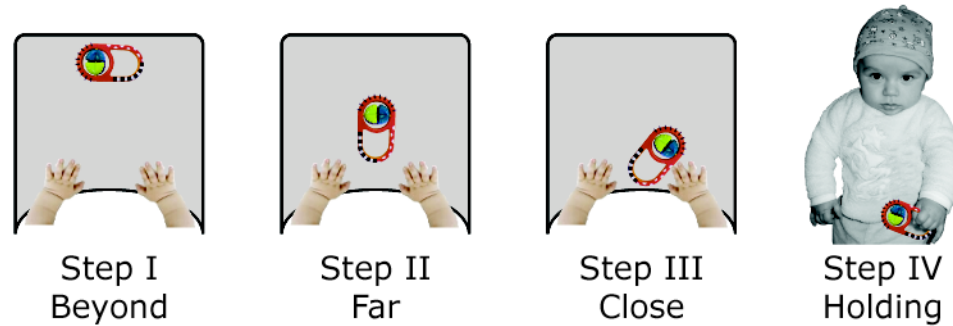


Figure 1: Schematic of the four-step reaching assessment.

Due to its sequential nature, the assessment was performed always in the same order (I. Beyond, II. Far, II. Close, IV. Holding). Each step lasted approximately 30 seconds and then the experimenter moved on to the next step. If an infant picked up the toy before the fourth step, then the infant was allowed to keep on holding the toy until the end of the reaching assessment.

2.3. Analysis of manual exploration data

Because manual exploration occurs rapidly, all infants were videotaped and subsequently coded offline by trained observers. To describe infants' exploratory actions in detail, I developed a frame-by-frame video analysis software to measure the duration of actions such as looking, reaching, touching, grasping, and mouthing (Libertus, 2008). For each still-frame (1/10 of a second), the observer made simple "yes" or "no" decisions about the infant's actions, providing high accuracy, capturing fine details, and allowing for objective assessment of behavior. Output from the coding software provided measures for looking (at object, parent, or experimenter), and manual

exploration of the object (such as reaching for, mouthing, touching, grasping, and lifting).

2.4 Eye-Tracking Procedure

Eye gaze provides information about infants' visual exploration of a display. Where infants look determines what kind of information can be obtained from the world. Therefore, eye-tracking measures complement manual-exploration measures of infants' learning and, especially with pre-verbal infants, allow accurate assessment of infants' visual preferences. A cornea-reflection based eye-tracking system (Tobii 1750) monitoring eye-gaze at 50 Hz was used in all eye-tracking studies reported in this dissertation. Eye-tracking studies were conducted in a dimly lit room. Stimuli were presented on a 17" screen at a resolution of 1024 x 786 pixel and infants were seated in a reclined bouncy chair, a stable high chair, or on their parent's lap at a distance of about 60 cm from the screen. At this distance, the screen subtended approximately 33.4×25.4 (H x V) degrees of visual angle. A five or nine-point calibration procedure was performed with each infant before eye gaze was recorded. While a complete calibration was always attempted, sometimes only few valid calibration points could be obtained (a minimum of 2 successful points were necessary to track eye gaze). To monitor tracking quality and detect drift, all eye-tracking experiments incorporated a number of central fixation stimuli (e.g., a looming pinwheel) throughout the experiment.

3. Experiment 1: The influences of simulated reaching experience on motor and social development

3.1 Introduction

The emergence and mastery of new motor skills may have implications for infants' cognitive and social development and their perception of the world. Evidence for the importance of motor development on infants' development in other domains has been observed in a number of studies that tested infants as they acquired new motor skills (e.g., Adolph, 2000; Biringen, et al., 1995; Clearfield, et al., 2008; Fogel, et al., 1992; Fogel, et al., 1999; Rochat, 1992). For example, following the onset of independent sitting and reaching abilities infants engage in more object-focused interactions with their parents (Fogel, et al., 1992; Fogel, et al., 1999). In general, following acquisition of a new motor skill (e.g., sitting or walking), changes in infants' cognitive, social, or emotional development have been observed (Biringen, et al., 1995; Campos, Bertenthal, & Kermoian, 1992; Clearfield, et al., 2008). However, evidence from previous studies remains indirect because it is possible that any number of other variables—in particular general maturational processes—may lead to the emergence of new motor skills and changes in cognitive or social abilities (Bertenthal, et al., 1994). Demonstrating that motor development has a causal effect on development in other domains remains a challenge for developmental psychologists.

One reason for the challenge is that age is often seen—mistakenly—as a proxy for infants' level of maturation. This notion is false for several reasons. First, with regard to maturation, an infant's birthday is an arbitrary point in time as some infants are born prematurely while others are born slightly after their due date. Age becomes a better predictor for the emergence of new skills (e.g., reaching) when it is calculated with

regard to an infant's calculated due date (van der Fits, et al., 1999). Second, age is confounded with experience. Older children had more time to practice a skill and experience its outcomes. And finally, even at the same age, there are considerable differences between infants with regard to their skills. For example, while some infants start to walk alone by eight months, others only start around 15 months of age (de Onis, 2006). When assessing behavior in 12-month-old infants, about half of the infants will have experienced independent locomotion for a month or longer whereas the other half will not have engaged in independent locomotion at all. Thus, age is not a very reliable predictor for overall development.

A more mechanistic approach to development is to study infants of similar age but with different motor skills (e.g., crawling and non-crawling seven-month-olds) to determine the impact of first-hand experiences with this particular skill. Findings from such studies show that the overall amount of experience an infant has with a new motor skill seems to predict development in other domains (Campos, et al., 1992). Unfortunately, the groups that were compared in such studies may be vastly different from each other. The experimenter cannot choose which infant starts to crawl early and which infant has to wait. In other words, there may be developmental or experience-related reasons for group differences between infants. Using an age-constant design, these confounding factors often cannot be identified or eliminated.

The problem of confounding variables can be avoided by using direct manipulation of motor experience. This approach has been used in studies on locomotion and reaching behavior (Bertenthal, Campos, & Barrett, 1984; Campos, et al., 1992; Needham, et al., 2002; Sommerville, et al., 2005). In particular, the studies on locomotor experience investigated infants' response to the "visual-cliff" apparatus

described in Chapter 1. Infants who experienced self-produced locomotion seemed to avoid the deep side of the visual cliff and when placed on the deep side an acceleration of their heart rate occurred. It should be noted that other studies have not observed evidence for a role of experience on infants' avoidance of the deep end of the visual cliff or for an increase in heart rate when placed on the deep end (e.g., Rader, Bausano, & Richards, 1980; Richards & Rader, 1983).

More recent evidence indicates that what infants learn from motor experiences is quite specific to the corresponding posture or mode of locomotion and has to be relearned when a different posture or mode of locomotion is used (Adolph, 1997, 2000; Adolph & Berger, 2006). For example, Adolph (2000) presented infants with a toy located at the other side of a gap between two surfaces. When placed in a highly familiar posture (sitting), nine-month-old infants correctly judged how far they could lean forward to reach for the toy without falling into the gap. In contrast, when placed in a less familiar posture (crawling) the same infants attempted to reach for the toy when the gap was too large and consequently fell into the gap (but were rescued by the experimenter). Therefore, infants did not learn to avoid the gap in general, rather learning to avoid too large of a gap was specific to a certain posture (Adolph, 2000). Such evidence argues against the emergence of a generalized fear of heights following locomotor experience and suggests that the impact of motor experiences on other domains of development may be more subtle and constrained. At the very least, the amount of experience an infant has with a specific motor skill is important for the understanding of her own abilities and the permissible actions that can be produced in any given situation. But the extent to which early motor experiences can influence development in different domains still remains unclear.

Providing infants with simulated reaching experience has been shown to change infants' perception of other people's intentions (Sommerville, et al., 2005). Following self-produced reaching experience, infants also showed longer exploration of, more interest in, and more multimodal engagement with objects (Needham, et al., 2002). Together, these results suggest that experience with a new motor skill influences both development in the motor domain (e.g., more advanced exploration following reaching experience) and in other domains (e.g., changes in social interaction following locomotor experience).

The goals of the present study were threefold. First, I sought to investigate the effects of active reaching experience on the emergence of independent grasping. Previously, increases in visual and manual exploration following active simulated reaching training have been noted in three-month-old infants (Needham, et al., 2002). However, whether simulated reaching training would also encourage actual independent reaching for and grasping of objects (the very skills practiced during training) has not been assessed. Reaching and grasping behavior are important developmental milestones as they enable infants to obtain objects for further inspection on their own.

Second, I wanted to examine whether the effects of active simulated reaching training are due to experiences of self-produced reaching actions or due to increased exposure to objects and more interaction with parents and/or experimenters. Therefore, I compared infants who received active simulated reaching training to infants who received passive training during which they only observed their parents move objects.

And third, I wanted to investigate the influences of early reaching experience on social development, in particular, infants' face-preference behavior. Fogel and colleagues

(1992) have noted that the onset of independent reaching and increased postural control marks the end of a face-to-face interaction period between infant and mother. As infants begin to engage in independent reaching, they become less interested in their mothers' face and more interested in objects. It is possible that face-preference and reaching behavior are related to each other and supported by a shared underlying mechanism. I hypothesized that two weeks of daily object-directed training sessions would jump-start the emergence of independent reaching and grasping behavior in the active-training group. Along with an increase in manual exploration, I therefore predict that infants will show a *decrease* in their interest in faces.

3.2 Method

3.2.1 Participants

To investigate the effects of reaching experience on the emergence of grasping and manual and visual exploration behavior, I manipulated infants' reaching experience using an active- vs. passive-group paradigm inspired by the classic study of Held and Hein (1963). Two groups of infants were followed over a two-week period while they received either active or passive reaching experience. The two trained groups were compared on their manual exploration and visual exploration to a group of untrained, age-matched three-month-old infants. Further, a group of untrained five-month-old infants was used as comparison group on the visual exploration measure. Detailed descriptions of each group are given in Table 1.

- I. **Active-Training Group (AT):** Infants in this group received simulated reaching experience using "sticky mittens" (Needham, et al., 2002). Infants were trained using infant mittens and toy blocks with Velcro[®] attached to both the mittens and the toys. Upon contact, the toys would

stick to the mittens allowing the infants to independently “pick up” the toys just by swiping or touching them.

- II. **Passive-Training Group (PT):** Infants in this group were similar in age and gender to the Active-Training group and also received similar amounts of exposure to the test and training objects. Infants were trained using the same mittens and toys as the AT group but here the toys would not stick to the mittens. Consequently, infants in the PT group did not experience self-produced reaching. Instead, their parents provided visual and tactile stimulation by moving the toys across the infant’s visual field and touching them to their mittens.
- III. **Untrained Three-month-old Group (NT3):** A group of untrained three-month-old infants served as a naïve comparison group for the trained groups and completed both the visual-preference and the manual-exploration task.
- IV. **Untrained Five-month-old Group (NT5):** An additional group of untrained five-month-old infants served as an older comparison group on the visual-preference task. This age group was included because typically three-month-old infants do not show independent reaching behavior while most five-month-old infants have already attained this skill. Therefore, this control group provided a measure for the visual behavior of infants who learned to reach on their own, without any training.

Table 1: Experiment 1, participant characteristics

Group	n	#F	Race	Age 1 st lab visit	Training duration	# of home visits	Age 2 nd lab visit	Parent Edu.	Birth weight
AT	18	9	15C, 1A, 2M	10.90 (1.75)	125 (23.70)	3.80 (0.38)	12.92 (1.77)	9.38 (2.99)	3621 (578)
PT	18	10	14C, 1B, 1A, 2M	10.90 (1.52)	144 (23.70)	3.80 (0.33)	12.93 (1.55)	9.94 (2.24)	3544 (470)
NT3	19	8	17C, 1B, 1M	--	--	--	12.61 (2.17)	10.05 (1.61)	3280 (377)
NT5	23	11	18C, 2B, 1A, 2M	--	--	--	19.70 (1.93)	9.60 (1.30)	3418 (515)

Note: The total number of participants in each group (n) and the number of females per group (#F) are indicated. All other values are group averages with standard deviations given in parentheses. Age is reported in weeks, birth weight in gram. Parents' education level was assessed on a scale from 0 (no High School degree) to 6 (Post-doctoral Training) for each parent (max. 12). Race abbreviations: C = Caucasian, B = Black or African American, A = Asian, M = More than one race.

3.2.2 Apparatus

The training materials for the active- and passive-training groups consisted of small infant mittens with the “loop” side of Velcro[®] fabric sewn to the palms and Duplo[®] blocks. For the AT group, the “hook” side of Velcro[®] fabric was attached the edges of the blocks, allowing the blocks to stick to the mittens. In contrast, for the PT group only black or white tape was attached to the blocks but no Velcro[®] and the blocks did not stick to the mittens. Three sets of blocks were provided to each parent: a single Duplo[®] block, a pair of same-color Duplo[®] blocks, and a triplet of same-color Duplo[®] blocks. During training, each set was presented sequentially to the infant for about 2-3 minutes

with multiple blocks presented side-by-side and touching each other. Following initial sticky mittens training in our lab, parents were asked to repeat the training daily for a period of two weeks and also received written and verbal instructions and a daily log to record their training sessions.

Eye-tracking measures were recorded using a Tobii 1750 eye-tracker as described in the General Methods.

3.2.3 Measures

Manual and visual exploration behaviors were assessed using a manual-exploration task and a visual-exploration task. Not all participants completed both measures described here (see Table 2). One infant from the AT group did not complete the visual-exploration measure due to fussiness. Three infants from the NT3 group did not complete the manual-exploration assessment due to fussiness ($n = 1$) or technical difficulties with the recording equipment ($n = 2$) and two different infants did not complete the visual-exploration measure due to fussiness. Consequently, five infants from the NT3 group were excluded from a regression model that required data from both measures. Two additional NT3 infants were identified as potential outliers using regression diagnostics (studentized residuals 2.5 and -2.1 respectively). Further examination revealed that these two infants were twins and born at our cutoff of 37 weeks gestational age. These infants were also excluded from the regression model.

- I. **Manual Exploration:** Manual-exploration behavior was measured in three-month-old infants using the four-step reaching assessment described in the General Methods. For the AT and PT groups, five to six longitudinal measures were collected over a two-week period. Two measures (Lab 1 and Lab 2) were taken in our laboratory at Duke

University and the remaining measures (Home 1-4) were taken in the infant's home. Using a short sampling interval with one measure every 2-4 days allowed for an accurate description of the developmental change over the two-week period (Adolph, et al., 2008). The untrained three-month-old comparison group completed the reaching assessment only once in our laboratory. Five-month-old infants were excluded from this measure because at this age infants already engage in independent reaching behavior.

- II. **Visual Exploration:** Visual-exploration behavior was measured in all groups on the second lab visit using a visual-preference paradigm. Eye-gaze was recorded using a Tobii 1750 eye tracker as described in the General Methods section and the visual-exportation assessment was always completed before the manual-exploration assessment on the second lab visit. A series of colorful faces and toys were shown side-by-side on a computer screen. The face-toy pairs were composed from four photorealistic faces (two female, all Caucasian) showing neutral expressions taken from the NimStim stimulus set (Tottenham, et al., 2009) and four photographs of commercially available infant toys (one teething ring, one stacker, and two grasping balls). From these images, eight unique face-toy pairs were created showing one face and one toy side-by-side in front of a uniformly white background. On the screen, faces and toys were similar in size and the distance between the two stimuli ranged from 3.8 – 6.4 cm ($M = 5.1$ cm). Each pair was presented for 10 seconds and was preceded by a looming pinwheel at the center of the screen to

ensure equal gaze offset prior to presentation of a face-toy pair and to monitor calibration quality. Face-toy pairs were presented in two random orders with about half of the infants receiving order 1 and the other half receiving order 2. Within each order, side of face-presentation and gender was counterbalanced (half of the faces were female, half of the faces were presented on the right side). Face-preference scores were calculated by combining data from all eight face-toy pairs, taking the proportion of looking duration to the toy and the face (with face + toy = 100%), and by subtracting the proportion of looking to the toy from the proportion of looking to the face (face-preference score = % face - % toy). The use of proportions accounts for differences in total looking duration between infants. A positive preference score indicates a face preference, a negative preference score indicates a toy preference, and a preference score of zero indicates no preference. Infants can be slow to disengage and shift their eye gaze to a new location (Hood & Atkinson, 1993; Ruff & Rothbart, 1996). Therefore, face-preference behavior was additionally assessed during the 1000 – 2000 ms time window following stimulus onset to allow infants time to disengage from the central fixation stimulus (see also Hood & Atkinson, 1993). Importantly, assessment of preference behavior during this time window is more adequately described as “orienting” because it captures infants’ initial response to the stimulus.

Table 2: Experiment 1, measures completed by participants

Group	Measures		
	Four-step reaching assessment	Eye-tracking: Visual preference	Regression analysis
AT	n=18	n=17	n = 17
PT	n=18	n=18	n = 18
NT3	n=16	n=17	n = 12
NT5	--	n=23	--

3.2.4 Procedure

Infants in the AT and PT groups visited the laboratory twice and were visited by experimenters from our lab on three to four occasions (see Table 1). Parents were asked to train their infants using the mittens and toys for 10 minutes each day over a two-week period. Additionally, on the first lab visit, on each home visit, and on the second lab visit the infants participated in the four-step reaching assessment. The visual exploration task was completed one time on the second lab visit. In contrast, infants in the untrained comparison groups only visited our lab once, had no home visits, and did not receive any training prior to being tested. For the three-month-old comparison group, the visit to the lab was identical to the second lab visit of both trained groups and consisted of the visual-exploration task and the manual-exploration task. The manual-exploration task was not suitable for five-month-olds and the NT5 group only completed the visual-exploration task. Because of their age, five-month-old infants would have performed at ceiling levels in the manual-exploration task. Differences in the training procedures are illustrated in Figure 2 and an outline of the experimental procedure is shown in Figure 3. The training procedures for the AT and PT groups were as follows:

I. **Active-Training (AT) Group:** Sticky mittens were placed over the infant's hands and one Duplo[®] block or a set of blocks was placed in front of the infant. The parent or experimenter drew attention to the blocks by pointing at and lifting a block. For each set of blocks, parents provided one demonstration of the mittens by guiding the infant's hand to a block and making it stick. Following this demonstration, the block was removed from the mittens and placed back on the table in front of the infant. Parents now provided verbal encouragement for the infant to pick up or swipe at the blocks. Upon successful contact, infants were allowed to manipulate and shake the blocks for about 10 seconds. The blocks were then removed from the mittens, placed back on the table, and the sequence was repeated. Parents were asked to rotate through the three sets of blocks once or twice until a total of 10 minutes had passed. This procedure was repeated each day for two weeks.



Figure 2: Experiment 1, example of the Active- and Passive-Training procedures. a) Active Training: Toys stick to the mittens upon contact. b) Passive Training: Toys are moved by the parent and do not stick to the mittens.

II. **Passive-Training (PT) Group:** Sticky mittens were placed over the infant's hands and one set of non-sticky block toys was placed in front of the infant. Attention was drawn to one of the blocks. The parent then lifted this block up to the eye level of the infant, tapped it briefly on the table, moved over to the left side, tapped the block on the table again, lifted the block to eye level and briefly touched the palm of the infant's hand with the block. Next the block was tapped on the table again, moved back to the center, and placed in its original position. The same sequence was repeated on the infant's right side. Parents were asked to rotate through the three sets of blocks once or twice until a total of 10 minutes had passed. This procedure was repeated each day for two weeks. Movement of the blocks was modeled after the block movements observed in the AT group. This procedure provided infants in the

passive-training group with similar levels of exposure to and experience with the training toys as the AT group but without experiencing self-produced reaching.

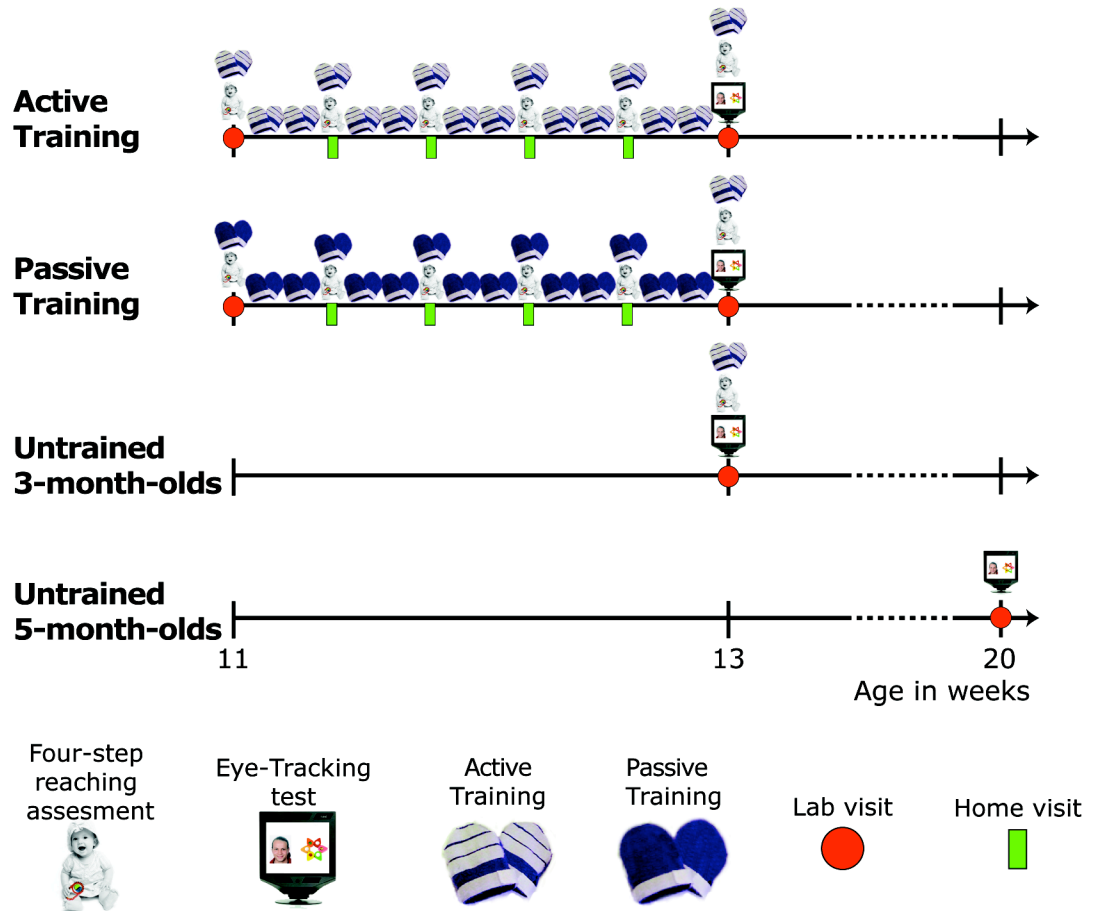


Figure 3: Experiment 1, outline of assessment and training schedule. Trained infants received daily training for a two-week period. On the second lab visit, all infants were first tested on the visual-exploration task.

3.2.5 Coding and Reliability

The four-step reaching assessment was coded from video recordings by trained observers using frame-by-frame coding software (see General Methods). Frame-by-frame coding captures fine details and allows for simultaneous assessment of several

behavioral measures. Infants' looking behavior was categorized as either looking at the experimenter, the toys, the parent, or as being distracted. For each looking measure, also the number of separate looking episodes was calculated. A looking episode was defined as one uninterrupted, continuous look. If the look was interrupted by a look elsewhere (e.g., from toy to experimenter), the looking episode ended. Manual exploration was categorized as reaching for, touching, or grasping the object. Reaching was defined as an arm movement towards the object while the infant was looking at the object. Touching was defined as any manual contact of the hands or fingers with the toy. Grasping was defined as any manual contact that allowed the infant to lift at least one corner of the toy off the table. Further, bi-manual and oral object contact were recorded.

To assess validity of the frame-by-frame coding procedure and coding reliability, manual exploration on the second lab visit was coded again in real-time by different trained observers for looking at and touching the toy (a total of 52 reaching assessments were coded this way, representing about 25% of all assessments in the study). The real-time coding method has been used in previous experiments on manual exploration (Needham, et al., 2002) and was compared to the corresponding frame-by-frame coding results. Correlations between the two coding methods were high ($r = 0.94$) indicating that the frame-by-frame coding produces reliable results. For all statistical analyses the frame-by-frame coding results were used.

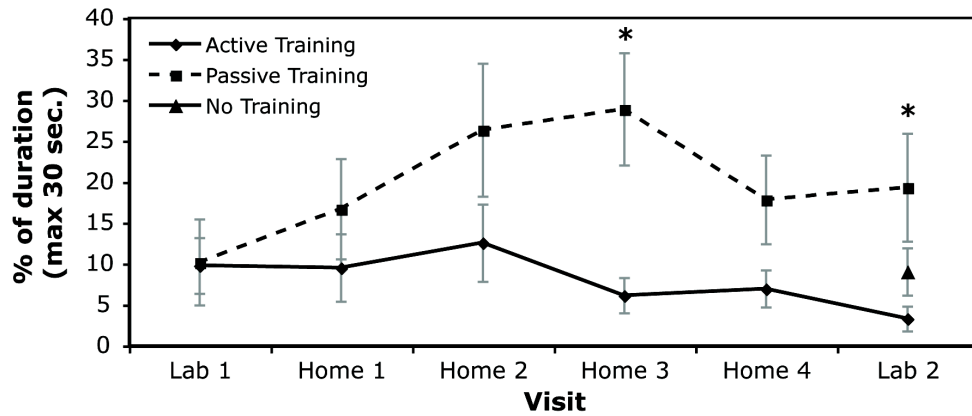
3.3 Results

3.3.1 Manual-exploration assessment

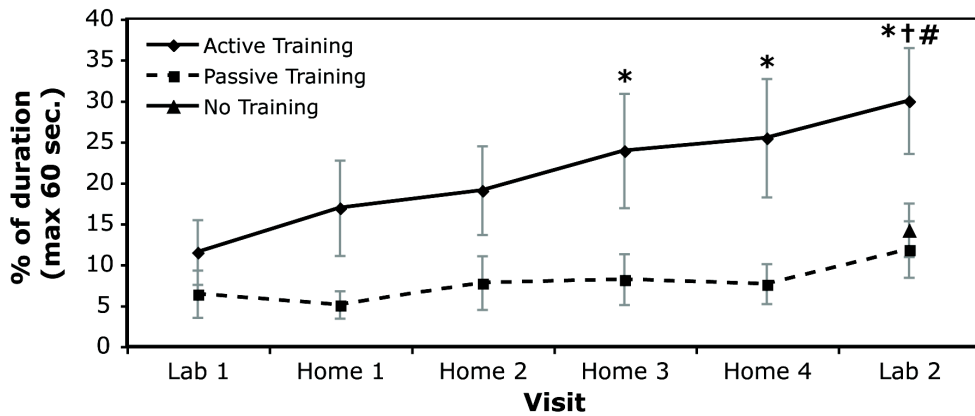
Only infants in the AT group showed significant increases in reaching and grasping behaviors over the training period. In contrast, the PT group showed no increases in grasping and reaching behavior but showed an increase in attention

towards the experimenter. The results for the manual-exploration behavior are shown in Figure 4 and are reported as proportions of the total trial duration. On each of the lab visits, percentage scores were compared using a 2 (Gender) x 3 (Group) between-subjects analysis of variance (ANOVA). Additionally, the two trained groups (AT and PT) were compared to each other on each home via separate 2 (Gender) x 2 (Group) ANOVAs. None of the analyses showed a main effect of gender or an interaction (all $ps > .070$) and as expected there were no significant effects of group prior to training (Lab visit 1) on all measures (all $ps > .340$). Each step of the four-step-reaching assessment provided different opportunities to interact with the toy and offered a different measure of interest. On Step I (toy placed beyond reach) the infant could only look at the toy but not touch it. On Steps II and III (toy placed first far, then close to hand) the infant could additionally reach out and grasp the object and on Step IV (holding) the toy was placed into the infant's hands.

a) Step I: Looking at experimenter duration



b) Step II + III: Reaching and grasping duration



c) Step IV: Looking at toy episodes

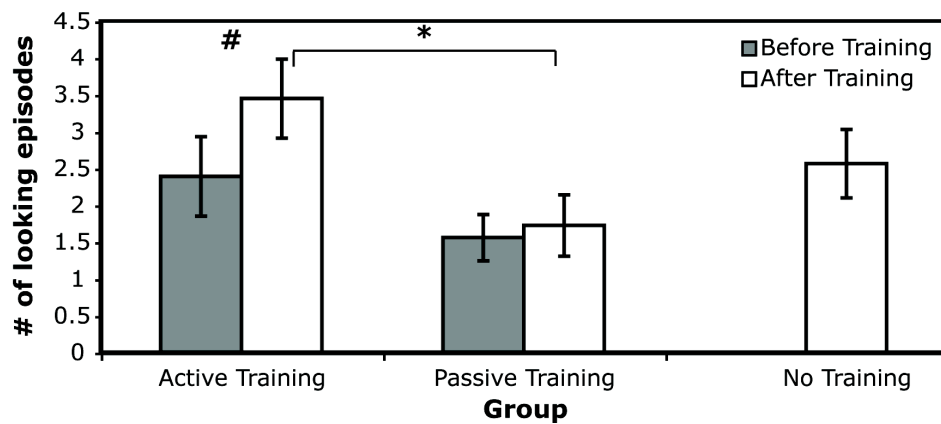


Figure 4: Experiment 1, manual-exploration results. Results for Steps I, combined Steps II and III, and Step IV of the reaching assessment are shown. Significant differences ($p < .05$) between the AT and PT group are indicated with a *, differences between AT and NT3 with a †, and significant within-group differences for the AT group (lab visit 1 vs. lab visit 2) are indicated with a #. Error bars represent SEM.

Manual exploration of the toy was impossible on Step I of the reaching assessment (toy beyond reach). Therefore, I focused on infants' attention towards the toy and towards the experimenter during this step. There were no overall differences in attention towards the toy between the AT, PT, and NT3 group on either of the two lab visits and also not on any of the home visits (all p s > .30). Across the three groups, infants spent about the same amount of time looking at the toy (approximately 65% of the time). However, looking behavior differed when they were not looking at the toy but at the experimenter. Significant differences between the AT ($M = 6.07\%$, $SD = 9.20$) and the PT ($M = 28.83\%$, $SD = 29.03$) group were present on the 3rd home visit ($F(1,32) = 9.439$, $p = .004$, $\eta^2 = .227$). On the 2nd lab visit the ANOVA indicated significant between-group differences ($F(2,46) = 3.709$, $p = .032$, $\eta^2 = .157$) and planned between-group comparisons revealed that infants in the AT group ($M = 3.22\%$, $SD = 6.41$) spent less time looking at the experimenter than infants in the PT group ($M = 19.26\%$, $SD = 27.97$, $p = .012$, 95% CI [-28.39, 3.67]). No other comparisons on the 2nd lab visit were significant (Figure 4a). Within-group analyses showed a borderline significant decrease in looking at the experimenter between the 1st and 2nd lab visit for the AT group ($t(17) = 2.082$, $p = .053$) but no effects in the PT group ($t(17) = -1.054$, $p = .307$; see Table 3).

On Steps II and III of the reaching assessment (toy far and close to hand), only the infants in the AT group showed a significant increase in reaching and grasping behavior (Figure 4b). There were no significant group differences prior to training ($p = .342$) but differences between the AT and PT group gradually emerged across the four home visits. By the 3rd home visit the AT group ($M = 23.82\%$, $SD = 29.66$) showed significantly more reaching and grasping behavior than the PT group ($M = 8.13\%$, $SD = 13.12$; $F(1,32) = 4.380$, $p = .044$, $\eta^2 = .128$). Also, on the 4th home visit the AT group ($M =$

25.39%, $SD = 28.00$) showed significantly more reaching and grasping behavior than the PT group ($M = 7.56\%$, $SD = 10.04$; $F(1,28) = 5.705$, $p = .024$, $\eta^2 = .164$). Finally, on the 2nd lab visit (i.e. the final test session) the ANOVA revealed significant between-group differences ($F(2,46) = 4.380$, $p = .018$, $\eta^2 = .156$) and planned between-group comparisons indicated that infants in the AT group ($M = 29.93\%$, $SD = 27.42$) engaged in more reaching and grasping than infants in the NT3 group ($M = 14.14\%$, $SD = 13.07$; $p = .026$, $[1.94, 29.64]$) and the PT group ($M = 11.79\%$, $SD = 14.69$; $p = .009$, $[4.70, 31.57]$). There were no significant differences between the PT and NT3 groups ($p > .700$). Within-group analyses revealed a significant increase in reaching and grasping behavior between lab visit 1 and lab visit 2 for the AT group ($t(17) = -3.875$, $p = .001$) but not for the PT group ($t(17) = -1.149$, $p = .266$; see Table 3).

On Step IV of the reaching assessment (holding toy), the toy was placed into the infant's hand making manual contact with the toy an irrelevant variable. Therefore, I instead focused on infants' attention to the toy. Similar to Step I, no significant differences in the looking duration were present between the AT ($M = 45.54\%$, $SD = 36.09$), the PT ($M = 53.54\%$, $SD = 40.71$) and the NT3 ($M = 38.17\%$, $SD = 32.05$) groups (all $ps > .200$). However, there were differences in *how often* (# of looking episodes) infants looked at the toy. On the 2nd home visit, the infants in the AT group ($M = 3.44$, $SD = 2.28$) produced more separate looking episodes to the toy than infants in the PT group ($M = 1.61$, $SD = 1.14$; $F(1,32) = 8.630$, $p = .006$, $\eta^2 = .206$). Further, at the end of the two-week training period a significant main effect of group was present ($F(2,46) = 3.594$, $p = .035$, $\eta^2 = .123$) and planned between-group comparisons revealed that the infants in the AT group ($M = 3.44$, $SD = 2.28$) showed more looking episodes than the infants in the PT group ($M = 1.72$, $SD = 1.78$; $p = .011$, $[0.42, 3.03]$; see Figure 4c). There were no significant

differences between the PT and NT3 ($M = 2.56$, $SD = 1.86$) groups or the AT and NT3 groups (all $ps > .190$). Within-group analyses revealed a significant increase in the number of looking episodes between lab visit 1 and lab visit 2 for the AT group ($t(17) = -2.257$, $p = .037$) but not for the PT group ($t(17) = -0.270$, $p = .790$; see Table 3 and Figure 4c). Infants in the AT group shifted their attention to and from the toy more often than infants in the PT group.

Table 3: Experiment 1, within-group analyses of the manual-exploration task

Within Group Analysis	Lab visit 1 vs. Lab visit 2	
	AT	PT
Step I: Looking at experimenter	$t(17) = 2.082$ $p = .053$ [-0.09, 13.05]	$t(17) = -1.054$ $p = .307$ [-27.40, 9.14]
Step II + III: Reaching and grasping duration	$t(17) = -3.875$ $p = .001$ [-28.61, -8.38]	$t(17) = -1.149$ $p = .266$ [-15.44, 4.55]
Step IV: Looking at toy episodes	$t(17) = -2.257$ $p = .037$ [-2.04, -0.07]	$t(17) = -.270$ $p = .790$ [-1.468, 1.135]

Note: 95% CI are given in square brackets.

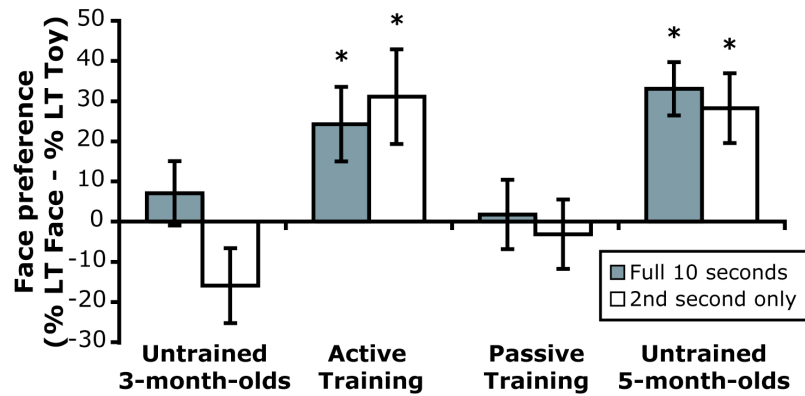
3.3.2 Visual-preference task

All groups were tested on the visual-preference task on their last visit to our laboratory. Results revealed that the three-month-old infants in the AT group behaved similar to the five-month-old infants in the NT5 group. Within-group comparisons (one-sample t-test) of the visual-preference task showed a significant preference for the face over the toy in the NT5 group ($t(22) = 4.98$, $p < .001$, 95% CI [19.28, 46.80]) and the AT group ($t(16) = 2.610$, $p = .019$, [4.54, 43.95]) but not in the PT ($t(17) = .207$, $p = .839$, [-16.35, 19.91]) group or NT3 group ($t(16) = .878$, $p = .393$, [-9.18, 22.15]; Figure 5a, solid bars).

To investigate rapid orienting towards faces, the 1000ms – 2000ms time window was selected for a separate analysis of face-preference behavior. This time window was selected because slow disengagement from a preceding fixation stimulus is common in young infants and may influence initial orienting responses (Ruff & Rothbart, 1996). Visual inspection of infants' horizontal eye-gaze position over time (Figure 5b) confirmed the validity of this time-window and indicated that the five-month-old infants first oriented towards the faces during the 2nd second while viewing a face-toy pair. Within-group comparisons during the 1000ms – 2000ms time window revealed a face preference in the NT5 group ($t(22) = 3.250, p = .004, [9.63, 45.93]$) and the AT group ($t(16) = 2.650, p = .018, [6.19, 56.04]$) but not in the PT group ($t(17) = -.3620, p = .722, [-21.41, 15.14]$) or NT3 group and ($t(16) = -1.226, p = .238, [-39.24, 10.48]$; Figure 5a, white bars).

In summary, only the NT5 and AT groups showed significant face-preference behavior and rapid orienting to faces. Stimulus characteristics such as complexity could not have caused these results because different groups—especially age-matched infants—responded differently to identical stimuli.

a) Face-preference scores



b) Horizontal eye-gaze position during face-preference task

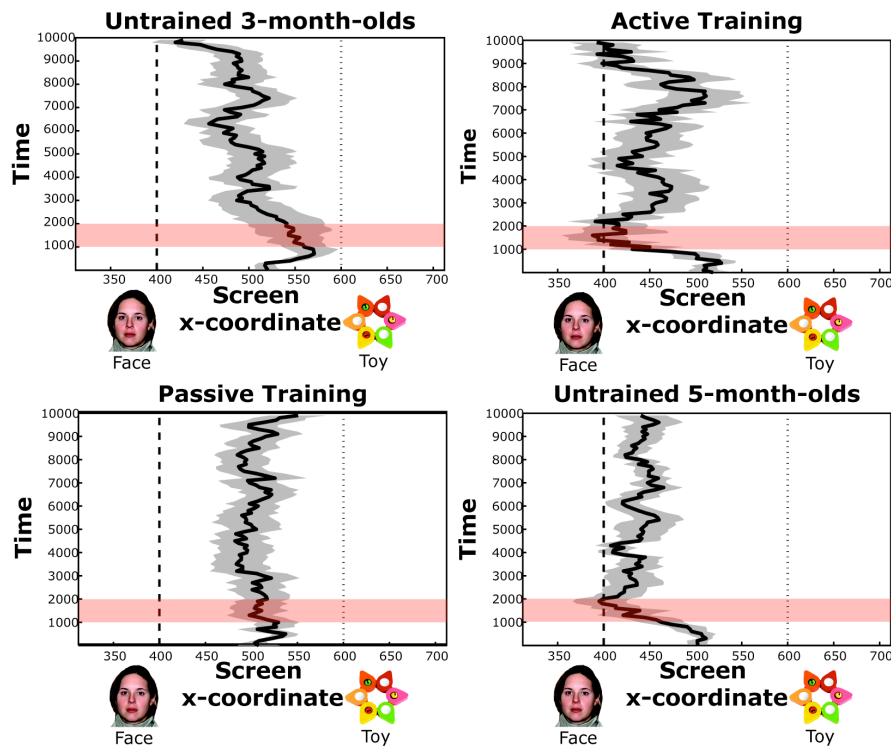


Figure 5: Experiment 1, face-preference behavior results. a) Overall face-preference scores for the four groups across the whole stimulus duration (solid bars) or during the 2nd second only (white bars). Positive values indicate a preference for the face stimuli. b) Time-course of face-preference behavior. Horizontal eye-gaze (x-axis) is plotted against time elapsed since stimulus onset (y-axis). The dashed and dotted lines indicate onset of face and toy area respectively. Red-highlighted area represents 2nd second of stimulus presentation. Error-bars and shaded area represent SEM. * $p < .05$.

3.3.3 Regression model

The reaching and grasping behavior reported in Steps II and III of the reaching assessment were very difficult behaviors for three-month-old infants. Consequently, infants engaged in very little of this activity (only around 10% of the time in the PT and NT3 groups, see Figure 4b). To assess the influence of motor behavior on face-preference behavior, I therefore additionally analyzed the overall amount of manual toy contact (touch duration) on the second lab visit for Steps II and III of the reaching assessment. Touching an object can occur purposefully or accidentally and more variability was present in this measure. A 2 (Gender) × 3 (Group) ANOVA on the duration of manual contact with the toy during Step II and III showed no effects of group or gender and no interactions (all $ps > .118$)

A hierarchical regression model was used to examine the relationship between motor and social behavior, in particular, whether the amount of manual toy contact during Steps II and III of the four-step reaching assessment predicted rapid orienting towards faces (face preference during the 2nd second) in three-month-old infants. Data was collapsed across all three groups since there were no significant differences in the toy-contact predictor variable between the groups. In the regression model, I controlled for factors that are known to influence developmental transitions such as demographic variables (birth weight, sex, and parent education) and variables related to visual attention (shifting of attention between toy and face) (Broekman, et al., 2009; Hediger, Overpeck, Ruan, & Troendle, 2002; Ruff & Rothbart, 1996).

Together, amount of toy-contact behavior, demographic factors and visual-attention factors explained a significant proportion of variation in three-month-olds' rapid orienting towards faces ($F(5, 41) = 4.870, p = .001, R_{Adj.}^2 = .296$). In the full model,

toy-contact behavior was a significant predictor of rapid orienting to faces ($\beta = .277$). Further, addition of the toy-contact variable to a model already containing demographic and visual-attention related variables explained a significant amount of additional variation in face-preference behavior ($R^2_{Change} = .073$, $F(1,41) = 4.750$, $p = .035$). Toy-contact behavior uniquely accounted for about 7.3% of additional variation in rapid face orienting. In agreement with previous findings (Broekman, et al., 2009; Hediger, et al., 2002), addition of the demographic variables to a model already containing toy-contact behavior and visual-attention related factors also explained a significant amount of additional variation in face-preference behavior ($R^2_{Change} = .199$, $F(3,41) = 4.340$, $p = .010$). In contrast, the addition of visual-attention related variables to a model already containing toy-contact behavior and demographic factors did not explain a significant amount of additional variation ($R^2_{Change} = .040$, $F(1,41) = 2.590$, $p = .115$). Thus, the duration of manual toy-contact behavior as assessed during a separate task and in a different context was a better predictor of rapid orienting towards faces than visual attention related variables measured during the visual-preference task (Figure 6).

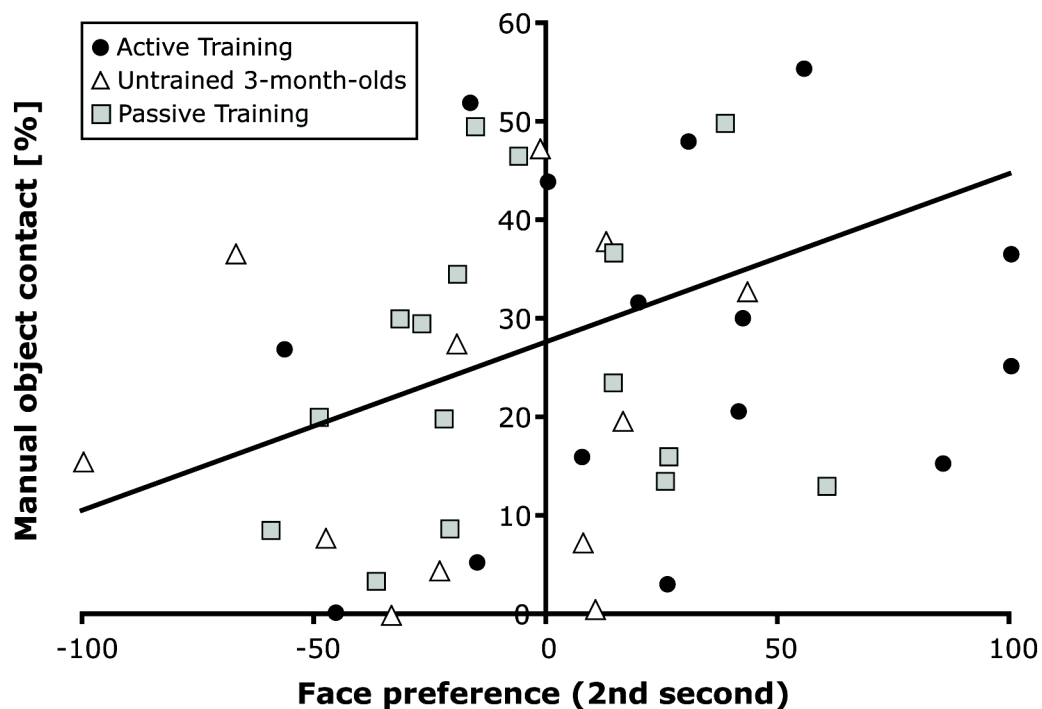


Figure 6: Experiment 1, relationship between manual object contact and face preference. Across all three-month-old groups of experiment 1, infants who engage in more manual contact with the object during the manual-exploration task also show stronger face-preference behavior during the visual-exploration task.

3.4 Discussion

Experiment 1 showed a relation between motor ability and rapid orienting to faces. Three-month-old infants who experienced approximately two hours of simulated reaching experience over a two-week period showed a significant increase in their reaching and grasping behavior and their preference for faces over objects. A stronger preference for faces following two weeks of object-directed training is surprising and counter to my initial predictions. Untrained infants and infants who passively observed reaching actions did not show increases in manual exploration or face-preference behavior.

The AT procedure and the PT procedure provided infants with similar experiences. Both groups received equal amounts of exposure to the mittens and toys used during the training sessions, experienced similar amounts of object-directed play sessions with their parents, and were both repeatedly visited in their home and tested on the four-step reaching assessment. Thus, AT and PT provided very similar training experiences except that infants in the AT group were able to contact and move objects themselves while the PT group only observed the objects being moved and touched to their hands by their parents. Emphasizing the role of self-produced motor experiences in development, a seemingly small difference in procedure led to significant changes in behavior between the AT and PT groups.

The concept of “contrastive evidence” or contrastive outcomes offers one explanation why self-produced action could have an impact on development. According to Baillargeon (1999, 2004), infants’ learning about the physical world involves three steps: First, contrastive evidence occurs when infants observe both the outcome of an event when a certain condition is met and a different outcome when the same condition is not met. Second, infants identify the conditions that led to the outcome. And third, infants develop an explanation for the condition-outcome pairs they observe (Baillargeon, 1999, 2004). This theory was originally developed to explain how infants learn to reason about the physical world and physical events. However, it may also apply here. Prior to wearing the mittens, infants’ accidental contact with an object could move it for a short period of time, but this movement may not be contingent on the movement of the infant’s hand following contact. For example, following a swat, a toy can continue to slide across the table while the infant’s hand remains still. However, while wearing the mittens, infants in the active-training group experience contrastive

evidence: arm movements before contact with the object did not move the object but arm movements following manual contact with the object caused further movement and allowed for control over the object's trajectory. Experiencing such contingencies and noticing that they only hold following manual contact may have encouraged further reaching attempts. Thus, in addition to practicing a new motor skill, active simulated reaching training may have motivated infants to engage more in manual object exploration and changed infants' everyday behavior and interactions with toys.

Supporting evidence for the notion that observing the outcome of self-produced actions can motivate infants to engage in more actions comes from studies using conjugate reinforcement of leg kicking in two- to six-month-old infants (e.g., Rovee & Rovee, 1969; Rovee-Collier, 1999; Rovee-Collier, Gekoski, Hayne, & Lewis, 1979). In this paradigm, a ribbon is tied to an infant's ankle and to a mobile hanging above the infant. Kicking the leg with the attached ribbon makes the mobile move. Infants quickly learn the contingency and increase their leg kicks to make the mobile move more. Experiencing the outcome of their own actions was reinforcing for the infants tested in Rovee-Collier's studies and encouraged them to reproduce the outcome repeatedly. In the AT paradigm, a contingency between hand and toy movements was present once a toy was attached to the mitten. It is unlikely that the training sessions alone can cause the observed changes in behavior. Rather, experiencing the outcome of their own actions during the simulated reaching training may have encouraged infants to reproduce the outcome with different objects throughout the day. If this hypothesis were true, I expect the benefits from active simulated reaching training to increase (at least initially) as time passes. This hypothesis will be explored in Experiment 4.

At the outset of Experiment 1, I predicted that two weeks of object-directed training would increase infants' interest in objects. In contrast to this prediction, following training infants showed an increased preference for faces during the visual-exploration task. Infants experienced additional exposure to faces in both the AT and PT procedure (the faces of the experimenter visiting the infant's home). However, only the AT procedure led to an increase in face-preference behavior suggesting that self-produced action experiences foster face-preference behavior. Across all three-month-old groups, the duration of manual object exploration was a significant predictor for rapid orienting towards faces. Why would *motor* experience accelerate orienting to faces?

The development of reaching and face processing are generally seen as unrelated. Studies on the development of infants' face processing focused on the importance of exposure to faces, on structural and featural aspects of faces, and on infants' ability to recognize or discriminate different faces (e.g., Farroni, et al., 2005; Pascalis & Kelly, 2009; Sangrigoli & de Schonen, 2004; Sugita, 2009; Turati, Macchi Cassia, Simion, & Leo, 2006). Studies on the development of reaching focused on the role of vision for reaching, on hand-eye coordination abilities, movement kinematics, and on the effects of specific motor training (e.g Lobo & Galloway, 2008; Lynch, Lee, Bhat, & Galloway, 2008; Rochat, 1989; von Hofsten, 1982). My results showed a relationship between manual-exploration behavior and the emergence of rapid orienting towards faces—a behavior that may have cascading effects on future social development. Rapid orienting towards faces seems adaptive as it provides additional exposure to social partners and may foster social development. If this relation holds, one would expect motorically delayed infants to be at a disadvantage regarding their social development. Indeed, studies with clinical populations offer evidence for such patterns. For example,

infants born with severe motor deficits due to spina bifida often show social deficits later in childhood (Lomax-Bream, Barnes, Copeland, Taylor, & Landry, 2007). Similarly, there is evidence for early fine and gross motor deficits in children with Autism Spectrum Disorders (ASD)—a disorder of impaired social functioning (Landa, 2008). Children who are later diagnosed with ASD seem to orient less towards faces and show abnormal attention to biological motion in infancy (Klin, Lin, Gorrindo, Ramsay, & Jones, 2009; Osterling, Dawson, & Munson, 2002). Following infancy, autistic children show deficits in gaze following and attention to faces (Kikuchi, Senju, Tojo, Osanai, & Hasegawa, 2009; Nation & Penny, 2008). The findings presented in Experiment 1 suggest that motor deficits in infancy that are affecting the quality and quantity of early self-produced actions may subsequently lead to impaired (slower and less pronounced) preference for faces. According to this view, motor deficits would be a *risk factor* and face preference would be an associated *risk process* affecting developmental outcome (Dawson, Sterling, & Faja, 2009).

Previously it was noted that following the onset of independent reaching, infants begin to show more interest in *objects* rather than faces (Fogel, et al., 1992). The results reported here suggest that face-preference behavior is dependent on the context. In a live setting with an actual toy in front of them, infants in the AT group did look less at the experimenter (see Figure 4a). However, in a different context when faces and toys were merely photographs displayed at a distance on a computer screen, infants in the AT group showed a preference for faces over toys. Both the distance between the infant and the computer screen (about 60 cm) and the infant's position (semi-reclined in a bouncy chair or parent's lap) may decrease attention to objects and account for differences in face-preference behavior between tasks. However, despite this context,

group differences showed that the AT experience influences face-orienting behavior beyond mere context effects.

There are at least four possible explanations of how reaching experience may cause changes in social-orienting behavior: (1) Following self-produced reaching experience, infants acquire a new understanding of *themselves* as agents who can act on and transform the world around them. In particular, they may realize that faces can be interacted with at a distance while this is not possible with objects. This understanding may change the perceived social affordances of faces (Zebrowitz, 2006) and increase attempts to interact with the unresponsive faces displayed here. (2) Agentive experience may change infants' understanding of *others* as intentional and goal directed agents. In this case infants may increase their attention towards faces over toys in order to infer the intentions of the people in their vicinity (Woodward, 2009). (3) Environmental enrichment has been shown to accelerate development of the visual system in mice (Cancedda, et al., 2004). Increased visual acuity following training could make complex stimuli such as faces more interesting. Lastly, (4) self-produced action experiences may promote the development of an "embodied-simulation" system that may be crucial for our social interaction abilities (Del Giudice, Manera, & Keysers, 2009; Gallese, 2007). These four explanations are not mutually exclusive and may all contribute to the observed findings to some degree.

The results of Experiment 1 suggest new directions for future research. In particular, do self-produced motor experiences affect other social cognition skills in addition to face-preference behavior? And is face-preference behavior related to other, later emerging social cognition skills? In Experiment 2, I will explore these questions by developing a novel measure for social cognition skills during the first year and by

comparing face-preference scores of untrained infants to their overall motor activity level as reported by a parent questionnaire.

4. Experiment 2: Relations between basic social cognition skills during the first year and influences of infants' overall activity level

4.1 Introduction

In Experiment 1, I have presented evidence suggesting that motor experience influences the emergence of face-preference behavior in three-month-old infants. Faces provide a range of important social information such as identity, gender, race, emotion, and direction of attention to important or interesting events in the environment. Faces therefore provide infants with the opportunity to learn about important social cues and preferential orienting towards faces may be an important initial step for future social development (Johnson, 2005).

However, the face-preference findings of Experiment 1 were surprising since previous results suggested that infants should show increased attention towards objects following the onset of independent reaching behavior (Fogel, et al., 1992). Therefore, Experiment 2 further investigated the role of motor activity on the emergence of face-preference behavior and the implications that a preference for faces may have for future development of other social cognition skills. In the present context, social cognition specifically refers to how infants process and respond to visually available information about other human beings. Infants' social cognition skills will be related to their overall activity levels, which will be gathered via questionnaires from their parents.

Navigating the social world can be a daunting task even for experienced adults, and is presumably difficult for infants to learn about as well. Newborns face this challenge while simultaneously learning how to interact with the physical world and how to operate their changing bodies. Breathing, eating, and other bodily functions have

to be mastered, sleep and wake patterns need to be established. In addition, infants have to learn how to interact and communicate with others and form social bonds. Newborns seem reasonably well equipped for their initiation into the social world. For example, several studies have shown that newborns prefer to look at face-like images over static or moving non-face-like patterns (Fantz, 1963; Goren, et al., 1975; Johnson, et al., 1991; Kleiner, 1987). Further, newborns even show a preference for upright over inverted faces when photographs of real faces are used (Macchi Cassia, Turati, & Simion, 2004). Thus, newborns come prepared to attend to upright, face-like images. An initial bias for faces is evolutionarily conserved across several species and has been established in humans, monkeys and chicks (Johnson, et al., 1991; Johnson & Horn, 1988; Sugita, 2008). Further, also present in newborn humans and chicks is a preference for displays of biological motions over random movement patterns (Bertenthal, Proffitt, & Cutting, 1984; Bertenthal, Proffitt, & Kramer, 1987; Simion, Regolin, & Bulf, 2008; Vallortigara, Regolin, & Marconato, 2005, Fox, 1982 #320). Thus, newborns from various different species seem to come prepared with biases to attend towards biologically and socially relevant stimuli.

At present, it is unclear what causes the preferences for biologically relevant stimuli in newborns. Sensitivity to faces or biological motion may be guided by structural or general perceptual biases, or by innate modules such as a “life detector” (e.g., Troje & Westhoff, 2006; Turati, 2004). Regardless, attending to biologically relevant stimuli early in life may be crucial for healthy development by ensuring sufficient exposure to faces and people (Johnson, 2005). Supporting this view, impairments in the processing of biological motion have been observed in children with autism spectrum

disorders (Klin & Jones, 2008). This suggests that preferences present early in life may have an impact on future social development.

Another social cognition skill that seems to be present relatively early on is the ability to follow the eye gaze of another person. Studies with adults indicate that another person's gaze direction triggers a reflexive shift of attention in the observer (e.g., Driver, et al., 1999). Newborns notice the eyes, prefer to look at and orient towards faces with eye gaze directed at them, and show rudimentary gaze-following behavior (Farroni, Csibra, Simion, & Johnson, 2002; Farroni, Massaccesi, Pividori, & Johnson, 2004). By three to five months of age, there is evidence for more consistent shifts of infants' visual attention towards the gaze direction of an observed person (Hood, Willen, & Driver, 1998; Moore, 2008; Reid & Striano, 2005). However, for infants to show sensitivity to gaze direction, they have to be in a supportive context where they observe an upright face, experience a period of mutual gaze (presumably to establish communicative intent or draw attention to the face), and experience lateral motion of the eyes (at least perceived or apparent motion) (Grossmann & Farroni, 2009). Over the first year of life, gaze following becomes more mature and precise and less dependent on such a supportive context. It has been suggested that the sensitivity to eye-gaze direction in infancy may be supported by general perceptual biases or by a specialized "eye-direction detector" in the brain (Baron-Cohen, 1994; Farroni, et al., 2005). These initial biases together with experience may play an important role for the development of mature gaze-following abilities.

Gradual learning and growth with experience can also be found in other domains of social cognition, such as understanding of others' actions. An increase in infants' action understanding and action anticipation abilities can be observed over the

first year of life. For example, at three months of age, infants do not seem to understand the intentions of an actor who is reaching for one of two objects (Sommerville, et al., 2005). By five months of age intention understanding emerges, but it is not before 12 months of age that infants show an understanding of an actor's goal based on gaze direction alone (Woodward, 1998, 2003). Anticipation of the outcome of an observed action (by showing predictive shifts of eye gaze) also only emerges by the end of the first year (Falck-Ytter, Gredeback, & von Hofsten, 2006).

The findings reviewed here suggest that social cognition skills develop rapidly over the first months and years of life and are derived from early perceptual biases and experiences. Learning about the social world is likely an experience-dependent (or influenced by the individual-specific environment) or experience-expectant (or influenced by the species-typical environment) process that shapes brain and behavior (Greenough, Black, & Wallace, 1987; Johnson & Morton, 1991; Nelson, 2001). Previous studies on the development of social cognition have used powerful infant controlled paradigms (e.g., habituation) to determine when a specific social cognition skill first emerges during infancy. However, few researchers have investigated how the various social cognition skills are related to each other (Carpenter, Nagell, & Tomasello, 1998).

The purpose of Experiment 2 was twofold. The primary goal of Experiment 2 was to complement Experiment 1 by investigating whether motor activity influences face-preference behavior also in the absence of motor training. Here, motor activity was measured indirectly via a parent report by using the Infant Behavior Questionnaire (IBQ) temperament scale (Rothbart, 1981). This was done to assess the infant's day-to-day motor engagement rather than the specific engagement in the laboratory context. The second goal of Experiment 2 was to investigate whether face-preference behavior is

related to other, later emerging social cognition skills. For this purpose, a novel eye-tracking based social cognition assessment (referred to as eye-tracking battery in the following) was designed to test infants' preference for faces, gaze-following skills, and prediction of action outcomes. Additionally, one item on this assessment estimated infant's visual acuity (by measuring preference for high spatial frequencies). Visual acuity is a biological factor that likely affects visual perception as it may limit the amount of information that is accessible to the infant in a visual display. The gaze-following measure of the eye-tracking battery was modified from previous studies discussed above to make it more challenging and appropriate for use with older infants.

The eye-tracking battery was not designed to show that infants have or do not have a certain skill at a very young age. Rather, its aim was to show how different aspects of social cognition build on each other and how face-preference behavior relates to motor activity level. I hypothesized that face-preference behavior is one of the most basic social skills and that it influences development of subsequent behaviors including gaze following. Further, given the results of Experiment 1, I expected that infants' motor activity level would predict face-preference behavior. Such a relation would complement the results of Experiment 1 and provide converging evidence that motor behavior is an important contributor to the development of social cognition skills. Finally, with regard to the other social cognition skills measured here, I expected all skills to show a monotonic increase with age. Older infants are expected to show stronger face preference, more gaze following, and faster action anticipation compared to younger infants. Only infants between the ages of three months to 11 months of age were tested because all the skills measured here were assumed to develop during the first year of life.

4.2 Method

4.2.1 Participants

Four infant groups participated in this experiment (see Table 4). The youngest group (three-month-olds) was chosen to be similar in age to the active- and passive-training groups of Experiment 1 to allow for comparison of the results. The social cognition skills measured here are assumed to be present or emerge during the first year of life. Therefore, the other age groups were chosen to roughly cover the first year of life. All infants were recruited as described in the General Methods. Additionally an adult comparison group of 23 college-aged adults was recruited from the Duke University undergraduate population.

Table 4: Experiment 2, participant characteristics

Group	n	#F	Race	Age (months)	Parent Edu.	Birth weight
3-month-olds	20	10	16C, 2B, 2A	3.52 (0.44)	8.95 (2.39)	3490 (504)
5-month-olds	19	10	15C, 3B, 1M	5.05 (0.71)	9.06 (2.53)	3445 (393)
9-month-olds	18	7	15C, 3A	9.02 (0.87)	9.93 (1.94)	3354 (492)
11-month-olds	18	9	16C, 2B	11.71 (0.55)	8.88 (2.12)	3335 (444)
Adults	23	14	--	20.83 (1.17) years	--	--

Note: The total number of participants in each group (n) and the number of female participants per group (#F) are group totals. All other values are group averages with standard deviations given in parentheses. Age is reported in months except for the adult group where age is reported in years. Education level of the parents was assessed on a scale from 0-6 for each parent separately (see Experiment 1, Table 1). Parent education, race and birth weight data were not obtained from adult participants. Race abbreviations: C = Caucasian, B = Black or African American, A = Asian, M = More than one race.

4.2.2 Apparatus

Eye-tracking measures were recorded using a Tobii 1750 eye-tracker as described in the general methods section. Eye gaze was recorded at 50 Hz, resulting in one measure every 20 ms.

4.2.3 Measures

I developed a social cognition eye-tracking battery using four short tests adapted from previous studies (Figure 7). Participants' eye gaze was recorded for all measures. Additionally, infants' activity level was assessed via a parent questionnaire. The elements of the eye-tracking battery consisted of several still images and short video clips as described in the following:

- I. **High-spatial-frequency (HSF) preference:** To estimate visual acuity, grayscale versions of one male and one female face were modified using a low-pass filter (making the image blurry) and a high-pass filter (reducing the image to fine contours and details). Image manipulations were performed using the Adobe Photoshop[®] Gaussian Blur (low-pass) or High-Pass Filter functions and were subsequently enhanced using the Adobe Photoshop[®] Auto Levels function. For each face, the low-spatial frequency (LSF) and the high-spatial frequency (HSF) version were then presented side-by-side twice for 10 seconds (counterbalancing the side of the low-pass image) in a preferential looking paradigm similar to the face-preference task of Experiment 1. The proportion of the time infants spent looking at the high-pass filtered and the low-pass filtered images was then calculated and a HSF preference score was derived ($\%HSF - \%LSF$). For participants with low visual acuity, the HSF image will appear uniformly gray whereas

the LSF image will remain relatively unchanged showing an out-of-focus image of a face. Consequently, participants with low visual acuity should show a preference for the blurred face over the gray area (a negative HSF-preference score). As visual acuity increases, the details on the HSF image become clearer and the preference should shift from the LSF image to the HSF image (a positive HSF-preference score).

- II. **Face preference:** This task was identical to the visual-comparison paradigm used in Experiment 1. A colorful face and a colorful toy were presented side-by-side for 10 seconds. In contrast to Experiment 1, here only a total of four different face-toys pairs were used to shorten this assessment.
- III. **Gaze following:** In this task, a colorful photograph of a female face was shown looking straight ahead with the same toy shown on her left and her right side. After 10 seconds, the image was replaced by a new image where the actor was now gazing towards one of the toys (either left or right) for 10 seconds. The same face and toys were used across two left-looking and two right-looking repetitions to account for side-biases (total of 4 trials). First, it was determined whether participants looked at the eyes of the model during the second immediately preceding the gaze shift of the model. Only these trials (valid trials) were further analyzed to ensure that participants noticed the shift in gaze direction of the model. Next, I calculated the proportion of valid trials (max. 4 trials) where participants looked at the same toy as the model (the target toy) at least once during the 10-second trial duration. Any look at the target toy counted as a gaze-following response. Participants who showed a gaze-following response on more

than 50% of all trials (= chance level) seem to be sensitive to observed gaze direction. The target toys and the face of the model remained on the screen for the entire duration of a gaze-following trial. Having a face and a toy compete for attention increased the ecological validity of the gaze following task and made the task more challenging and appropriate for use with older infants. In a supportive context with multiple cues, already newborns show rudimentary gaze-following abilities (Farroni, et al., 2004).

- IV. **Action anticipation:** Infants' anticipatory eye movements were measured in two contexts. First, a video clip of a female actor walking behind a central occluder (pillar of an archway) and re-appearing on the other side after about 1.7 seconds was shown. During the walking event, the whole body of the actor was visible and the actor was walking at normal speed. A total of 12 occlusion events were shown with the actor walking back and forth behind the central occluder (total video duration equaled 108 seconds). Arrival of gaze at the other side of the occluder was calculated in relation to the re-appearance of the actor. Second, a video of an actor lifting and moving toys from the left side of a table and dropping them into a bucket on the right was shown. The bucket was transparent and infants could see toys fall down into it. A toy was lifted, moved to the center, held static at the center for about 2 seconds, and then transported in a smooth movement (lasting about 2 seconds) over to the bucket. This video clip lasted 80 seconds and during this time the actor moved six toys from the left side of the screen to a bucket on the right. The actor's face was not visible on the video. Anticipatory looking was measured while the toy was

moved from the center to the bucket. Again, arrival of gaze at the goal object (the bucket) was calculated in relation to the approaching hand of the actor. In both of these measures, a negative score indicated that gaze was predictive and arrived at the target location before the actor arrived at this location (re-emerged from the occluder or placed the object into the bucket). In contrast, a positive score indicated that gaze was reactive and arrived at the target location after the actor (for similar methods see Falck-Ytter, et al., 2006).

- V. **Activity Level:** Activity level was assessed in all infants using the Infant Behavior Questionnaire (IBQ) temperament scale. A caregiver of the child completed the questionnaire during the experiment. The activity level dimension on the IBQ measures gross motor activity of the child such as squirming, kicking, and locomotor activity (Rothbart, 1981). Therefore, this measure is a proxy of infants' overall motor activity and experience with self-produced limb movements. Even though this is a rather coarse measure of motor ability, activity level may strongly influence how infants acquire new motor abilities. According to Thelen's work (1995; 1983), some infants may be very active and face the challenge to learn how to control and coordinate their activity whereas other infants may be very inactive and need to learn how to energize and activate the muscles in their limbs. Based on their baseline activity levels, these infants face different challenges when learning a new motor skill.

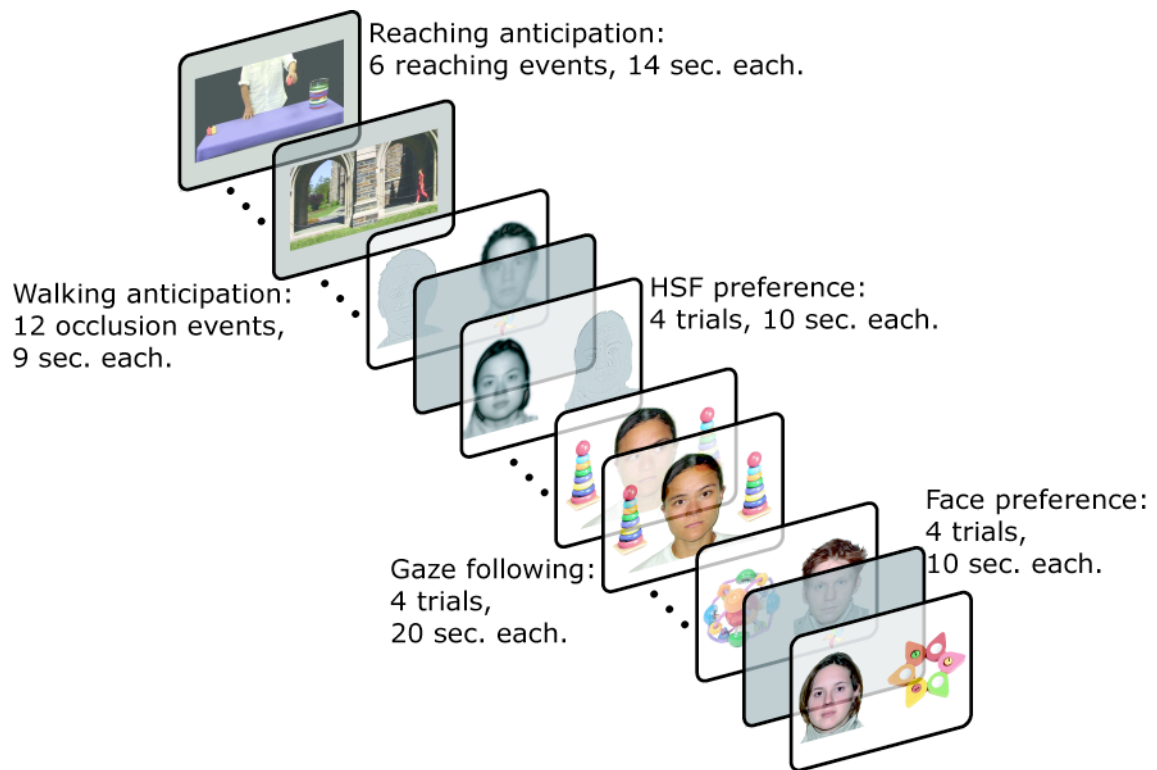


Figure 7: Experiment 2, measures of the eye-tracking battery. Stimuli were always presented in this order. A series of still images were used for the assessment of face preference, gaze following and HSF preference. Action anticipation was measured using dynamic video clips.

4.3 Results

All normally distributed measures of the eye-tracking battery were analyzed using separate 2 (Gender) x 5 (Group) between subject ANOVAs. Unless otherwise stated, none of the reported measures showed an effect of gender or interactions (all $ps > .135$). Therefore, the data was collapsed across gender for follow-up analyses. The main focus of Experiment 2 was on the developmental pattern of face preference and other social cognition measures, whether activity level predicted face-preference behavior above and beyond demographic and maturational factors (e.g., age, birth weight, HSF preference as estimate for visual acuity), and the relationship between face-preference

behavior and other social cognition measures. Face-preference behavior peaked around nine months of age and then decreased again. In contrast, gaze-following and action-anticipation behaviors showed linear developmental patterns. Supporting the results of Experiment 1, activity level was a significant predictor of face-preference behavior in three-month-old infants and face preference was correlated with gaze-following behavior.

4.3.1 HSF preference

As shown in Figure 8, HSF preference increased rapidly from five to nine months of age. HSF preference estimates visual acuity and is a measure for the development of the visual system. A 2 (Gender) x 5 (Group) between-subject ANOVA revealed significant between-group differences in HSF-preference behavior ($F(4,86) = 5.176, p = .001, \eta^2 = .183$). Post-hoc comparisons (Tukey's HSD) revealed significant differences between the adults and three-month-olds ($p = .001, 95\% CI [-67.79, -12.13]$) and between adults and five-month-olds ($p = .004, [-64.89, -8.44]$). There were no significant differences between the infant groups on HSF preference (all $ps > .145$). Within-group analyses show that a HSF preference was present in nine-month-olds ($t(16) = 2.417, p = .028, [2.5, 38.05]$), eleven-month-olds ($t(16) = 3.654, p = .002, [9.09, 34.22]$), and in adults ($t(22) = 5.579, p < .001, [22.91, 50.06]$).

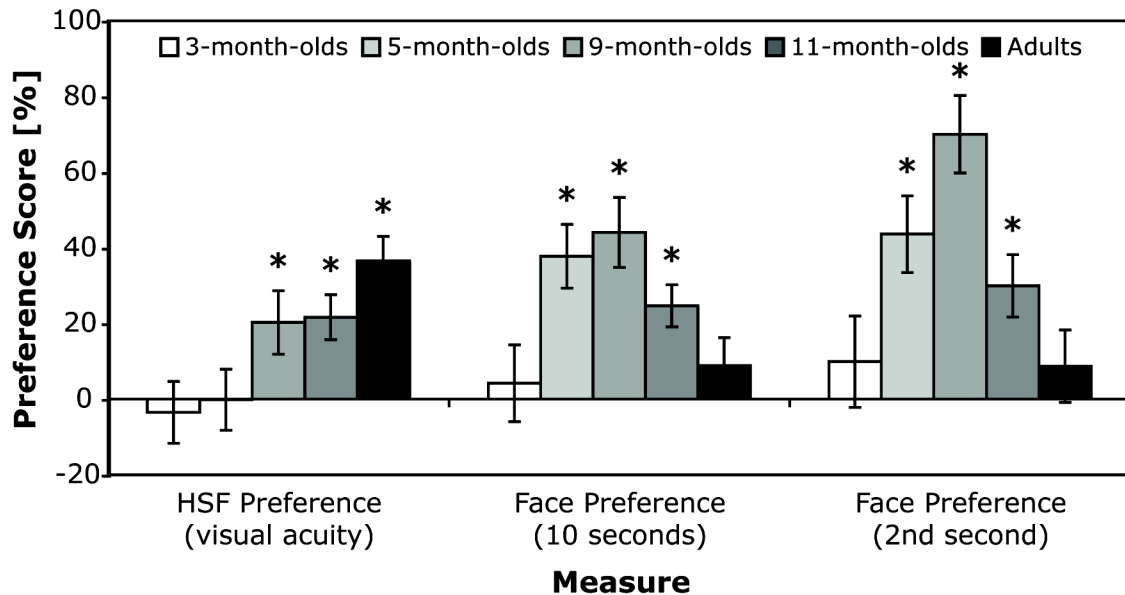


Figure 8: Experiment 2, HSF preference and face preference results. Preference scores are shown for all five age group. Error bars represent SEM. * $p < .05$.

4.3.2 Face preference

As shown in Figure 8, face preference and orienting to faces (face preference during 2nd second) increased rapidly from three to five months of age and decreased again between nine and 11 months of age. The horizontal eye-gaze position over time is shown in Figure 9 (compare to Figure 5b of Experiment 1). Separate 2 (Gender) \times 5 (Group) between-subject ANOVAs revealed a significant between-group difference in face-preference behavior during the full stimulus duration ($F(4,88) = 3.926, p = .006, \eta^2 = .14$), and during the 1000-2000 ms time window ($F(4,88) = 5.506, p = .001, \eta^2 = .189$). Post-hoc comparisons (Tukey's HSD) for the full-duration measure revealed a weaker face-preference in three-month-olds compared to five-month-olds ($p = .038, 95\% CI [-65.92, -1.2]$) and compared to the nine-month-olds ($p = .009, [-72.69, -7.05]$). Further, nine-month-olds showed a stronger face-preference than adults ($p = .023, [3.37, 66.95]$). Results were similar for orienting to faces during the 1000-2000 ms time window: nine-

month-olds showed a stronger face preference than five-month-olds ($p = .001$, [19.55, 100.69]) and than adults ($p < .001$, [21.99, 100.59]). No other post-hoc comparisons were significant.

Within-group analyses showed that a face-preference and rapid orienting to faces first emerged around five months (full duration: $t(18) = 4.465$, $p < .001$, [19.99, 55.53]; 2nd second: $t(18) = 4.301$, $p < .001$, [22.3, 64.91]), peaked at nine months (Full duration: $t(17) = 4.757$, $p < .001$, [24.52, 63.61]; 2nd second: $t(17) = 6.860$, $p < .001$, [48.48, 91.56]), and was still present at eleven months (full duration: $t(17) = 4.430$, $p < .001$, [12.91, 36.4]; 2nd second: $t(17) = 3.643$, $p = .002$, [12.61, 47.29]) but was not present in adults anymore (both $ps > .240$; Figure 8). However, visual inspection of the horizontal eye-gaze position over time indicated that the adult group would show a clear face preference during the first 1000 ms following stimulus onset (Figure 9). Thus, adults seemed to show a faster orienting response compared to infants.

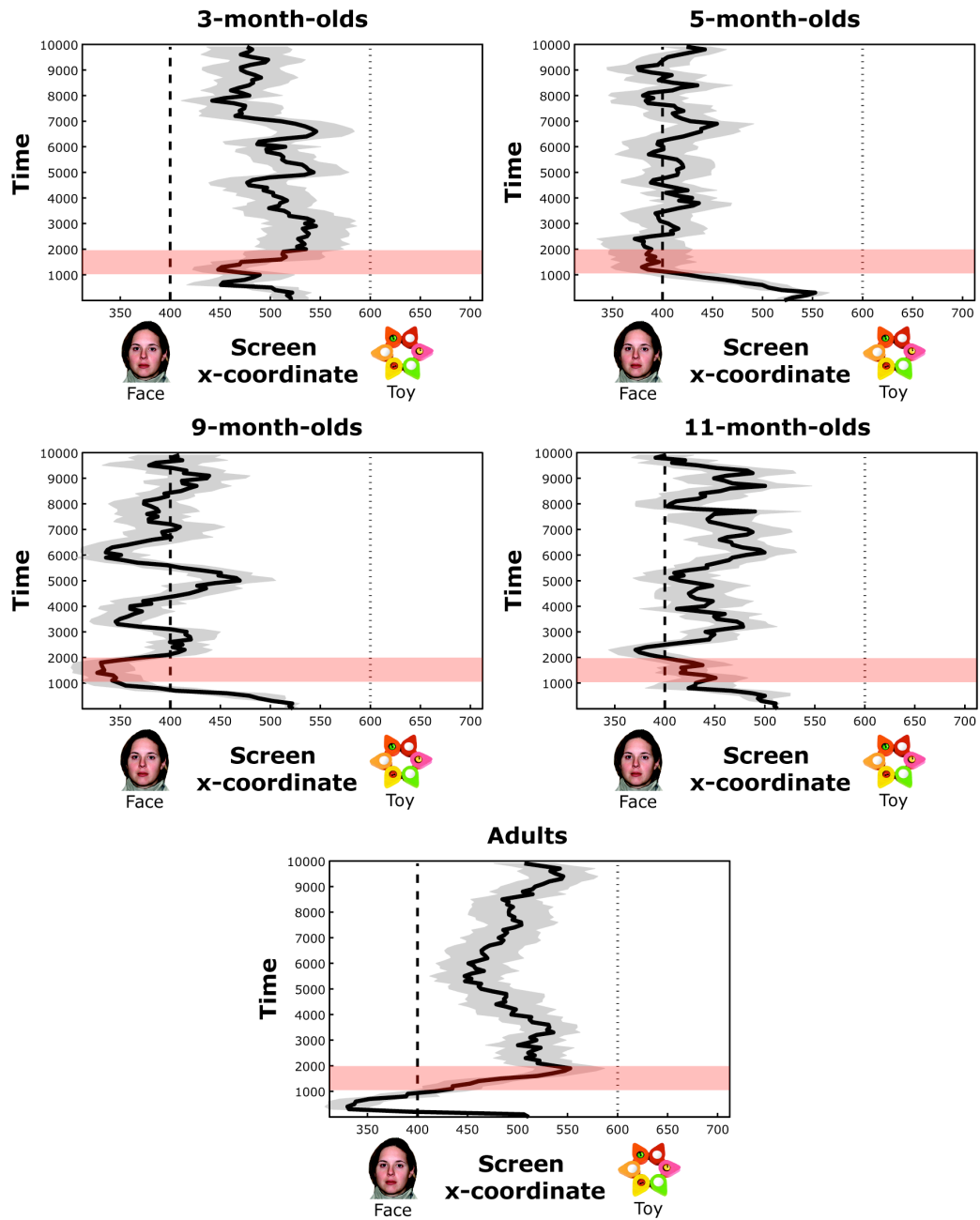


Figure 9: Experiment 2, horizontal eye-gaze position during face-preference task. Starting at five months of age, all infant groups show a preference for faces over toys, especially during the 1000-2000 ms time window (red highlighted area). Adults show no overall face preference but rapid orienting to faces in the first 1000 ms. Gray shaded area represents SEM.

4.3.3 Gaze following

To assess gaze-following behavior, the number of trials where infants looked at least once in the same direction as the model on the screen was calculated and expressed as proportion of all valid trials (max. 4 trials). As shown in Figure 10, a consistent gaze-following response emerged between nine and 11 months of age. Separate Kolmogorov-Smirnov tests for normality indicated that gaze-following data of the five-month-old ($D(19) = .226, p = .011$), the nine-month-old ($D(16) = .221, p = .036$), the 11-month-old ($D(16) = .457, p < .001$), and adult groups ($D(23) = .467, p < .001$) had non-normal distributions. Therefore, non-parametric analysis methods were used. A Kruskal-Wallis test revealed significant differences between all groups ($H(3) = 19.451, p = .001$). Mann-Whitney tests were used to follow up this finding. A Bonferroni correction was applied and only differences at a .005 level of significance (total of 10 comparisons) are reported. Results indicated less gaze-following behavior in the three-month-olds compared to the 11-month-olds ($U = 61.5, p = .002$) and to the adults ($U = 88.0, p < .001$). There were no significant differences between the other groups at the .005 level of significance.

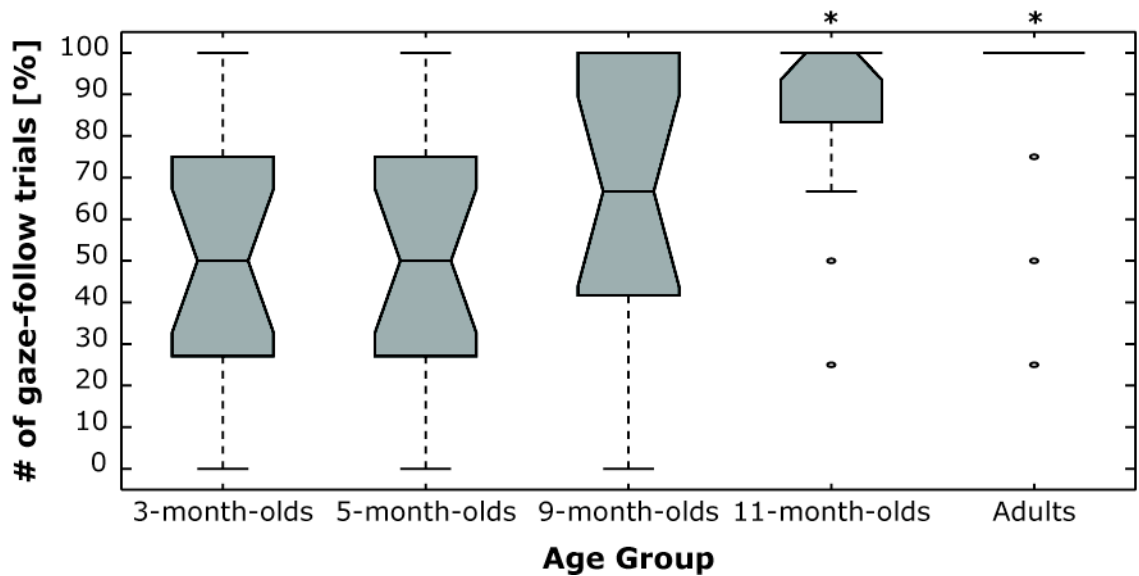


Figure 10: Experiment 2, results of gaze-follow task. Boxplots show the median number of successful gaze-follow trials. * $p < .05$ binomial procedure.

For within-group analyses, the number of infants that showed a gaze-following response on more than 50% of all valid trials (50% = chance because infants had a choice between two objects) was calculated and compared using the binominal procedure. Only seven out of 20 three-month-olds ($p = .074$), nine out of 19 five-month-olds ($p = .176$), and 11 out of 18 nine-month-olds ($p = .121$) showed a gaze-following response on more than 50% of all trials. In contrast, 15 out of 18 eleven-month-olds ($p = .003$) and 19 out of 23 adults ($p = .001$) showed a gaze-following response on more than 50% of all trials.

4.3.4 Anticipation of actions

Results of the two action-anticipation tasks are illustrated in Figure 11. For each task, separate 2 (Gender) x 5 (Group) ANOVAs were conducted. There was a significant effect of group for the walking-anticipation task ($F(4,80) = 38.095, p < .001, \eta^2 = .648$). Post-hoc comparisons (Tukey's HSD) revealed faster anticipation in adults compared to

all infant groups (all $ps < .001$). Eleven-month-olds showed faster anticipation than three- ($p < .001$, 95% CI = [-1201, -440]) and five-month-olds ($p = .002$, [-963, -162]) but were only marginally different from the nine-month-old group ($p = .064$). Finally, nine-month-olds showed faster anticipation compared to three-month-olds ($p = .014$, [-809, -61]) but not compared to five-month-olds ($p = .721$), and there were no differences between three- and five-month-olds ($p = .310$). Within-group analyses revealed reactive eye gaze (values larger than 0) in three-month-olds ($t(19) = 6.739$, $p < .001$, [471, 895]), five-month-olds ($t(15) = 4.559$, $p < .001$, [226, 622]) and nine-month-olds ($t(15) = 2.641$, $p = .019$, [48, 447]). For the eleven-month-old group, arrival of eye gaze was not significantly different from zero ($t(14) = -1.282$, $p = .221$) and only the adult group showed predictive eye gaze ($t(22) = -10.018$, $p < .001$, [-871, -572]).

On the reaching-anticipation task, the ANOVA revealed a significant main effect of Group ($F(4,74) = 4.912$, $p = .001$, $\eta^2 = .186$) and a significant gender x group interaction ($F(4,74) = 2.798$, $p = .032$, $\eta^2 = .105$). Separating the data by gender, two follow-up ANOVAs revealed a significant between-group difference for male participants ($F(4,37) = 5.697$, $p = .001$, $\eta^2 = .381$) and only a marginally significant one for female participants ($F(4,37) = 2.489$, $p = .060$, $\eta^2 = .212$). Within-group analyses for all female participants showed that arrival of gaze was predictive only for the adult group ($t(14) = -4.678$, $p < .001$, 95% CI [-728, -268]) and not significantly different from zero (neither predictive nor reactive) in all of the infant groups (all $ps > .271$). In contrast, within-group analyses for all male participants showed that arrival of gaze was predictive for the adult group ($t(8) = -2.614$, $p = .031$, [-1007, -63]) and the eleven-month-old group ($t(4) = -4.119$, $p = .015$, [-1120, -218]), reactive in the five-month-old group ($t(7) = 2.477$, $p = .042$, [42, 1785]), and there were no differences in the three- and nine-month-old groups (both $ps > .300$).

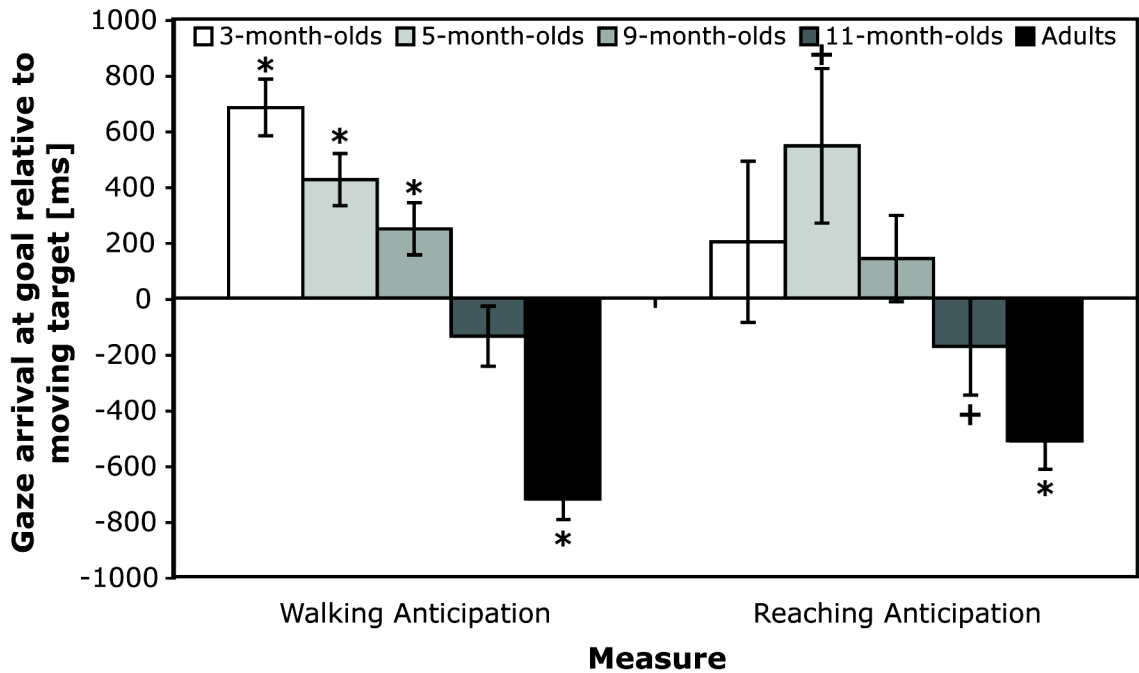


Figure 11: Experiment 2, results of the action anticipation tasks. Positive values denote reactive eye gaze and negative values denote predictive eye gaze. Only adults showed predictive eye gaze in both tasks. Error bars represent SEM. * $p < .05$. + $p < .05$ for male participants only (note that group means across males and females are plotted).

4.3.5 Regression models on motor activity and face preference

As an estimate for infants' motor activity, the temperament dimension "activity level" was assessed via parent questionnaire. A 2 (Gender) \times 4 (Group) ANOVA on activity level revealed a significant main effect of group ($F(3,65) = 7.888, p < .001, \eta^2 = .254$) but no effects of gender or interactions (both $ps > .280$). Post-hoc comparisons (Tukey's HSD) revealed that activity level increased with age and three-month-olds ($M = 3.71, SD = 0.98$) were rated lower on this measure than nine-month-olds ($M = 4.61, SD = 0.71; p = .002, 95\% CI [-1.51, -0.27]$) and 11-month-olds ($M = 4.75, SD = 0.44; p < .001, [-1.68, -0.40]$).

Based on the results of Experiment 1, I predicted that the level of motor activity would influence face-preference behavior. This hypothesis was tested with a regression

model predicting face-preference behavior. In addition to activity level, demographic variables (age, birth weight and gender), and HSF preference (as estimate for infants' visual acuity) were included as predictors in the model. Overall, the model explained a significant amount of variation in face-preference behavior for both the three-month-old group alone ($R_{Adj.}^2 = .387, F(5,14) = 3.395, p = .032$) and all infant groups combined ($R_{Adj.}^2 = .174, F(5,65) = 3.952, p = .003$). In both cases, activity level was a significant predictor for face-preference behavior (three-month-olds: $t(14) = -2.493, p = .026, \beta = -.503$; all infants: $t(65) = -2.302, p = .025, \beta = -.286$). Therefore, activity level is a significant predictor for face-orienting behavior at three months of age. Activity level was not a significant predictor in separate regression models for five, nine, and 11-month-olds (all $ps > .100$).

Analogous to Experiment 1, I further hypothesized that activity level would predict rapid orienting to faces (face preference during the 2nd second only). To test this hypothesis, the same regression model as above was used to predict face-preference behavior during the 1000ms-2000ms time window (see Experiment 1). Together, activity level, demographic factors, and HSF preference explained a significant proportion of variation in three-month-olds' rapid orienting towards faces ($R_{Adj.}^2 = .452, F(5,14) = 4.137, p = .016$). Again, activity level was a significant predictor for rapid face-orienting in this model ($t(14) = -2.300, p = .037, \beta = -.438$). However, this was not the case across all infant groups combined. The same model across all groups was significant ($R_{Adj.}^2 = .097, F(5,65) = 2.510, p = .039$) but only age and gender were significant predictors for rapid orienting to faces. Thus in three-month-olds, activity level accounts for a significant amount of variation in rapid orienting to faces above and beyond influences of age, gender, birth weight, and HSF preference. The relation between face-preference and activity level is

negative, for every unit increase in activity level, there is an associated 0.5 unit (face-preference score) *decrease* in rapid orienting to faces.

4.3.6 Correlations among social cognition behaviors

To determine how the various social cognition measures collected in Experiment 2 relate to each other during infancy, Pearson’s correlation coefficients were calculated. To increase the number of subjects for the correlation analysis, the three- and five-month-old infant groups were combined and the nine- and 11-month-old infants groups were combined. These combinations were selected because adjacent groups were close in age (only two months difference) but showed different trends regarding their face-preference behavior (i.e. increasing from three to five months but decreasing from nine to 11 months, see Figure 8). Results of the correlation analyses are shown in Table 5 for three- and five-month-olds and Table 6 for nine- and 11-month-olds.

Table 5: Experiment 2, correlations between social cognition measures for 3-5-month-old infants

	Age	BW	HSF	FP	GF	RA	WA
Age	1.00	.097	.029	.447**	.204	.076	-.296
BW		1.00	-.071	.134	-.203	.175	.270
HSF			1.00	-.453**	.353*	-.122	-.071
FP				1.00	-.324*	.226	-.135
GF					1.00	-.402*	-.104
WA						1.00	-.027
RA							1.00

Note: All values are Pearson’s correlation coefficient *r*. Significant results are highlighted in bold. Age was measured in weeks. Abbreviations: BW = birth weight (in grams), HSF = HSF preference, FP = face preference, GF = gaze following, WA = walking anticipation, RA = reaching anticipation. * $p < .05$. ** $p < .01$.

For the combined three- to five-month-olds, face-preference behavior was significantly correlated with age in weeks ($r_{39} = .447, p = .004$), with visual acuity as measured on the HSF-preference task ($r_{39} = .453, p = .004$), and with gaze-following behavior ($r_{38} = -.324, p = .047$). The correlation between face preference and gaze following was negative, indicating that infants who showed a strong face preference showed fewer gaze-following responses. A regression model with gaze following as dependent variable and age, gender, birth weight, HSF preference, and face preference as predictors further explored the relationship between face-preference and gaze-following behavior. Together, face-preference behavior, demographic factors, and HSF preference explained a significant proportion of variation in three- to five-month-olds' gaze-following behavior (full model: $R_{Adj}^2 = .187, F(5.32) = 2.697, p = .038$). Face-preference behavior was a significant predictor for gaze following when age, gender, birth weight, and HSF preference were controlled for ($t(32) = -2.098, p = .044, \beta = -.390$). Further, gaze following was correlated with HSF preference ($r_{38} = .353, p = .030$) and anticipation of reaching actions ($r_{30} = -.403, p = .028$).

Table 6: Experiment 2, correlations between social cognition measures for 9-11-month-old infants

	Age	BW	HSF	FP	GF	RA	WA
Age	1.00	.176	.086	-.177	.389*	-.297	-.474**
BW		1.00	-.154	-.029	.004	-.152	-.011
HSF			1.00	.230	.366*	.207	-.413*
FP				1.00	-.068	.257	-.202
GF					1.00	-.232	-.408*
RA						1.00	.148
WA							1.00

Note: All values are Pearson's correlation coefficient r . Significant results are highlighted in bold. Age was measured in weeks. Abbreviations: BW = birth weight (in grams), HSF = HSF preference, FP = face preference, GF = gaze following, WA = walking anticipation, RA = reaching anticipation. * $p < .05$. ** $p < .01$.

For the combined nine- and 11-month-olds, there were no significant correlations between face-preference behavior and any of the other variables. However, gaze-following behavior showed significant correlations with age ($r_{32} = .389, p = .028$), HSF preference ($r_{32} = .366, p = .039$), and anticipation of walking actions ($r_{28} = .408, p = .031$). Also significantly correlated with anticipation of walking actions were age ($r_{31} = -.474, p = .007$) and HSF preference ($r_{30} = -.413, p = .023$).

4.4 Discussion

4.4.1 Activity level and face-preference behavior

The primary goal of Experiment 2 was to investigate the relationship between overall activity level and face-preference behavior in three-month-old infants. In contrast to Experiment 1, where motor behavior was quantified directly via manual exploration

of toys in trained infants, activity level in Experiment 2 was assessed using the activity level dimension of the Infant Behavior Questionnaire (Rothbart, 1981) in naïve, untrained infants. The IBQ measure of activity level is a proxy for infant's day-to-day motor engagement and consequently their experience with self-produced (but possibly accidental and uncoordinated) movements. As such, investigating the effect of motor activity on face-preference behavior complements the results obtained in Experiment 1.

Experiment 2 showed that activity level was a significant predictor of face-orienting behavior in both three-month-old infants alone and in all infant groups combined. Therefore, infants' orienting to faces is influenced by their own motor ability (Experiment 1) and activity level (Experiment 2). Together, Experiments 1 and 2 provide converging evidence for a role of motor behavior on the development of face-orienting behavior. However, while in Experiment 1 the relationship between duration of manual object exploration and orienting to faces was positive (more exploration was associated with a stronger preference for faces), the relationship between activity level and orienting to faces in Experiment 2 was negative: Infants who were rated high on their activity level tended to show weaker face-orienting behavior.

A negative relation between activity level and orienting to faces seems to contradict Experiment 1. However, the temperament dimension "activity level" assesses mostly gross motor activity such as kicking, squirming, and locomotor activity (Rothbart, 1981). Experiment 1 has shown a positive relation between reaching out and touching an object with the hands and face-orienting behavior. Reaching for an object requires coordinated and controlled movement of the arm, hand, and fingers. Depending on their overall motor activation, infants face different challenges when engaging in object-directed reaching behaviors. In particular, active infants who show

strong motor activity first need to learn how to focus their energy and counteract their motor activity before they can engage in controlled reaching and grasping behaviors (Thelen, et al., 1993). Therefore, the negative relation between activity level and face-orienting behavior may be consistent with a positive relation between reaching and face-orienting behavior.

Experiments 1 and 2 indicated that orienting to faces is mainly driven by an emerging control over reaching movements in infants. With the onset of reaching, infants may also become more aware of their own abilities and the affordances a current situation offers for interactions with an object (Gibson & Pick, 2000). With regard to the face-preference task, infants may realize both that the object is too far away for manual interactions and that the person on the screen is an intentional agent who could be interacted with (Woodward, 2009; Yonas & Hartman, 1993). Such observations may make faces more interesting than objects in the context tested here.

4.4.2 Face-preference behavior and its relation to other social cognition abilities

The second goal of Experiment 2 was to determine whether face-preference behavior is related to other, later emerging social cognition skills. To answer this question, I first needed to establish that face-preference behavior—as assessed here—emerges before other social cognition skills and is further correlated with other social cognition skills. A preference for faces over toys was indeed the earliest emerging social cognition skill in Experiment 2. Face-preference emerged quickly between three to five months of age, peaked around nine months of age and then leveled off again. The peak in a preference for faces around nine months confirms results from a previous study that investigated infants' attention while viewing video clips with animated characters

(Frank, Vul, & Johnson, 2009). However, in contrast to the results by Frank and colleagues (2009), I observed a decrease in face preference following nine months of age with adults showing no preference for faces anymore. One reason for this discrepancy may be the use of static images in my study. Adults showed very rapid orienting towards the face and likely finished processing the face within the first second of stimulus presentation. Subsequently, the static face did not continue to attract adults' attention. In the context of a static face-toy pair, adults may have been compelled to attend to both stimuli equally whereas in the context of an animated movie, faces carry meaning and are changing (in expression and direction of gaze) and therefore may have attracted more attention.

With a preference for faces emerging early in development (around five months), it is possible that this behavior influences subsequently emerging social cognition skills. Correlation and regression analyses indeed confirmed that face-preference behavior is related to or predicts gaze-following behavior in three- to five-month-old infants. The relation between face preference and gaze following was negative: A stronger preference for faces was associated with fewer gaze-following responses. The gaze following stimuli used in Experiment 2 showed one pair of identical toys to the left and right of an actor's face. The two toys remained visible throughout and did not suddenly appear as in previous studies on gaze following (e.g., Farroni, et al., 2004; Hood, et al., 1998). Further, the face of the model did not disappear following a gaze shift of the model. Thus, the face and target toy directly competed for the infant's attention and there was no salient cue (such as sudden appearance) that drew attention to the toys. With a face and toy competing for attention, the gaze-following trials were very similar to the face-preference trials and one would predict a negative relation between these measures.

While face-preference trials measured infants' *engagement to faces*, the gaze-following trials measured infants' *disengagement from faces*. Thus, it appears as if face-preference behavior is detrimental for gaze-following behavior. However, from a developmental perspective, infants first have to learn to orient towards faces in order to make use of the information provided in a face. Subsequently, infants have to learn to disengage from the face. Infants who show a strong preference for faces early in development provide themselves with more opportunities to learn about the information provided by faces (Johnson, 2005) and may become able to disengage from faces earlier. A longitudinal study design would be necessary to test this hypothesis directly.

In addition to its correlation with face-preference behavior, gaze-following behavior was also correlated with the anticipation of the goal of grasping actions at three to five months of age and with the anticipation of a person re-appearing from behind an occluder at nine- to 11 months of age. Correlations among face-preference, gaze-following, and action-anticipation behaviors show that different social cognition abilities are intertwined and possibly build on each other. In particular, gaze-following behavior seems to be an essential social cognition skill for future learning and development (Moore, 2008). However, Experiment 2 showed that face-preference behavior emerges before gaze following in development. It is possible that face-preference behavior, via its influences on gaze-following behavior, is major contributor to the development of later emerging social cognition skills. This hypothesis has implications for the emergence of developmental disorders of social cognition and should also be investigated longitudinally.

While the primary focus of Experiment 2 was on face-preference behavior and its relation to motor activity and to other social cognition measures, I also assessed two

other social cognition skills, gaze-following behavior and action anticipation. I will discuss the results of these two social cognition abilities in the following.

4.4.3 Gaze-following behavior

One measure of the eye-tracking battery assessed infants' ability to follow the gaze of an actor on a computer screen. Previous studies have measured this ability in a supportive context and observed gaze-following behavior already in the first month of life (Farroni, et al., 2004). In Experiment 2, I chose a different approach using a more naturalistic context and observed gaze-following behavior emerging more slowly over the first year.

Reliable orienting in the same direction as an observed actor on a computer screen only occurred in 11-month-old infants, much later than previously reported (Farroni, et al., 2004; Reid & Striano, 2005). One reason for this difference may be that the stimuli used here did not provide a very supportive context for this behavior (Grossmann & Farroni, 2009). First of all, the target object was visible to the infants already before the model shifted her gaze. Thus, the model's shift of gaze direction was not contingent on the appearance of a target object. Second, the gaze shift of the model was not animated—instead of showing smooth lateral movement, the eyes jumped from looking straight to looking left or right. Finally, the model's face remained on the screen throughout the gaze-following trials, competing for attention with the target toy. Together, these three factors may have made it difficult for infants to infer the model's intentions. However, the supportive context that facilitates gaze-following behavior was removed intentionally to make the task more challenging and appropriate for use with older infants. The procedure used here may provide a measure for gaze-following behavior that is more ecologically valid. In the real world, objects do not suddenly

appear out of nowhere and people do not disappear once they moved their eyes to the left or right. While already newborns can show a gaze-following response, I fail to find successful gaze following before 11 months of age. In a more naturalistic context where multiple stimuli compete for attention, gaze-following behavior seems to emerge late during the first year of life.

4.4.4 Action anticipation

Anticipation of the outcome of an action is seen as a hallmark of action development (von Hofsten, 2004). I tested anticipation of action outcomes in two different situations: 1) A person walking behind an occluder and reappearing on the other side. 2) A person reaching for toys and placing them into a bucket. I observed evidence for anticipatory eye-movements only in 11-month-old infants and in adults but not in the younger infant groups. This suggests that anticipation of action outcomes develops late in the first year of life.

In a study similar to the walking context used here, observation of a ball rolling behind an occluder and re-appearing on the other side elicited anticipatory eye-gaze behavior in 4-6-month-old infants (Johnson, Amso, & Slemmer, 2003). Four-month-olds showed fewer and slower anticipatory eye movements than six-month-old infants but benefited from a short training period where the un-occluded object trajectory was visible. In contrast, in my study three- and five-month-old infants did not reliably anticipate the reappearance of a walking person from behind an occluder. It is possible that the context of a “human-walking” made it harder for infants to predict the trajectory of the person. A walking person is less predictable than a ball and may decide to stop or turn around at any time. Perception of an intentional agent walking additionally adds the need to interpret and understand the observed actions. This may

require a first-hand understanding of the observed action via a mirror-matching system (Gallese, Rochat, Cossu, & Sinigaglia, 2009) and experiences of self-produced locomotion may be necessary prior to the emergence of such an understanding. During the first year, infants begin to engage in several forms of self-produced locomotion (variants of crawling, cruising, aided and eventually independent walking) and learn from these experiences (Adolph & Berger, 2006; Adolph & Eppler, 1998; Gesell, 1934; McGraw, 1935). Walking in particular can emerge as early as six to 13 months of age (de Onis, 2006). It is possible that older infants may show anticipatory gaze patterns in this task if they have experienced upright locomotion.

Speaking against such an interpretation, anticipatory eye-movements in the context of goal directed hand actions were only observed in adults and 12-month-old infants but not in six-month-old infants (Falck-Ytter, et al., 2006). However, reaching and grasping behavior already occurs around 4-5 months of age (Pomerleau & Malcuit, 1980). By six months infants had experience with this ability and consequently should show anticipation of reaching actions. Using a similar paradigm as Falck-Ytter and colleagues (2006), I measured anticipation of reaching actions in the eye-tracking battery. My results replicated their general findings: predictive eye-gaze was evident in adults but not in any of the infant groups. Indicating that anticipation behavior eventually emerges around 12 months, the 11-month-old males tested in Experiment 2 showed predictive gaze. The reaching event seems to be simpler than the walking event since it does not involve occlusion. However, it is possible that the lack of occlusion makes the task more difficult since the ongoing hand movements of the model capture infants' attention. Except for five-month-old males, arrival of gaze at the target location was not reactive in the reaching context. Rather, infants seemed to be drawn to the hand and

colorful object as they moved across the screen. Thus, the saliency of the reaching event may distract infants younger than 12 months of age. Eventually, they develop better attentional control and can disengage from the salient hand movements of the actor.

The different results observed for males and females on the reaching-anticipation task were surprising. The pattern of results indicated predictive gaze patterns in males but not in females. No previous studies suggested such an interaction. But note that in the study by Falck-Ytter and colleagues (2006) where anticipation was observed in 12-month-old infants, more males than females were tested (24 males vs. 17 females in the 12-month-old group) and gender was not considered as a factor in their statistical analyses. Some previous studies suggest differences in motor development between males and females. While there is no evidence for prenatal differences in motor activity between boys and girls, gender differences become evident in infancy with males being more active than females (DiPietro, Kivlighan, Costigan, & Laudenslager, 2009; Eaton & Enns, 1986). However, Experiment 2 did not reveal gender differences on the activity level measure used here. By adolescence, gender differences seem to exist on pure motor tasks (e.g., agility, grip strength, tapping speed) with boys performing better than girls. But these differences are likely influenced by environmental factors (Thomas & French, 1985). Therefore, the gender differences within separate age groups on the reaching-anticipation task should be interpreted with caution. Sample sizes were very small for these comparisons and results need to be replicated with larger samples.

The eye-tracking battery developed in Experiment 2 shows that several social cognition skills emerge during the first year of life. Face-preference behavior appears already around five months of age and seems to be one of the most basic social cognition skills. In contrast, gaze-following behavior becomes evident around 11 months of age

and only mixed evidence was observed for anticipation of actions before 12 months of age. It is likely that the later emerging social cognition skills build on earlier emerging skills. Correlations between various social cognition measures support this hypothesis. Further, infants' activity level as reported by their parents was a significant predictor for face-preference behavior. Therefore, motor experience and activity could have a significant impact on future social development by shaping early face-preference behavior in three-month-old infants.

5. Experiment 3: Influences of external encouragement and first-hand experiences on infants' motor and social development

5.1 Introduction

In Experiment 1, I investigated the effects of the simulated reaching paradigm on reaching behavior and the emergence of orienting towards faces. In Experiment 3, I will return to issues raised in Experiments 1 and investigate the impact of two novel training procedures on the emergence of reaching and grasping behavior. The eye-tracking battery developed in Experiment 2 will be used to assess whether the training procedures also influence social cognition skills, in particular face-preference behavior.

Previous work by Needham and colleagues (Needham, et al., 2002; Sommerville, et al., 2005) showed that simulated reaching experience (active training) increases infants' object exploration and their understanding of others' intentions. Similarly, the results reported in Experiment 1 showed that active training increases infants' reaching and grasping behavior and provided support for a connection between motor ability and face-preference behavior. It is tempting to interpret the positive results of training studies as supporting the idea that motor training might accelerate overall development. However, currently there is no evidence for such an argument. Further, the primary goal of training and enrichment studies should not be to improve or accelerate development, but rather to determine the processes, experiences, and mechanisms that propel an infant from one developmental stage to the next (but see McGraw, 1970). Experimental manipulations of motor behaviors (such as reaching or walking) allow for observation of the outcomes associated with these experiences.

Controlled training studies reduce the number of confounding variables that are found in a natural environment and may therefore help to identify which experiences are necessary for developmental transitions to occur. For example, the results of Experiment 1 showed that active training (AT) encouraged reaching, grasping, and face-preference behavior. Ruling out influences of the training situation, context, and materials, passive training (PT) elicited no changes in infants' behavior. However, the AT procedure was still very rich and supportive, providing several additional experiences that may influence infants' engagement with objects and people. Which components of the AT procedure were essential for eliciting reaching, grasping, and face-preference behavior? In order to determine which aspects of the AT procedure were necessary to bring about changes in infants' behavior, I first needed to identify what kind of experiences were present in the AT procedure. Sticky mittens in the AT group allowed the infants to experience simulated reaching. In contrast, the non-sticky mittens in the PT group thwarted infants' efforts to engage in self-produced reaching (by covering the fingers). In addition to this main difference, two further experiences were prominent in the AT procedure but absent in the PT procedure.

The first experience present in the AT procedure was parental encouragement to act on the training toys. Parents were instructed to encourage infants to make contact with the toys (by pointing and making comments). Several studies suggest that three-month-old infants are sensitive to triadic (infant-object-parent) relations and gaze direction of the caregiver (Striano & Reid, 2006; Striano & Stahl, 2005). However, infants do not need to have an understanding of others' intentions to show shared attention behavior (Corkum & Moore, 1998). Therefore, it is unclear whether triadic interactions are meaningful for three-month-old infants and whether they encourage infants to act

on the shared objects. Thus, while the parental encouragement in the AT group drew attention to the training toys, motivated infants to act on the toys, and elicited shared attention with their parents, it is unclear whether these experiences were contributing to the changes in exploration and face-preference behavior.

A second component present in the AT procedure was that infants experienced control over the movement and trajectory of the training toys following manual contact. While wearing the sticky mittens, accidental or purposeful contact with the training toys caused them to stick to the mittens. Once a toy attached to the mittens, toy movement became contingent on infants' arm movements until the toy was removed from the mitten by the parent.

These two experiences provided infants with two kinds of motivation to act on toys themselves—external and internal motivation. Both external and internal motivation were likely involved in causing the behavioral changes elicited by the AT procedure. However, it is unclear if only one of these experiences is sufficient or whether both are necessary for changing infants' behavior. In Experiment 3, I selectively manipulated external and internal motivation to determine their impact on motor and social development. Two groups of three-month-old infants were trained using different produces. The first group—referred to as the encouragement-experience group—received training designed to increase their motivation to act upon and obtain an object placed in front of them. The second group—referred to as the movement-experience group—received training designed to provide them with experience of being able to control and move an object in the absence of external motivation to do so. Both groups were tested on the four-step reaching assessment of Experiment 1 and on the eye-tracking battery developed in Experiment 2.

Different results were predicted for the two training groups of Experiment 3. External encouragement by parents is present throughout infants' daily lives. However, it is unclear whether three-month-old infants are sensitive to external encouragement and make use of this information to guide their own actions. Therefore, I hypothesized that the encouragement-experience procedure would not increase manual exploration, face-preference behavior, or gaze-following behavior. It is possible that infants in the encouragement group become faster in anticipating the goal of reaching actions—but not walking actions—since their parents demonstrated this behavior to them during the training sessions and the infants were also allowed to attempt reaching on their own.

In contrast, the movement-experience procedure allows infants to experience control over external objects—an experience that was present in the AT group but not the PT group of Experiment 1. As discussed in Experiment 1, experiencing the effects of self-produced arm movement on objects (regardless if the object was offered by a parent or acquired by the infant herself) provides infants with a form of contrastive evidence (Baillargeon, 1999) and may enable infants to learn more about their own abilities. Therefore, I hypothesized that experiencing control over objects would encourage face-preference behavior (as suggested by Experiment 1) and consequently would decrease gaze-following behavior (as suggested by Experiment 2). However, because the parent attaches the toy to the infant's hand and the infant is never allowed to practice independent reaching, I did not predict that movement-experience training would increase reaching and grasping behavior or anticipation of observed reaching or walking actions.

A third possibility is that neither external nor internal motivation alone are sufficient but that both components are necessary to elicit changes in behavior. In this

case, neither the encouragement nor the movement group should show changes in their motor or face-preference behavior.

In addition to social cognition measures, the eye-tracking battery includes a task that estimates visual acuity (high-spatial frequency preference). Visual acuity limits the amount of information that is available to the infant and therefore may be a factor that strongly influences infants' response to visual stimuli (i.e. all stimuli in the eye-tracking battery). Predictions regarding performance on the HSF-preference task in Experiment 3 are difficult to make because it is still unclear how experience affects the development of visual acuity. In general, visual acuity increases rapidly over the first months of life and seems to mostly depend on maturational factors (Banks & Salapatek, 1978). However, newborn mice show faster eye opening and visual acuity development when raised in an enriched environment (Cancedda, et al., 2004). Two points argue against similar patterns in human infants following motor training. First, the comparison group in the enrichment study by Cancedda and colleagues (2004) was raised under "standard laboratory" conditions, which can be seen as a form of deprivation. The results of Cancedda and colleagues (2004) may only apply to comparisons between deprivation and enrichment conditions. Second, human infants tend to grow up in an already highly enriched environment where additional motor enrichment may have no further impact on visual system development. Therefore, I did not predict differences between trained and untrained infants on the HSF-preference measure.

Two groups of infants were trained and tested in Experiment 3 and their manual and visual exploration was compared to trained and untrained infants from Experiments 1 and 2. In Experiment 1, the difference between the AT and PT groups showed that the presence of in-home sessions did not affect infants' manual-exploration

and face-preference behavior. Therefore, the home-visit component of Experiment 1 was removed for Experiment 3. This reduced the complexity and need for resources of Experiment 3 but also removed infants' additional exposure to novel faces (of the experimenters) over the training period—a factor that might influence face-preference behavior.

5.2 Method

5.2.1 Participants

Two groups of three-month-old infants were tested at the beginning and at the end of a two-week training period (Figure 12) using a procedure similar to Experiment 1 (see Figure 3). Infants received either parental encouragement to grasp a toy (encouragement experience) or were allowed to move an object that was securely placed into their hands (movement experience). I tested 18 infants in the encouragement-experience (EE) group and 19 infants in the movement-experience (ME) group (see Table 7 for details about the participants). An additional five infants were recruited but excluded from the final sample due to fussiness resulting in failure to complete the study (n=3) or equipment failure and technical issues (n=2).

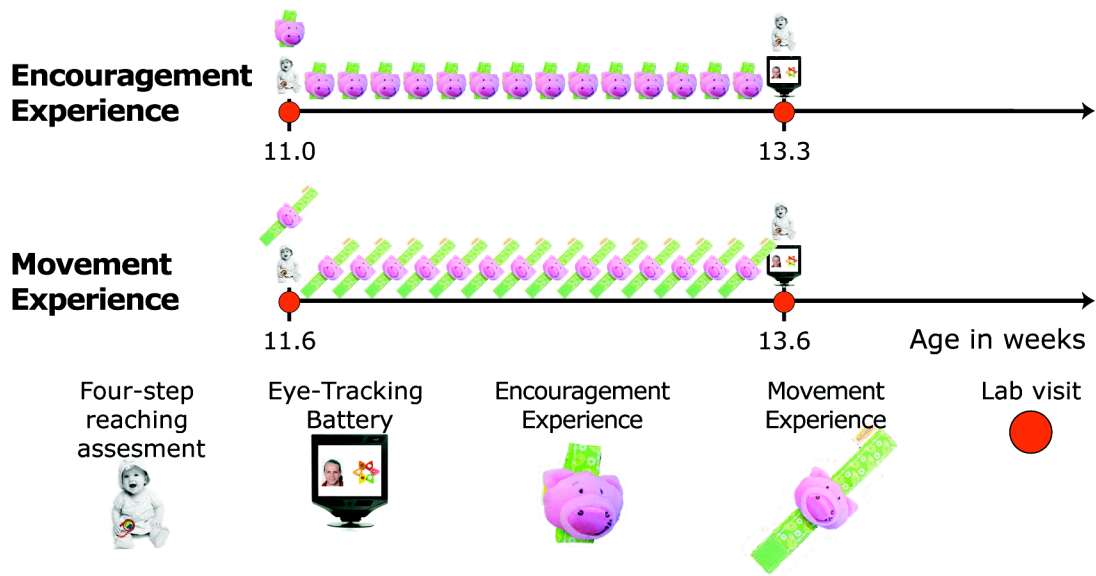


Figure 12: Experiment 3, outline of assessment and training schedule.

Both groups completed a manual reaching task and an eye-tracking task (Figure 12). For the EE group, data on the reaching task was not available from 2 infants due to fussiness resulting in failure to complete the trial and due to technical difficulties. Also for the EE group, data on the eye-tracking task was not available from one infant due to failure to obtain a useable calibration. For the ME group, data from one infant on the eye-tracking task was not available due to calibration failure.

Table 7: Experiment 3, participant characteristics

Group	n	#F	Race	Age 1st lab visit	Training duration	Age 2nd lab visit	Parent Edu.	Birth weight
EE	18	9	12C, 3B, 1A, 2M	11.00 (1.95)	102.38 (28.70)	13.35 (2.06)	8.17 (2.53)	3682 (661)
ME	19	7	16C, 3B	11.59 (1.59)	102.08 (29.74)	13.59 (1.84)	9.42 (1.80)	3354 (583)

Note: EE= encouragement-experience group, ME = movement-experience group. The total number of participants in each group (n) and the number of females per group (#F) are group totals. All other values are group averages with standard deviations given in parentheses. Age is reported in weeks, birth weight in gram. Parents' education level was assessed as in Experiments 1 and 2. Race abbreviations: C = Caucasian, B = Black or African American, A = Asian, M = More than one race.

5.2.2 Procedure

Analogous to Experiment 1, infants were invited to our lab for two visits approximately two weeks apart. On the first visit, infants' reaching skill was measured using the four-step reaching assessment (see General Methods and Experiment 1). Next, an experimenter demonstrated the group-specific training procedure to the parent. Parents then received printed training instructions, a set of wrist rattles, and a reaching tray. The training procedures for the two groups were as follows:

- I. **Encouragement-experience group (EE):** A wrist rattle (closed to form a graspable loop) was placed beyond reach on the table in front of the infant and the parent drew attention to the rattle. Next, the parent lifted the rattle to the infant's eye level, made comments about the rattle (e.g., its color, shape, sounds it makes), and then placed it on the table next to the infant's hands and continued to encourage the infant to touch the

rattle. After about one minute (regardless of the infant's grasping attempts or success), the rattle was placed back in the beyond-reach position. This sequence was repeated until a total of 10 minutes had passed. During training, the parent showed great interest in the rattle, pointed at and talked about the rattle, and provided the infant with encouragement to act on the rattle. However, the parent was asked to refrain from helping the infant to reach for or obtain the rattle. Infants had to engage in self-produced reaching and grasping in order to obtain the rattle (see Figure 13a).

- II. **Movement-experience group (ME):** A wrist rattle (open, lying flat on the table) was placed beyond reach on the table in front of the infant and the parent engaged with the infant but did not look at or talk about the rattle. Next, the parent lifted the rattle and secured it around the infant's palm using attached Velcro® straps. While the toy was attached to the infant's hand, the parent continued to talk to the infant and encouraged arm movements but did not refer to, point at, or draw attention to the rattle. After approximately one minute (regardless of the infant's activity), the rattle was placed back in the beyond-reach position. This sequence was repeated until a total of 10 minutes had passed. During training, the parent showed no interest in the rattle and did not direct attention to the rattle. However, the parent always placed and secured the rattle into the infant's hand. Infants did not have to engage in independent reaching to obtain and move the rattle (see Figure 13b).

Total training experience was assessed using a daily-log (see Table 7). In contrast to Experiment 1, parents were explicitly asked to sit across from their infant during the training and to engage the infant in face-to-face interactions during the training sessions. Following the two-week training period, parents brought their infants back to our lab for a second visit. During this visit, infants participated (in this order) in the eye-tracking battery of Experiment 2 and the four-step reaching assessment of Experiment 1.

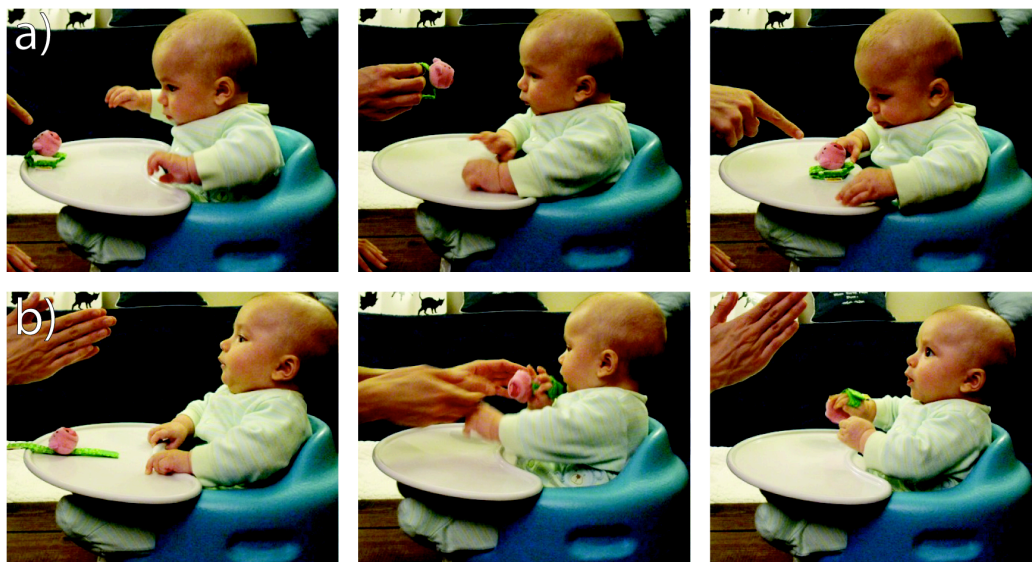


Figure 13: Experiment 3, examples of training procedures. a) Encouragement Experience: Parent draws attention to toy but does not help infant. b) Movement Experience: Parent does not draw attention to toy but attaches it to the infant's hand.

5.2.3 Measures

Reaching activity was measured and scored using the four-step reaching assessment and coding procedures described in the General Methods section. As in Experiment 1, each step of the four-step reaching assessment offered different opportunities to interact with the toy. In Step I (toy placed beyond reach) the infant

could only look at the toy but not touch it—therefore touching the toy was not a variable of interest here. Steps II and III (toy placed at midline and close to hand) were combined because both allowed for reaching and grasping behavior. In Step IV, the toy was placed into the infant’s hands, again making manual contact an irrelevant variable. Thus, for each step a different measure was of interest: In Step I, I focused on the amount of time the infants spent looking at the experimenter. Steps II and III I examined infants reaching and grasping behavior. And in Step IV, I looked at how frequently infants shifted their visual attention back and forth from the toy (looking episodes). Trained observers coded infants’ manual exploration from video recordings. Thirty-eight percent of the trials were coded by two observers and compared for reliability. Overall reliability was high ($r = .88$).

In addition to the four-step reaching assessment, the complete eye-tracking battery of Experiment 2 was used in Experiment 3. All measures and scores were defined and calculated as in Experiment 2. However, infants in this study did not complete the IBQ temperament questionnaire because the four-step reaching assessment already provided a more direct measure for motor behavior and exposure to the training procedure may have influenced parents’ responses on the questionnaire by focusing more on infants’ motor behavior.

5.3 Results

5.3.1 Manual exploration

In order to determine how the different training procedures of Experiment 1 and 3 influenced manual-exploration behavior, the ME and EE groups of Experiment 3 and the AT and PT groups of Experiment 1 were compared in the following analyses. Manual-exploration behavior was not affected by two weeks of training with either the

ME or EE procedure. Results of the four-step reaching assessment are shown in Figure 14. No between-group differences were expected on the first lab visit (prior to training), separate 2 (Gender) x 4 (Group) ANOVAs for each step of the reaching assessment confirmed this assumption (Step I: $p = .431$; Steps II+III: $p = .723$; Step IV: $p = .056$). Therefore, analyses focused on between group differences on the second lab visit (following training) using separate 2 (Gender) x 4 (Group) ANOVAs for each step of the reaching assessment. Similar to Experiment 1, none of these analyses revealed a main effect of gender or a group x gender interaction (all $ps > .15$). Within-group differences (before vs. after training) were performed using paired-sample t-tests.

On Step I of the reaching assessment, infants' attention towards the experimenter was affected only by the PT procedure of Experiment 1 (Figure 14a). Following training experience, a between-subjects ANOVA revealed a significant main effect of group ($F(3,63) = 4.148, p = .010, \eta^2 = .164$). Between-group comparisons (Tukey's HSD) indicated that the PT group ($M = 19.26, SD = 27.97$) looked significantly longer at the experimenter than the AT group ($M = 3.23, SD = 6.41; p = .015, 95\% CI [2.42, 29.64]$), the EE group ($M = 4.82, SD = 6.57; p = .041, [1.41, 28.47]$), and the ME group ($M = 3.0, SD = 5.57; p = .012, [2.79, 29.64]$). Within-group analyses revealed no significant differences between the two lab visits for all four groups. Thus, the group-level differences on the second lab visit were caused by slight (non-significant) decreases in attention towards the experimenter in the AT group ($t(17) = 2.082, p = .053$) and ME group ($t(18) = 1.815, p = .086$) on the one hand, and a slight increase in attention towards the experimenter in the PT group on the other hand ($t(17) = -1.054, p = .307$).

On Steps II and III of the reaching assessment, only the AT procedure of Experiment 1 led to a significant increase in reaching and grasping behavior (Figure

14b). Following training experience, a between-subjects ANOVA revealed a significant main effect of group ($F(3,63) = 3.440, p = .022, \eta^2 = .132$). Between-group comparisons (Tukey's HSD) indicated that the AT group ($M = 29.93, SD = 27.42$) engaged in more reaching and grasping behavior than both the PT group ($M = 11.8, SD = 14.69; p = .044, 95\% CI [.37, 35.89]$) and the ME group ($M = 12.43, SD = 18.24; p = .050, [-.03, 35.03]$). However, no significant differences were observed when comparing the AT group to the EE group ($M = 16.05, SD = 18.62; p = .199, [-32.19, 4.43]$). Within-group analyses revealed significant differences between the two lab visits only for the AT group ($t(17) = -3.875, p = .001, [-28.61, -8.38]$) but not for any of the other groups.

On Step IV of the reaching assessment, only the AT group showed a significant increase in shifting attention to and from the toy (Figure 14c). Following training experience, a between-subjects ANOVA revealed a significant main effect of group ($F(3,63) = 3.173, p = .030, \eta^2 = .124$). However, between-group comparisons (Tukey's HSD) revealed no significant differences between the groups. Marginally significant differences suggest more switches in the AT group ($M = 3.44, SD = 2.28$) than both the PT group ($M = 1.72, SD = 1.78; p = .060, 95\% CI [-.05, 3.5]$) and the EE group ($M = 1.63, SD = 1.86; p = .052, [-.009, 3.65]$). No significant differences were observed when comparing the AT group to the ME group ($M = 1.95, SD = 2.12; p = .119, [-0.25, 3.25]$). Within-group analyses provided a clearer picture and indicate that only the AT group showed a significant increase in shifts of attention from the first to the second lab visit ($t(17) = -2.257, p = .037, [-2.04, -.07]$).

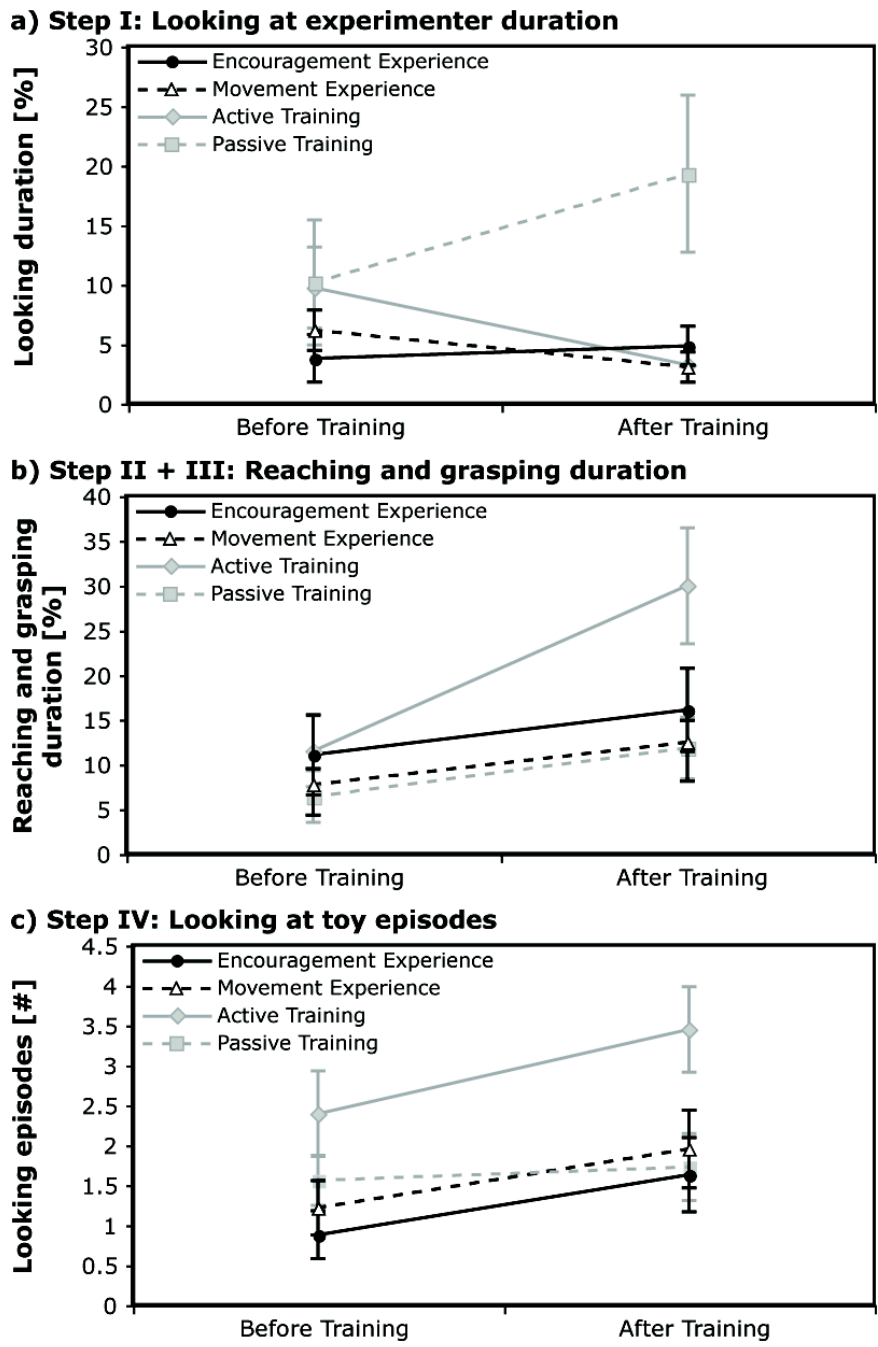


Figure 14: Experiment 3, manual-exploration results. Results for Step I, combined Steps II and III, and Step IV of the reaching assessment are shown. AT and PT data is taken from Experiment 1. No significant differences were present for the ME or EE group on the measures of the reaching assessment. Error bars represent SEM.

5.3.2 Eye-tracking tasks

Results of the eye-tracking battery are shown in Figure 15 and Figure 16. Face-preference behavior was compared across the untrained three-month-old participants and the trained AT and PT groups from Experiment 1, the untrained three-month-old participants from Experiment 2, and the trained EE and ME groups from Experiment 3.

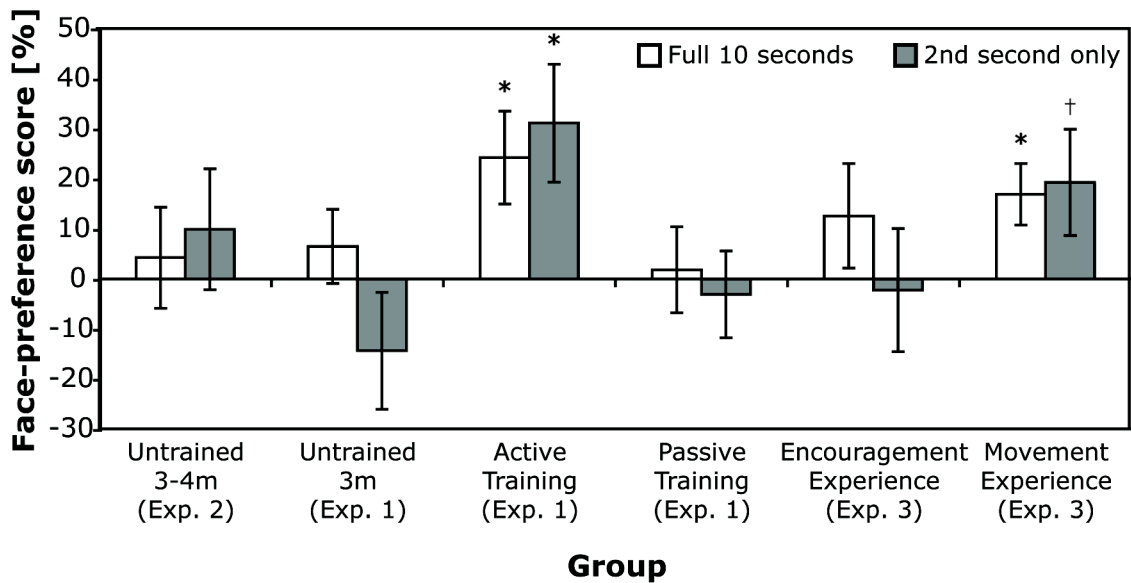


Figure 15: Experiment 3, combined face-preference results for Experiments 1-3. Face-preference behavior for the full stimulus duration (white bars) and during the 2nd second only is shown for all three-month-old infants from studies 1-3. Error bars are SEM. * $p < .05$, † $p = .087$.

Separate 2 (Gender) \times 6 (Group) ANOVAs failed to reach significance for face-preference behavior over the full trial duration ($F(5,95) = .747, p = .590, \eta^2 = .040$) but revealed a significant main effect of group for rapid orienting towards faces (face-preference during 2nd second) ($F(5,95) = 2.324, p = .049, \eta^2 = .100$). Post-hoc comparisons (Tukey's HSD) between all groups did not reach significance. In Experiment 1, only the AT group showed a significant face preference during the 2nd second of stimulus presentation. Planned contrasts between the AT group and the training groups of

Experiment 3 revealed a significantly stronger face preference in the AT group when compared to the EE group ($p = .038$, 95% CI [-66.51, -1.86]) but no significant differences between the AT and the ME groups ($p = .637$, [-40.62, 24.98]). Within-group analyses support these patterns of results and indicated a significant preference for faces over toys in the ME group over the full trial duration ($t(17) = 2.751$, $p = .014$, [3.93, 29.85]). Similarly, face-preference behavior for the ME group during the 2nd second of stimulus presentation was approaching significance ($t(17) = 1.817$, $p = .087$, [-3.1, 41.61]). In addition to the ME group, only the AT group showed a significant preference for faces (Figure 15 and Table 8). As predicted, the ME training procedure encouraged face-preference behavior in three-month-old infants.

Table 8: Experiment 3, within-group comparisons of face-preference behavior

Group	Within-group analysis (one-sample t-test, 2-tailed)	
	Face preference (full 10 seconds)	Face preference (2 nd second only)
Untrained 3-month-olds (Experiment 3)	$t(19) = .415$ $p = .683$ [-17, 25.4]	$t(19) = .818$ $p = .424$ [-15.43, 35.23]
Untrained 3-month-olds (Experiment 1)	$t(16) = .878$ $p = .393$ [-9.18, 22.15]	$t(16) = -1.226$ $p = .238$ [-39.42, 10.48]
Active Training (Experiment 1)	$t(17) = 2.609$ $p = .019$ [4.54, 43.95]	$t(17) = 2.647$ $p = .018$ [6.19, 56.04]
Passive Training (Experiment 1)	$t(17) = .207$ $p = .839$ [-16.35, 19.91]	$t(17) = -.362$ $p = .722$ [-21.41, 15.14]
Encouragement Experience (Experiment 4)	$t(16) = 1.205$ $p = .246$ [-9.55, 34.7]	$t(16) = -.182$ $p = .858$ [-28.31, 23.83]
Movement Experience (Experiment 4)	$t(17) = 2.751$ $p = .014$ [3.93, 29.85]	$t(17) = 1.817$ $p = .087$ [-3.1, 41.61]

Note: Values in square brackets represent 95% CI. Significant results are highlighted in bold.

The remaining three measures of the eye-tracking battery (HSF preference, gaze following, action anticipation) were compared between the untrained three-month-old group of Experiment 2 and the EE and ME groups of Experiment 4. The development of a preference for the high-spatial frequency content on a face (estimate for visual acuity) is strongly dependent on an infant's age and I predicted no differences on this

maturational measure. A between-group ANOVA confirmed this prediction and revealed no differences between the groups on the HSF-preference score ($F(2,49) = 1.742$, $p = .186$, $\eta^2 = .060$). Goal anticipation of reaching actions was predicted for the EE group. However, results did not provide support for this prediction (Figure 16). Separate between-group ANOVAs revealed no differences between the groups on anticipation on neither the walking-occlusion events ($F(2,44) = .303$, $p = .740$, $\eta^2 = .012$) nor the reaching events ($F(2,36) = .379$, $p = .688$, $\eta^2 = .018$).

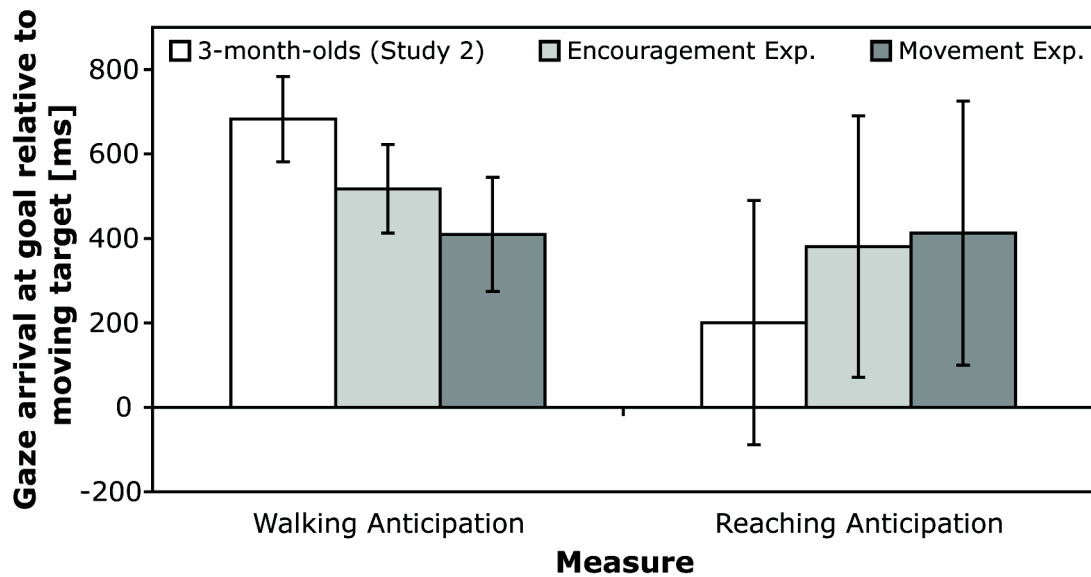


Figure 16: Experiment 3, results of anticipation tasks by training condition.

Finally, differences were predicted for gaze-following behavior. Gaze following was defined as in Experiment 2: The number of trials where infants looked at least once in the same direction as the model on the screen was calculated and expressed as proportion of all valid trials (trials that were preceded by a look at the actor's eyes during the second before the actor shifted her gaze, max. 4 trials). Separate Kolmogorov-Smirnov tests showed that gaze-following data for all three-month-old groups was

normally distributed (all $ps > .071$). Nevertheless, the same non-parametric analysis strategies as applied in Experiment 2 were used. A Kruskal-Wallis test revealed no significant differences between the three groups ($H(2) = 1.627, p = .443$). This result was also confirmed by a one-way ANOVA ($F(2,45) = .781, p = .464, \eta^2 = .034$).

For within-group analyses, the number of infants showing a gaze-following response on more than 50% of all valid trials (50% = chance) was calculated and compared using the binominal procedure. The number of infants who showed a gaze-following response on more than 50% of all trials was not significant in either of the groups compared here. Only seven out of 20 infants in the three-month-old group of Experiment 2 showed a gaze-following response on more than 50% of all trials ($p = .074$). Ten out of 16 infants in the EE group ($p = .122$) and only nine out of 19 infants in the ME group showed a gaze-following response on more than 50% of all trials ($p = .185$).

5.3.3 Correlations between demographic, social cognition, and manual measures

Given the results observed in Experiments 1 and 2, I was interested in the relation between demographic, social cognition, and manual-exploration measures of Experiment 3. To examine relations between these different variables, Pearson's correlation coefficients were calculated for data from the ME and EE groups. Correlation coefficients are reported in Table 9.

All infants in the ME and EE groups were of approximately the same age and there were no significant correlations between age and any of the social cognition or manual-exploration variables. Replicating the results of Experiment 2, visual acuity (as estimated by the HSF-preference task) showed a significant positive correlation with gaze-following behavior ($r_{29} = .592, p = .001$, two-tailed). A strong preference for the

high-spatial frequency content on a face was associated with a stronger gaze-following response. This relation did hold when calculating correlations separately for the ME group ($r_{16} = .701, p = .002$) but not for the EE group ($r_{13} = .427, p = .143$) group due to the small sample size for this within-group correlation.

Also replicating the results of Experiment 1, infants' face-preference behavior (here over the full 10-second duration, neither training groups of Experiment 3 showed rapid orienting to faces) was positively correlated with reaching and grasping behavior on Steps II and III of the four-step reaching assessment ($r_{33} = .392, p = .024$). More reaching and grasping activity was associated with a stronger preference for faces over toys. This relation did not hold when calculating correlations separately for the ME ($r_{18} = .395, p = .104$) or EE ($r_{15} = .431, p = .109$) group due to small sample sizes for within-group correlations.

Finally, reaching and grasping behavior also showed a significant negative correlation with infant's anticipation of reaching actions ($r_{25} = -.649, p < .001$). More reaching and grasping activity was associated with infants' eye gaze arriving earlier at the goal of a grasping action (the correlation is negative because negative values on the anticipation task indicate predictive gaze). This relation held when calculating correlations separately for the ME ($r_{14} = -.624, p = .017$) or EE ($r_{11} = -.700, p = .016$) group.

Table 9: Experiment 3, correlations among demographic, social cognition and manual-exploration measures

	Age	HSF	FP	GF	RA	WA	R&G
Age	1.00	.060	.096	-.047	-.137	.192	.171
HSF		1.00	-.206	.592**	-.176	.121	-.014
FP			1.00	-.126	-.061	-.081	.392*
GF				1.00	.050	-.202	-.042
RA					1.00	.110	-.649**
WA						1.00	-.141
R&G							1.00

Note: All values are Pearson's correlation coefficient r . Significant results are bold. Age was measured in weeks. Abbreviations: HSF = HSF preference, FP = face preference, GF = gaze following, RA = reaching anticipation, WA = walking anticipation, R&G = reaching and grasping behavior (Step II and III of four-step reaching assessment). * $p < .05$, ** for $p < .01$.

5.4 Discussion

Two novel object-directed training procedures were introduced in Experiment 3 and compared to the two training procedures of Experiment 1. Superficially, all four procedures provided infants with similar experiences: A parent engaged the infant with toys for about 10 minutes each day for a period of 14 days (parent's daily logs suggest that they completed approximately 70% of the requested training duration, see Table 7). However, the specific way in which parents and infants engaged with the toys and the degree to which the infant was allowed to explore the toy herself were varied systematically.

In Experiment 3, infants in the EE group were actively encouraged by their parents to attend to the training toy and were allowed to attempt to grasp the toy themselves but did not receive any help from their parents. Given their young age, infants in the encouragement group were very unlikely to succeed in grasping the toy. In contrast, parents of the ME group of Experiment 3 did not draw attention to the training toy. Infants in the movement group were able to engage with the toy themselves and experienced toy movement that was contingent on their hand movements. However, infants in the ME group did not have to reach for the toy themselves, but it was securely attached to their hands by a parent. In Experiment 1, infants in the PT group observed their parents act on toys but were not encouraged to act on the toys themselves, did not experience the outcomes of their own actions, and could not obtain or move the toy on their own. Finally, infants in the AT group of Experiment 1 received all of the experiences described above at once and had to engage in independent reaching to obtain and move the toy but were aided in this process by “sticky mittens” (Needham, et al., 2002).

Results showed that only the infants in the AT group of Experiment 1 increased their reaching and grasping behavior as well as their preference for faces over toys on a computer screen. In Experiment 1, I have argued that the availability of “contrastive evidence” (Baillargeon, 1999, 2004) may be one factor that encourages reaching and grasping behavior: Initially, hand movements and toy movements are unrelated. Following manual contact, hand and toy movements are contingent on each other. In Experiment 3, a form of contrastive evidence was present in the ME group but did not encourage independent reaching and grasping. What was missing in the ME group was the need for self-produced reaching before contrastive evidence became available.

Together, the results of Experiment 1 and 3 suggest that engaging in self-produced actions and experiencing their outcome appears to be the main component that encourages infants to engage in independent reaching.

Alternatively, it is conceivable that experiences of self-produced actions and observation of actions interact and strengthen each other: First-hand experiences of actions and their associated outcomes may increase infants' attention towards the actions of others, foster an intention-based understanding of these actions, and consequently facilitate learning via observation. By ten months of age, infants show an intention-based understanding of actions. Infants at this age show an increased interest in sequences of familiar actions that were interrupted in the middle of an intention unit (Baldwin, Baird, Saylor, & Clark, 2001). This sensitivity to intention units is likely learned early in life and may be necessary for understanding of others' intentions and goal directed behaviors. Experiences of self-produced actions may facilitate infants' understanding of intention units and therefore make observed actions more meaningful. Supporting this hypothesis, brief exposure to the active-training procedure has been shown to facilitate infants' understanding of others' actions (Sommerville, et al., 2005). Therefore, synergies between self-produced reaching experience and action observation may be another factor contributing to the effectiveness of the active-training procedure. Even though the AT, PT, and EE groups all saw their parents lift and manipulate a toy, it is possible that only infants in the active-training group were able to understand and subsequently use these observations to inform their own actions.

Aside from measuring manual exploration, Experiment 3 also investigated the impact of the EE and ME procedures on social cognition skills using the eye-tracking battery developed in Experiment 2. The face-preference component of the eye-tracking

battery was also used in Experiment 1. As predicted, infants in the ME group showed an increase in face-preference behavior. However, in contrast to the AT group of Experiment 1, no rapid orienting towards faces (face preference during the 2nd second) was present in the ME group. One reason for this difference may be that parents of the ME group did not draw attention to the training toys. Consequently, infants in the ME group may have failed to attend to their own actions on the toy and experienced fewer opportunities to develop an understanding of themselves and others as intentional agents (Woodward, 2009).

Faces convey important information about another person such age, gender, mood, focus of attention, and emotion. Therefore, preferentially attending to faces is important for overall social development and can be observed already in newborns (Goren, et al., 1975; Johnson, et al., 1991). Two accounts have been presented to explain face-preference behavior in infancy. First, it has been suggested that neonatal orienting to faces is driven by automatic, sub-cortical mechanisms that are subsequently complemented or replaced by cortical face-processing mechanisms (Morton & Johnson, 1991). According to this model, early orienting to faces helps to shape the developing cortical face processing system (Johnson, 2005). Following the neonatal face-preference period, orienting to faces increases gradually as the cortical face-processing system becomes shaped by experience. Second, a saliency-based account for increasing attention to faces around four-months of age has been proposed by Frank and colleagues (2009). According to this theory, increasing sensitivity to intermodal redundancies may be one factor that explains infants' increased attention to faces from four to nine months of age: As infants become older they are thought to pay more attention to faces, especially the mouth region, because of the intermodal information present here. Indeed, infants are

sensitive to intermodal redundancy and this ability may facilitate perceptual discrimination abilities and general cognitive development (e.g., Bahrick, 2003; Bahrick, Flom, & Lickliter, 2002; Bahrick & Lickliter, 2000; Lewkowicz, 2010). Attending to the intermodal information present in faces (e.g., seeing movement of the mouth and hearing of words) may also facilitate language learning (Dodd, 1979; Kuhl & Meltzoff, 1982).

Both face-processing theories described above explain the emergence of a preference for faces in terms of information that is passively perceived. Neither takes into account how infants act on toys or interact with another person. However, the studies reported in this dissertation suggest that infants' own actions have a strong influence on face-preference behavior.

The results reported in Experiments 1, 2, and 3 have shown that—in the context used here—face preference first emerges around four to five months of age. Independent reaching also emerges around four to five months of age (Pomerleau & Malcuit, 1980; von Hofsten & Ronnqvist, 1988) and around this age infants are likely to have experienced manual engagement with objects in a triadic (infant-object-parent) situation while playing with their parents. Such dynamic interactions with objects and caretakers allow infants to learn about their own abilities and the intentions of others and therefore may foster interest in faces as potential social interaction partners. I have provided evidence for this theory in Experiment 1, 2, and 3. In Experiment 1, I observed that manual object exploration predicts rapid orienting to faces above and beyond demographic and attention-related factors. In Experiment 2, I have shown that infants' activity level is a negative predictor for face-preference behavior when demographic factors and visual acuity (HSF preference) are controlled for. Activity level has been also

suggested to have a negative impact on infants' reaching behavior: When making the transitions into reaching, very active infants first need to slow down their movements and learn how to appropriately energize their hands in order to contact an object (Thelen, et al., 1993). Therefore, a negative relation between activity level and face preference supports the idea of a positive relation between reaching behavior and face preference. In Experiment 3, I have shown that experiences of control over an object (ME group) increased face-preference behavior and that reaching and grasping behavior are positively correlated with and face-preference behavior in three-month-old infants. Together, my results provide strong support for the idea that infants' own engagement in manual exploration behavior is related to the emergence of a preference for faces in three-month-old infants.

One possible explanation for a relation between motor experiences and face-preference behavior is that growing motor experiences change infants' understanding of the affordances for interaction offered by a toy and a face over a distance (Gibson & Pick, 2000). With reaching experience infants learn that a toy placed beyond reach cannot be interacted with (Yonas & Hartman, 1993). In contrast, a face affords social interactions such as smiling or mutual eye contact (Zebrowitz, 2006). Following experiences of control over objects, infants may realize this relation and take it into account when exploring their visual environment.

Finally, neither the encouragement nor the movement experience had an observable effect on gaze-following behavior or action anticipation behavior. However, correlation results provided support for influences of motor experiences on social cognition measures. Reaching and grasping behavior showed a positive correlation with face-preference behavior and a negative correlation with anticipation of reaching

actions. No correlation for walking actions was observed. The negative correlation between reaching and grasping behavior and anticipation of reaching actions indicates that those infants who engaged in more reaching and grasping behavior themselves showed a better understanding of the goal of an observed reaching action (eye gaze arrived at the goal location earlier). Unfortunately, I did not test the AT group of Experiment 1 on the eye-tracking battery of Experiment 2. Given the results reported in Experiment 3, I would predict that anticipation of reaching actions improves following the AT procedure. Future studies are needed to test this prediction and to investigate whether the AT experience would have an influence on gaze-following behavior.

6. Experiment 4: Long-term effects of simulated reaching experience

6.1 Introduction

How experience and environment affect development is a question of great interest for researchers, clinicians, and policy makers alike (Zeanah, 2009). It has been suggested that there are sensitive periods early in life when experiences are required or can strongly influence development (Greenough, et al., 1987; Knudsen, 2004). On the one hand, negative and traumatic experiences (such as abuse) are generally considered to be harmful for development. On the other hand, training and environmental enrichment are generally perceived as fostering positive developmental outcomes. In reality, the dichotomy between these two forms of experiences is not as clear-cut since too much stimulation can be just as detrimental as too little stimulation. For example, overstimulation is a risk factor for preterm infants and is associated with negative developmental outcomes such as hearing loss, vision problems, and increased levels of stress and irritability of the infant (Aita & Goulet, 2003; Blackburn, 1998).

How long lasting are the effects of early experiences? Studies have addressed this issue by focusing on the effects of early negative experiences such as stress. The hormones involved in the body's stress response seem to have an impact on normal brain development and consequently on cognitive, emotional, and motor outcomes. For example, administration of synthetic corticosteroids in newborn rats (3rd and 4th postnatal day, corresponding to 27-34 week old human fetus) has effects on neurologic development and causes transient delays (lasting up to 20 days) in the acquisition of motor skills (Gramsbergen & Mulder, 1998). In human infants, prenatal maternal stress is associated with delayed cognitive and motor development at eight months of age as

well as negative effects on temperament (Buitelaar, Huizink, Mulder, de Medina, & Visser, 2003). Thus, stressful events early in life can have short-term influences on development (in particular motor development) and may lead to long-term changes in brain development.

On the other end of the spectrum, enrichment and motor training seem to be beneficial and encourage or even accelerate normal development. Enrichment is often used in animal studies (e.g., van Praag, Kempermann, & Gage, 2000) whereas motor training is more common in studies with humans. Both procedures share that they enable the participant to practice their own motor skills. Indeed, providing opportunities for high levels of voluntary physical activity (e.g., in a running wheel) is an essential component of environmental enrichment procedures in rodents (Sale, Berardi, & Maffei, 2009). In adult humans, training with a new motor skill (e.g., juggling) leads to a transient increase in gray matter and a change in white matter structure (increased functional anisotropy) of the brain (Draganski, et al., 2004; Scholz, Klein, Behrens, & Johansen-Berg, 2009). However, whether motor training—especially if it occurs in early infancy—has long-lasting influences on development is still unclear.

The findings described in Experiment 1, together with previous results by Needham and colleagues, show that active simulated reaching training leads to changes in motor development, action understanding, and potentially social perception (Needham, et al., 2002; Sommerville, et al., 2005). These changes occur rapidly over a short period of time. Increased grasping and social orienting behavior likely provides the infants in the active-training group with an advantage over untrained infants. How long lasting is this advantage and how strongly does early motor training affect later development? As discussed in Experiment 1, it is possible that active simulated reaching

experience motivates infants to engage in more independent exploration of the environment following the training period. Similarly, accelerated orienting to faces would provide trained infants with more exposure to faces. Both behaviors are important and are likely to influence future development (Bushnell & Boudreau, 1993; Johnson, 2005). Therefore, I hypothesized that active simulated reaching experience at three months of age would have long lasting influences on future motor, social, and cognitive development. To test this hypothesis, I re-recruited some of the infants from Experiment 1 for a follow-up experiment one year after their original training. Out of all the possible aspects of development that may be affected by simulated reaching experiences at three months of age, I focused on three specific domains.

First, as a measure for influences on social development I focused on perspective-taking abilities. Perspective taking is an important ability for interactions with others and can be seen as an extension of intention understanding. Simulated reaching experience has been shown to foster intention understanding and may consequently improve later perspective-taking skills (Sommerville, et al., 2005).

Second, to assess changes in motor development I focused on the quantity and quality of manual exploration skills. Previous findings indicate a positive relationship between eye-contact behavior in newborns and exploration quantity and quality in two-year-olds (Keller & Zach, 1993). Therefore, increased orienting towards faces in the active-training group of Experiment 1 may subsequently lead to improved exploration behavior and prehension strategies.

And third, to complement my behavioral measures I asked parents to complete two temperament questionnaires (Putnam, Gartstein, & Rothbart, 2006; Rothbart, 1981). Temperament is generally seen as constant throughout development. However, some

temperament dimensions are related to the behavioral constructs measured here (e.g., activity level and attention focusing). Therefore, it is possible that simulated reaching experience also affects some temperament dimensions.

6.2 Method

6.2.1 Participants

Of the 18 infants who participated in the active-training group of Experiment 1, I successfully recruited 14 infants (78%) back to our lab (active-training return group or trained group, see Table 10). As comparison group, 14 untrained infants who had not previously participated in Experiment 1 were recruited (see Table 10). A naïve comparison group was chosen to assess the effects of the overall training and testing experience and to avoid any influences from prior testing on this group. Infants from the passive-training group were too young to participate in Experiment 4 at the time of recruitment.

Table 10: Experiment 4, participant characteristics

Group	n	# F	Race	# walking	Age	Birth weight	Parent Edu.
Active-training return	14	8	13 C, 1 M	11	14.7 (0.34)	3400 (347)	9.14 (2.9)
Untrained comparison group	14	8	14 C	11	14.8 (0.24)	3355 (303)	9.21 (1.5)

Note: The total number of participants in each group (n), the number of females per group (# F), and the number of independently walking infants per group (# walking) are indicated. All other values are group averages with standard deviations given in parentheses. Age is reported in months, birth weight in gram. Education level of the parents was assessed on a scale from 0-6 for each parent separately (see also Experiment 1). Race abbreviations: C = Caucasian, B = Black or African American, A = Asian, O = Other, M = More than one race.

6.2.2 Apparatus

Participants were tested in a room that was empty except for a rectangular box covered with brown contact paper (43.8 × 55.9 × 66 cm, H×W×D). The box served as a toddler-sized table and different toys were placed either on this box or the floor during the experiment. First, a set of three small bird toys (see Figure 17) consisting of a bell toy (8.3 × 7.6 × 3.8 cm), a mirror-toy with the mirror covered using blue tape (11.4 × 8.9 × 3.8 cm), and a wooden abacus with colorful beads and plastic links (10.2 × 15.2 × 1.5 cm) were used in a perspective-taking task (for comparison see methods and materials in Moll, Carpenter, & Tomasello, 2007; Moll & Tomasello, 2007). Second, a large wooden box (shown in Figure 18a) with four sides to explore and a bead maze attached on top (38 × 18 × 18 cm) was used in a sustained-exploration task. Finally, a modified paintbrush handle (shown in Figure 18b) with bells attached to it (16.5 × 10.2 × 2.5 cm) was used in a novel object exploration task. All infants were tested at Duke University except for two infants from the trained group who were tested in their homes.

6.2.3 Measures

Four different measures were used in this experiment to assess social skills, manual exploration skills, and temperament. The four tasks were completed in the same order for all infants.

- I. **Perspective-taking task:** This task was adapted directly from studies on perspective taking by Moll and colleagues (Moll, et al., 2007; Moll & Tomasello, 2007). A pair of experimenters (A and B) played with one infant. Experimenter B sat next to the infant and sequentially presented two novel toys to the infant on a small table. Experimenter A passively observed the infant playing with each toy from a short distance

(approximately 2-3 meters). Once the infant explored a toy for 30 seconds, experimenter B brought the toy over to experimenter A and then both experimenters played with the toy for 30 seconds together. Experimenter B then returned to her position next to the infant. Throughout the play session, experimenter A never had joint engagement with the infant and the toys. Finally, experimenter A announced that he needed to go, waved good-bye, and left the room. While experimenter A was outside the room, experimenter B played with the infant using a third novel toy.

Experimenter A never saw or played with the third toy. After one minute, experimenter B placed all toys on the table side-by-side (counterbalancing toy position). Experimenter A re-entered the room and asked: *“Do you see that one! That looks great, can you show me that toy?”* The experimenter then extended one hand and looked at the infant (but not the toys) waiting for her to give him one of the three toys. Which toy was handed to the experimenter was the dependent measure of the perspective-taking task. An understanding of what the experimenter knows and has experienced would lead the infant to give the experimenter the toy he did not see (the third toy) while he was outside the room. A bird-eye schematic of this procedure is shown in Figure 17.

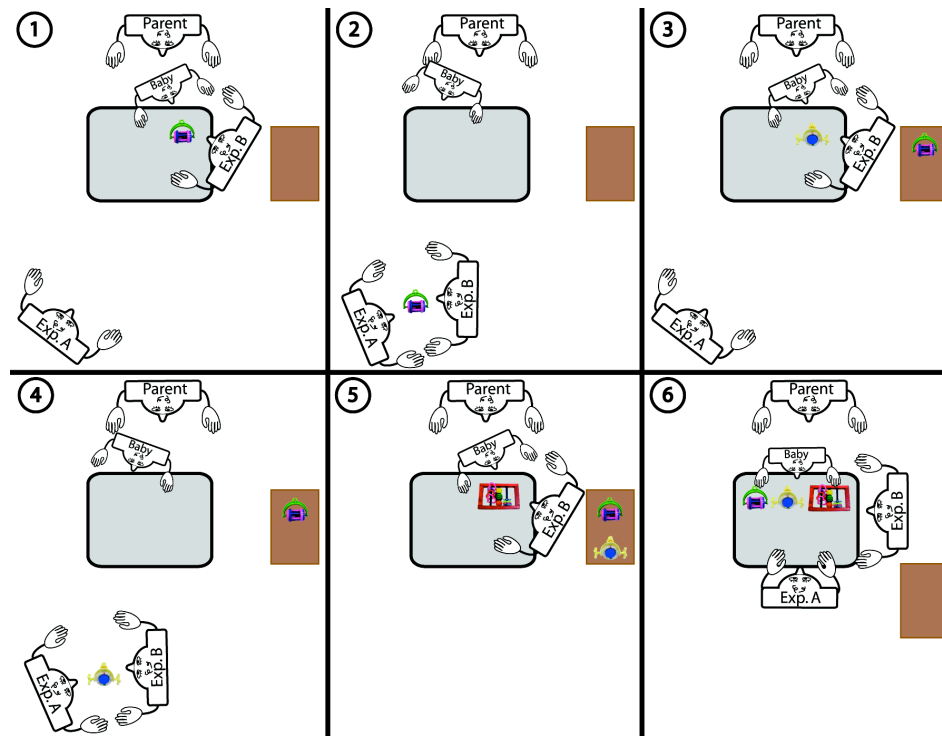


Figure 17: Experiment 4, bird-eye schematic of perspective-taking task.

II. **Sustained-exploration task:** To answer the question whether the active-training experience increased infant's object-directed attention, I designed a task that measured infants' independent engagement with a toy. In this task, a wooden tabletop bead-maze toy (Figure 18a) was presented to the infant. This toy was similar to toys used previously to measure exploration behavior (Keller & Zach, 1993). First, attention was drawn to all four sides of the toy and verbal encouragement was provided. Then, the toy was placed on the table or floor and the infant was allowed to explore the toy independently. For about five minutes, both experimenters and parents looked down and pretended to read or closed their eyes. The infant could choose to either explore the toy

independently for the whole duration, loose interest after some time, or try to engage the parent or experimenters to play (however, neither the parent nor the experimenter responded to these requests). Active exploration of the toy was defined as all object-directed behaviors including looking at the toy, reaching for the toy, touching, grasping, or lifting the toy with one or both hands, mouthing the toy and shaking or rotating the toy.

- III. **Novel object exploration task:** To assess infants' exploration quality, I designed a task that presented infants with a novel object that is visually appealing but whose function was unknown. Will infants show an efficient grasp at the center of mass (CoM) that allows for a secure grip and easy handling of the object? Or will they choose a visually appealing location for their grasp? In this task, a modified paintbrush handle with bells attached to the top and colorful tapes around the center and base (shown in Figure 18b) was used. Visually, several parts of the object were appealing (e.g., the top with the bells or the large base). However, considering the CoM, the object should be held in the middle where it also becomes narrow and is grasped most easily (see estimated CoM in Figure 18b). The object was presented to the infant by one experimenter holding it with two flat hands—without providing any clues on how to grasp the object. The object was placed on a table and the infant was encouraged to pick up and explore the object for a period of two minutes. Throughout this procedure, parents were instructed not to touch or lift the object. If the infant offered the object to the parent or experimenters,

the object was received using flat, open hands without grasping the object and the object was placed back on the table. Video recordings of the infant handling the toy were coded for the location of the supporting grasp (either top, middle, or base). If two hands were used, either the one that touched more of the toy or the one that touched the same position for a longer period of time was considered the supporting hand.

- IV. **Temperament questionnaire:** Two questionnaires that measure temperament during infancy and later childhood were used to assess temperament. First, the Infant Behavior Questionnaire (IBQ), which has been validated for infants, aged between three and 12 months (Rothbart, 1981). And second, the Early Childhood Behavior Questionnaire (ECBQ) that has been validated for 18 – 36-month-old toddlers (Putnam, et al., 2006). Since no comparable temperament scale was available for the ages tested here (14-15-month-olds), parents were asked to complete both the IBQ and ECBQ questionnaires. In instances where both questionnaires measured the same aspects of temperament (e.g., activity level), the two scales were combined. Otherwise only the ECBQ was used. Questionnaires were provided in a pre-paid return envelope and sent home with the parents following their visit to our lab and returned via mail.

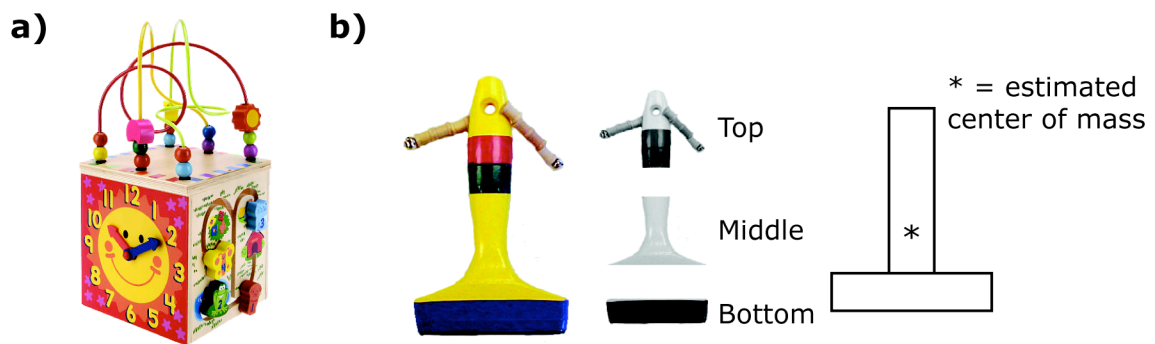


Figure 18: Experiment 4, objects used in a) sustained-exploration task and b) novel-object exploration task. For the novel-object exploration task, three areas on the object were distinguished (top, middle and bottom). The estimated center of mass of the novel object is indicated with a *.

6.2.4 Coding and Reliability

Responses during the perspective-taking task were coded off video recordings by trained observers. Observers first decided which toy, if any, the infant handed to the experimenter. Additionally, since many infants did not hand a toy, touching behavior was coded for 20 seconds or until a toy was handed to the experimenter using frame-by-frame coding software (see General Methods). The first toy that was handed to the experimenter was counted as the infant's final choice. If no toy was handed, then the toy that was touched for the longest duration was counted as the infant's final choice. All infants touched at least one toy. Discrepancies between which toy was handed to the experimenter and which toy the infant touched the longest were rare (4 infants, 2 in each group). To assess coding reliability, a second observer re-coded touching behavior of all infants. Agreement between the two coders was high ($r = 0.92$).

Behavior during the sustained exploration task was coded for a maximum duration of 300 seconds off video recordings by trained observers. Frame-by-frame

coding software (see General Methods) was used to record where infants were looking (toy, parent, experimenter, or distracted) and how they were interacting with the toy (reaching, touching, grasping, lifting, mouthing, bi-manual exploration, shaking, or rotating). To assess coding reliability, a second observer coded a sample of 12 infants from the video material (40%). Agreement between the two coders was high ($r=0.97$).

Behavior during the novel-object grasping task was coded for a maximum duration of 120 seconds off video recordings by trained observers. Again using frame-by-frame coding software (see General Methods), the hand location during manual contact with the toy (top, middle, or bottom) was recorded. The middle of the object was defined as the area between the green tape on the top of the toy and the blue tape on the bottom of the toy (Figure 18b). Grasp location in ambiguous cases where two areas were contacted at the same time was determined by judging which part of the object was touched by the larger proportion of the hand. If the infant used both hands and touched different parts of the object simultaneously, the supporting grasp was determined based on the context of the action (either the hand that touched more of the object or the hand that touched the toy for longer) and the location of this hand was coded. To assess coding reliability, a second observer coded a sample of 16 infants from the video material (57%). Agreement between the two coders was high ($r=0.94$). Second, the number of times infants dropped, lifted, threw, or placed the object on the table were counted in real-time off the video recordings. Two observers recorded these counts for all 28 infants. Overall reliability between the observers was good ($r=0.86$).

6.2.5 Data Analysis

For the perspective-taking task, the dependent measure was which toy the infant selected to give to the experimenter when asked for a toy. Toys were numbered by order

of presentation (order was counterbalanced). Always the last toy (toy 3) was unknown to the experimenter and represented the correct choice. The number of infants that correctly selected this object was then calculated and compared to chance (33% for 3 toys).

For both the sustained-exploration and the novel-object grasping tasks, total duration of manual or visual exploration was coded and then transformed into percentage of total trial duration. However, trial duration was held constant at 300 seconds and 120 seconds respectively. Therefore, the percent scores were equivalent to the raw scores.

Further, exploration behavior over time was analyzed in the sustained-exploration task. An exploration time course was constructed by coding infants' behavior every 0.1 seconds for whether a certain behavior was present (1) or not (0). For negative behaviors (e.g., being distracted is the absence of visual exploration of the toy) this coding scheme was reversed (0 if the child was distracted and 1 otherwise). This was done for 10 measures: Looking at the toy, looking at the experimenter, looking elsewhere (distracted), touching the toy, grasping the toy, lifting the toy, exploring the toy using both hands, mouthing the toy, shaking the toy, and rotating the toy. For the time-course analysis, all 10 measures were first combined and then averaged for every second. The resulting exploration time course ranged from 0-10 for every second (total of 300 data points). On this measure, a higher score indicates more complex exploration behavior.

6.3 Results

6.3.1 Perspective-taking task

Results of the perspective-taking task are shown in Figure 19. Using the binomial procedure, I compared the number of infants in each group that selected the first, second, or third toy to chance (33%). In both the trained and the control group, no toy was selected by significantly more infants than would be expected by chance. However, in the trained group 7 out of 14 infants (50%) selected the third toy (the one not seen by the experimenter). This proportion is approaching significance ($p = .0887$). In contrast, the control group showed a tendency to select the second toy (7 out of 14 infants; $p = .0887$).

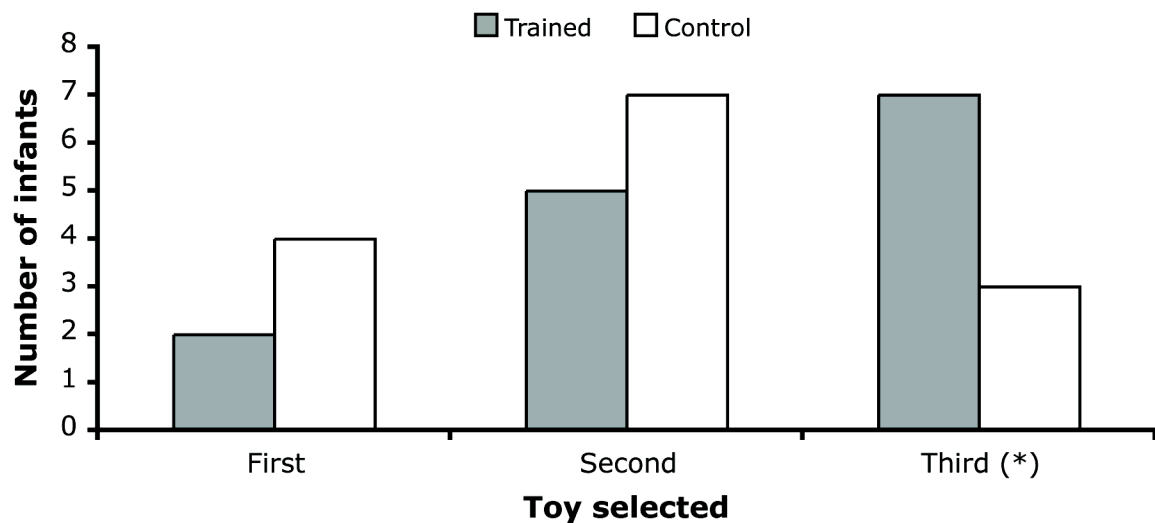


Figure 19: Experiment 4, results of the perspective-taking task. Infants were asked to hand the experimenter one toy. Choosing at random, an equal number of infants (approximately 4-5 infants) should have selected the first, second and third toy. The third toy was unknown to the experimenter and represented the correct choice (*). Seven out of 14 infants in the trained group selected this toy.

6.3.2 Sustained-exploration task

Results of the sustained-exploration task are shown in Figure 20 and show that trained infants engaged in more manual exploration of the toy compared to untrained infants. A multivariate analysis of variance (MANOVA) with group (trained vs. control) and gender as between-subject factors was conducted on seven behavioral measures: duration of looking at the toy, looking at the experimenter, being distracted, touching the toy, grasping the toy, bi-manual exploration, and rotating the toy. Three additional measures— lifting toy, mouthing toy, and shaking the toy— were removed from this analysis due to violations of the homogeneity of variances assumption (Levene's test, all $p < .01$). Overall, the MANOVA revealed a significant main effect of group ($F(7,18) = 3.477, p = .016, \eta^2_p = .575$) indicating that in this task, manual exploration and visual engagement of trained infants differed significantly from untrained infants. There were no effects of gender and also no gender by group interaction (both $p > .35$).

Follow-up 2 (Gender) \times 2 (Group) ANOVAs for each measure further indicated several significant between-group differences (Figure 20a). The total amount of time that infants were distracted from the toy was significantly greater in the control group compared to the trained group ($F(1,24) = 10.302, p = .004, \eta^2 = .289$). In contrast, infants in the trained group spent significantly more time touching the toy ($F(1,24) = 11.784, p = .002, \eta^2 = .298$), grasping the toy ($F(1,24) = 8.519, p = .008, \eta^2 = .259$), rotating the toy ($F(1,24) = 6.131, p = .021, \eta^2 = .187$), and engaging in bi-manual exploration of the toy ($F(1,24) = 7.195, p = .013, \eta^2 = .226$). Thus, trained infants engaged in more manual exploration of the toy. There were no significant differences between the groups on the total amount of time they spent looking at the experimenter ($F(1,24) = .002, p = .969, \eta^2 <$

.001) and there was only a trend for the trained group to look longer at the toy compared to the untrained group ($F(1,24) = 3.580, p = .071, \eta^2 = .129$).

Were the differences in exploration behavior between the trained and the control group already present at the onset of the exploration period? Or did both groups start out with similar levels of exploration but the trained group was able to sustain this level of exploration for a longer period of time? To answer this question, I investigated the time course of exploration behavior (Figure 20b). For the exploration time course, all measures (now including mouthing, lifting, and shaking of the toy) were combined into one exploration score for each second (see methods). Higher values on the exploration score indicate more complex exploratory behaviors. For each second, exploration was compared between the trained and control group using the non-parametric Wilcoxon-Ranksum test. To account for multiple comparisons, differences were only considered significant if at least five consecutive seconds showed statistically significant differences (at $p < .050$). Exploration behavior of trained infants was more complex compared to control infants during three time windows: A 7-second window from second 194-201 ($W_{Min.} = 248, p_{max.} = .039$), a 12-second window from second 274-286 ($W_{Min.} = 246, p_{max.} = .049$) and an 8-second window from second 292-300 ($W_{Min.} = 250, p_{max.} = .031$). All three significant time windows occurred during the last third of the exploration period. Trained and control infants initially showed similar levels of exploration complexity, but only trained infants were able to sustain this level of exploration behavior over an extended period of time.

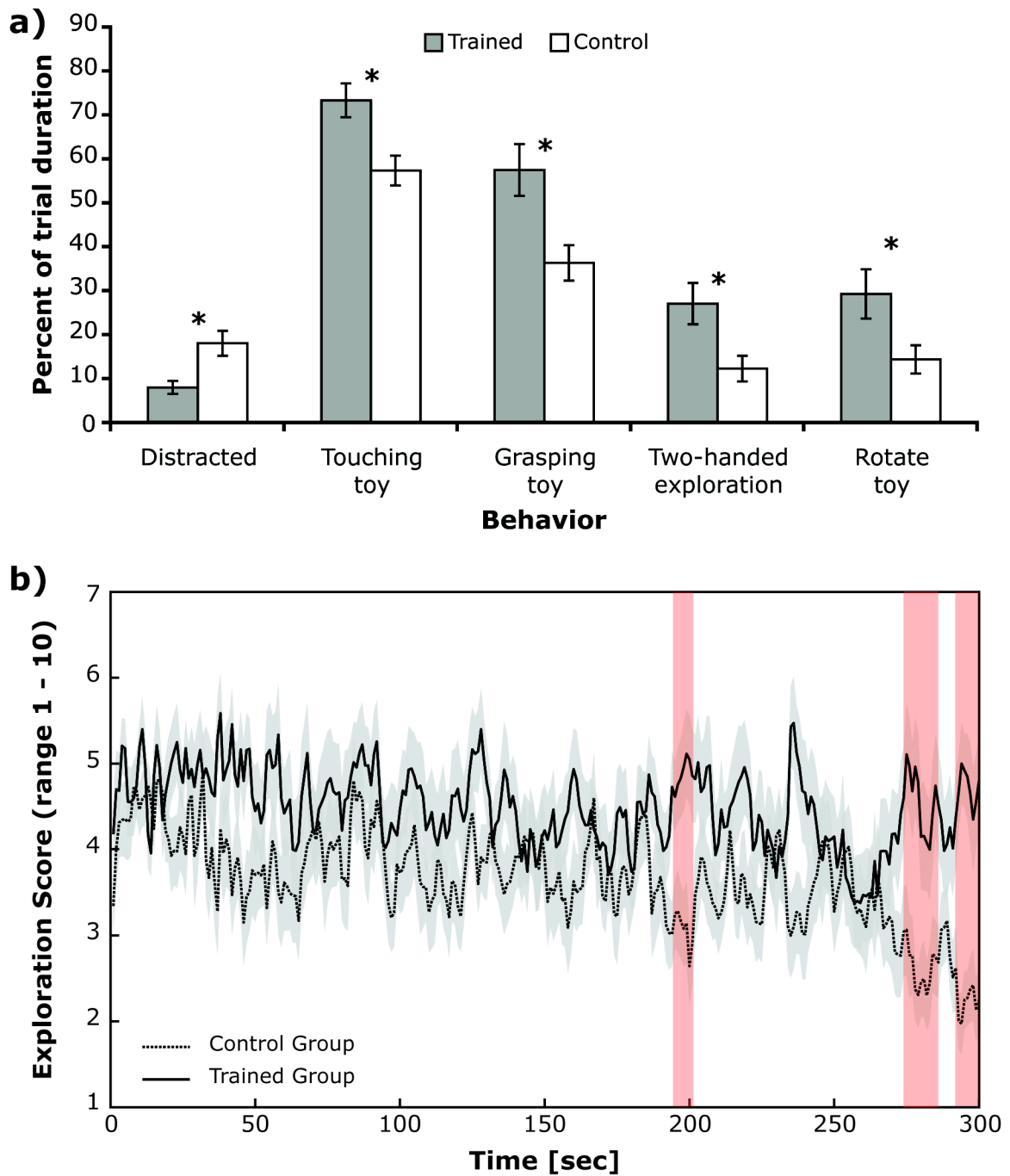


Figure 20: Experiment 4, results of the sustained-exploration task. a) Differences between individual measures across the 300-second exploration period. b) Time-course of exploration behavior. Significant differences between trained and control infants are highlighted in red ($p < .05$). Error-bars and gray shaded areas represent SEM. * $p < .05$.

6.3.3 Novel object exploration task

Results of the novel object exploration task are summarized in Figure 21 and show that trained infants preferred to touch the novel object at the center of mass. First, location of the hands while touching the novel object was analyzed separately for each group. For the trained group, 10 out of 14 infants preferred to touch the middle part of the object. Using the binomial procedure, this proportion of infants is significantly larger than expected by chance (33%; $p = .003$). The remaining four out of 14 infants touched the top part of the object the longest ($p = .214$). In contrast, the control group showed the reverse pattern. Here only 4 out of 14 infants preferred to touch the middle part ($p = .214$), 2 out of 14 infants preferred to touch the bottom part (binomial procedure, $p = .078$), and the majority (8 out of 14) of infants in this group preferred to touch the top part of the toy ($p = .040$).

Of particular interest was the duration each infant spent touching the toy in the middle—the center of mass for the object used. Comparing the duration of touching the center of mass using a 2 (Gender) \times 2 (Group) ANOVA revealed a significant effect of group ($F(1,24) = 7.823, p = .010, \eta^2 = .242$) but no effects of gender and no interaction (both $ps > .469$). Infants in the trained group ($M = 40.80\%, SD = 25.65$) touched the center of mass (middle) significantly longer than infants from the control group ($M = 18.30\%, SD = 10.94$). No significant group differences were present for the duration of touching the top part ($p = .069$) or touching the bottom part ($p = .932$) of the object (Figure 21a). There was, however, a significant effect of gender for touching the bottom part of the object ($F(1,24) = 7.128, p = .013, \eta^2 = .225$), with males ($M = 18.2\%, SD = 11.96$) touching

the bottom part more than females ($M = 8.3\%$, $SD = 6.95$). Thus, trained infants preferred to touch the center of mass (middle portion) of the novel object (Figure 21a).

To determine whether grasping the center of mass is indeed beneficial for handling the object used here, I compared the number of times the toy was dropped by preferred touch location (Figure 21b). Across both groups, 14 infants preferentially grasped the object at the center of mass (middle group) and 14 infants grasped the toy at other locations (top-or-bottom group). Comparisons of the middle group and the top-or-bottom group revealed a significant difference in the number of drops ($t(26) = 2.193$, $p = .037$). On average, infants who touched the center of mass dropped the object half as often ($M = 1.21$, $SD = 1.37$) as infants who touched the toy elsewhere ($M = 2.43$, $SD = 1.55$).

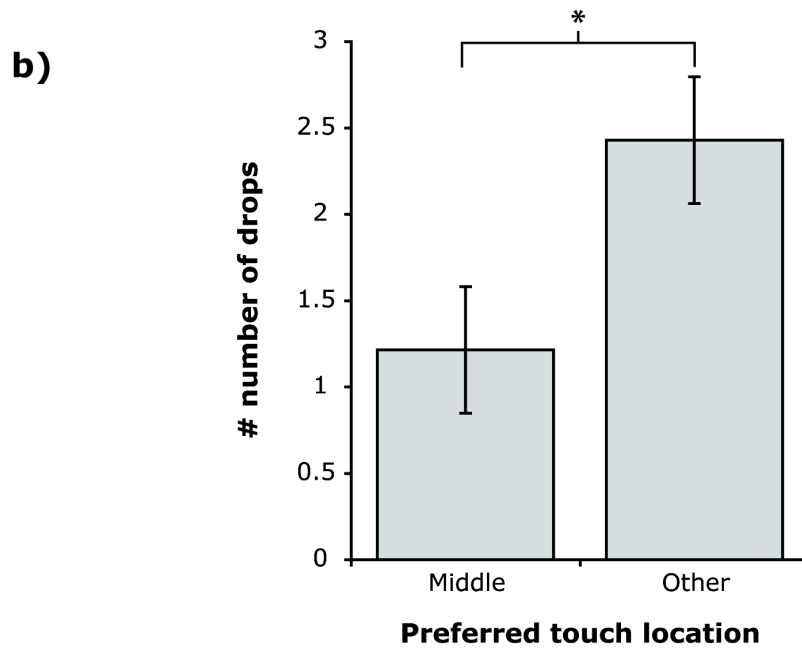
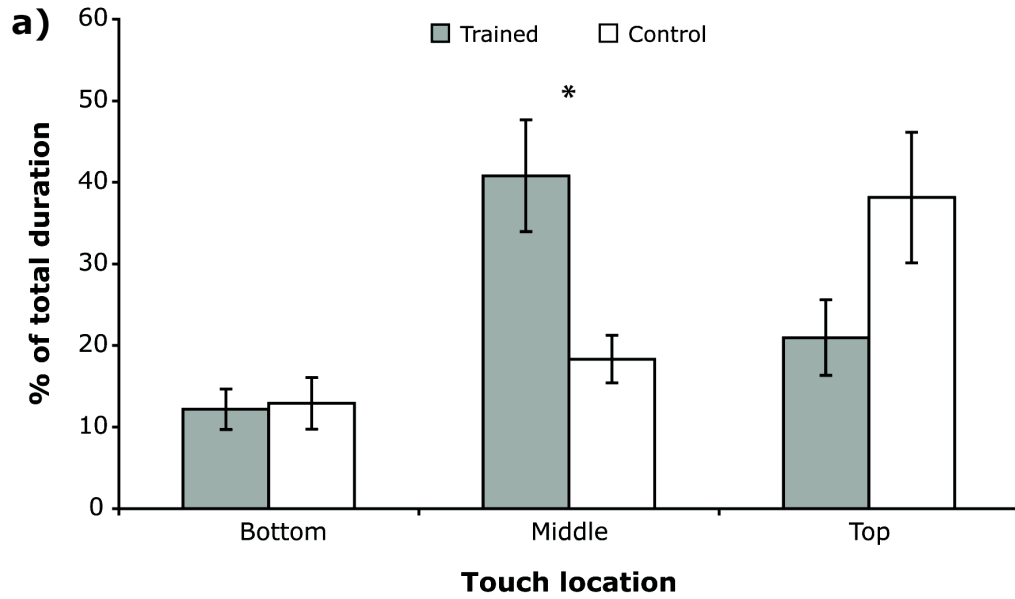


Figure 21: Experiment 4, results of the novel object exploration task. a) Touch duration (in % of total duration) by location. b) Number of times the object was dropped by preferred-touch location (collapsing across groups). Error-bars represent SEM. * $p < .05$.

6.3.4 Temperament questionnaire

Between-group comparisons on the temperament questionnaire are summarized in Table 11 and show that trained infants were rated higher on attention focusing but lower on impulsivity compared to untrained infants. Two temperament questionnaires were used, the IBQ and the ECBQ. When both scales assessed the same construct (e.g., activity level) they were combined (marked with † in Table 11). Otherwise only the ECBQ data was used. To reduce the overall number of statistical comparisons, only a selection of temperament measures based on previous findings and their relevance for the engagement with objects were selected (van den Boom, 1994). Temperament was compared between the trained and control group using the non-parametric Wilcoxon-Ranksum test. Group medians and statistical results are reported in Table 11. In agreement with results of the sustained exploration task, infants in the trained group were rated higher on their ability to focus their attention. Further, infants in the trained group were rated higher on soothability and lower on shyness and impulsivity.

Table 11: Experiment 4, temperament differences

Group	Measure					
	Activity Level†	Attention Focusing†	Soothability†	Attentional Shifting	Impulsivity	Shyness
Trained	8.46	8.02	11.59	4.3	5	2.75
Control	8.65	6.29	10.55	4.5	5.375	3.67
Trained vs. Control	W = 172.0 p = .880	W = 132.0 p = .026	W = 134.0 p = .034	W = 168.5 p = .724	W = 128.0 p = .014	W = 136 p = .044

Note: Significant between-group comparisons are bold. † = combined IBQ + ECBQ score. Combined scores range from 0 – 14, Scores of the IBQ or ECBQ alone range from 0 – 7.

6.3.5 Correlations between measures

Finally, correlations were calculated to determine whether relationships exist between the four tasks used in Experiment 4 (Table 12). Infants' performance on the perspective-taking task was dichotomous (selecting target toy vs. non-target toy). Similarly, grasping of the novel object could be divided into two categories (touching center of mass vs. not touching center of mass). Using these categories, correlations were calculated with touching duration on the sustained-exploration task and attention focusing and impulsivity from the temperament assessment. These measures were selected because they showed the most pronounced differences between the trained and control groups. The non-parametric correlation measure Kendall's τ was calculated. For correlations with one dichotomous variable (such as Target and Touch in Table 12) the p-value associated with the coefficient τ is equivalent to a Wilcoxon-Ranksum test comparing the two groups of the dichotomous variable (Field, 2005).

Results are reported in Table 12 and indicated a significant positive relation between touch duration on the sustained-exploration task (Task II) and touching of the center of mass in the novel-object exploration task (Task III). Infants who preferred to touch the novel toy at the center of mass in Task III engaged in longer manual exploration of the box in Task II ($M = 214.59$ sec., $SD = 42.88$) compared to infants who did not prefer to touch the center of mass of the novel object ($M = 172.55$ sec., $SD = 40.35$; $W = 154.50$, $p = .026$). Prolonged exploration in infants who prefer to touch an object at the center of mass supports the notion that grasping an object at the center of mass is more efficient and provides a more secure grasp on the object (enabling longer exploration). However, it should be noted that both Task II and Task III assessed infants' manual exploration and that similarity between the tasks can account for positive

correlations between them to some degree. No other correlations were significant, although there was a borderline significant negative correlation between touching of the center of mass in Task III and the Impulsivity score of the temperament measure (Task IV). Infants who preferred to touch the novel toy at the center of mass in Task III were rated lower on their impulsivity by their parents in Task IV ($M = 4.33$, $SD = 1.45$) compared to infants who did not prefer to touch the center of mass of the novel object ($M = 5.22$, $SD = 0.68$; $W = 124.50$, $p = .054$).

Table 12: Experiment 4, correlations between measures

Task	I: Target	II: Touch	III: CoM	IV: Attention	IV: Impulsivity
I: Target	---	-.042	-.298	.105	-.066
II: Touch		---	.357*	.216	-.239
III: CoM			---	.094	-.323†
IV: Attention				---	-.180
IV: Impulsivity					---

Note: Values represent correlation coefficient Kendall's τ . Tasks are numbered as in the methods section. I: Target = selection of target toy on perspective-taking task; II: Touch = touching duration on sustained-exploration task; III: CoM = grasping at CoM on novel-object exploration task; IV: Attention = temperament score attention focusing; IV: Impulsivity = temperament score impulsivity.

* $p = .026$; † $p = .054$

6.4 Discussion

The results of Experiment 4 show that simulated reaching experience at two to three months of age can have long-lasting effects on future development. In the short term, active simulated reaching increased reaching, grasping, and face preference behavior (Experiment 1). Early reaching experiences and acquired skills seemed to

influence the quality and quantity of manual exploration skills, development of temperament, and potentially social skill development approximately one year later.

Due to the longitudinal nature of Experiment 4, it is possible that the sample of infants who returned for this study was different from the naïve comparison group. Parents who agree to participate in a two-week training study and are willing to continue the study one year later may be more involved with their children and provide them with a more stimulating and active environment than the average parent. While I cannot rule out this possibility, three points argue against general differences between the two groups. First, when parents were recruited to participate in the training study of Experiment 1 they were not informed about Experiment 4. As a result, the longitudinal nature of Experiment 4 cannot have affected their decision to participate in Experiment 1. Second, I was able to re-recruit a very high proportion of participants to return for Experiment 4 (78%) and parents were offered appointments during any time or day of the week. For this reason, the sample of trained infants in Experiment 4 also included parents who work full time and may not have agreed to participate in our studies during regular business hours (note that infants in the control group were also offered appointments on any time or day of the week). And third, the two groups were very similar on a number of demographic variables (see Table 10). Therefore, it is unlikely that the trained and control groups of Experiment 4 were sampled from different populations. More likely, the differences between the groups stem from the motor training experiences of Experiment 1.

One domain that may be influenced by motor training early in life is the quantity and quality of manual exploration activity. The duration of engagement with an object is both a measure of exploration quantity as well as exploration quality in infants.

Experiment 4 indicated that active motor enrichment at three months of age increased infants' engagement and exploration of novel objects at 14 months of age. Several explanations may account for such an increase. First of all, active motor enrichment may have improved infants' manual exploration skills. Having better exploration skills could in turn reduce the attentional and cognitive demands of the exploration situation in Experiment 4. Finding the task less demanding, trained infants may have had more resources available to sustain their exploration for longer. Second, experiencing success with their early grasping attempts while wearing sticky mittens may have increased infants' motivation to interact with toys and subsequently encouraged longer engagement with objects. Third, the effects of motor enrichment on infants' social orienting may have caused an increase in exploration activity. Following active motor enrichment, infants in Experiment 1 showed increased attention towards faces over toys. Previous reports observed a positive relation between infant-caregiver eye-contact behavior of newborns and duration of exploration at two years of age (Keller & Zach, 1993). It is possible that early face-preference behavior has a similar positive effect on exploration of objects one year later. And lastly, findings of Experiment 1 also showed an increase in rapid orienting towards faces (face preference during the 2nd second), indicating faster processing speed. Consequently, motor training could have increased infants' overall speed of processing. Faster processing of information has been associated with the development of intelligence and therefore may have a beneficial effect on attention, cognition, and motivation (Kail & Ferrer, 2007).

A further measure of exploration quality is how an object is grasped. In particular, it is more efficient to plan hand shape and placement of the hand before the object is contacted rather than to adjust the position of the hand afterwards. Already

five-month-old infants seem to plan the shape and orientation of their hand before grasping an object (Barrett, Traupman, & Needham, 2008). Between 11 and 13 months of age infants increasingly make use of visually available information about the center of mass (CoM) of an object prior to grasping (Barrett & Needham, 2008). Experiment 4 further showed that—irrespective of training experience—grasping an object at the CoM is more efficient and leads to a more secure grip resulting in fewer drops of the object. Correlation analyses suggested that grasping an object preferentially at the CoM was associated with longer manual exploration during the sustained exploration task. Presumably, an efficient and secure grasp enables infants to explore objects for a longer period of time. Overall, trained infants were more likely than untrained infants to touch the CoM of a novel, unknown object. Thus, grasping is more efficient in 14-month-old infants who experienced motor training at three months of age.

Over their first year, infants' understanding of another person's actions becomes more sensitive and requires fewer direct cues (such as manual contact). When infants observe an actor reaching repeatedly for the same of two objects, seven-month-old infants seem to expect the actor to have the intention of grasping this particular object and not the other one. If the actor suddenly decides to reach for the other object, seven-month-olds detect this change of the actor's goal and respond by increasing their attention towards the event (Woodward, 1998). In contrast, if the actor is merely looking at one of the objects repeatedly, infants respond to a change in actor-object relation only by 12 months of age (Woodward, 2003).

Similar results have been observed with regard to infants' perspective-taking skills. A transition point in perspective-taking abilities seems to occur around 14 months of age (Moll, et al., 2007; Moll & Tomasello, 2007). If a person actively plays and interacts

with a 14-month-old infant using toys, the infant is subsequently able to infer which toys the person has seen before and which ones not. However, if the infant only observes the adult interacting with toys by himself, 14-month-old infants do not seem to know which toys the person has seen or has not seen. By 18 months of age, infants succeed in both cases (Moll, et al., 2007; Moll & Tomasello, 2007). Thus, 14-month-old infants need to experience joint engagement with another person in order to infer something about that person's mental state or knowledge.

Understanding of the intentions behind observed actions does not seem to be present at three months of age. However, brief (less than 5 minutes) motor training session using the active-training paradigm (which does include a social component in the parent-guided training context) facilitated understanding of actor-object relations in three-month-old infants (Sommerville, et al., 2005). Therefore, I hypothesized that simulated reaching experience would also facilitate perspective-taking skills in 14-month-old infants. The results of the perspective-taking task in Experiment 4 do not provide conclusive evidence for advanced perspective-taking skills in trained 14-month-olds. However, the results are approaching significance and show promising patterns. This is encouraging given that the sample size of Experiment 4 was limited to 14 infants per group – previous studies on perspective-taking skills had a sample of 28 infants (Moll & Tomasello, 2007). Thus, it is possible that the sample size of Experiment 4 was too small to detect clear preferences for the target toy.

Finally, in addition to the changes in manual interaction with objects and understanding of other social beings I also observed changes in infants' temperament. Temperament is the biological component of personality and is thought to reflect lasting traits of a person. Long-term stability of childhood temperament traits on adult behavior

and physiology has been noted by several studies (e.g., Caspi & Silva, 1995; Kagan, Snidman, Valikahn, & Towsley, 2007; Schwartz, Wright, Shin, Kagan, & Rauch, 2003). At the same time, environmental influences on temperament— in particular parenting style, culture, social class, and historical era—have also been reported (Kagan, et al., 2007; van den Boom, 1994).

Temperament of the trained infants was not measured prior to their training. Consequently, interpreting differences in temperament between the groups should be done with caution. Given the data collected in Experiment 4, it is impossible to determine if temperament was affected by the active-training experience or if differences existed prior to training. However, some temperament variables such as activity level, attention focusing, and attentional shifting are related to the behavioral measures recorded in Experiment 4. Results showed that parents rated trained infants higher on their attention focusing abilities compared to untrained infants. This is in agreement with the behavioral results of the sustained exploration task, providing converging evidence from direct observation and parental questionnaires that active-motor training at three months of age encouraged focusing and sustaining of attention at 14 months of age.

Despite the developmental stability of temperament, gene-environment interactions have been noted for aspects of personality and temperament (Caspi, et al., 2002; Caspi, et al., 2003; Schmidt, Fox, Perez-Edgar, & Hamer, 2009). Further, maternal stress during pregnancy has been suggested to influence the development of attachment related temperament traits (Buitelaar, et al., 2003). Therefore, it is possible that the active-training experience can affect the development of temperament as well. On the one hand, correlation analyses in Experiment 4 suggested a relation between infants'

grasping behavior (in Task III) and their temperament (impulsivity, Task IV), providing some evidence for the notion that motor experience and ability can influence temperament traits. On the other hand, experimental manipulation of parent's sensitive responsiveness to their infants has been associated with more secure attachment and more exploration behavior (van den Boom, 1994). At the present time, I cannot determine whether the lasting effects of the active-motor training were caused by changes in the infant's ability or by changes in the parent's interactions with the infant.

Together, the results of Experiment 4 demonstrate that providing two- to three-month-old infants with motor training that encourages early grasping and reaching behavior can have long-term effects on exploration quality and quantity, the development of some temperament traits, and potentially even the development of social understanding skills. While the observed changes in behavior were statistically significant, it remains an open question whether they also have practical significance. It is possible that the developmental benefits of motor enrichment do not make a substantial difference in the day-to-day lives of the trained infants. Future studies will be necessary to answer this question. Further, it is unclear what has caused the long-term effects I have observed in Experiment 4. The active-training experience of Experiment 1 encouraged early grasping and reaching behavior in three-month-old infants. The long-term effects of this intervention could be caused by the training experience itself, by the subsequent behavior of the infant or the parent, or a combination of these factors. Infants who engage in independent reaching and grasping provide themselves with additional opportunities for learning. Similarly, once parents realize that their child is now able to engage in independent reaching and grasping they may change how they interact with

the infant and encourage future independent exploration behavior. Most likely, both of these factors contributed to the long-term effects observed in Experiment 4.

7. General Discussion

Researchers have noted that there are connections between motor, cognitive, and social development in infancy (e.g., Bushnell & Boudreau, 1993; Gibson, 1988; von Hofsten, 2004). However, only very few studies have investigated the specific effects of active, self-produced motor experiences on cognitive and social development in human infants. What are the benefits of self-produced motor experiences for future development? The findings reported in Experiments 1, 3, and 4 address this issue and show that early motor experiences have both short-term and long-term effects on infants' behavior and development. Further, converging evidence from Experiments 1-3 strongly suggests a connection between motor ability and face-preference behavior. Together, these results have implications for our understanding of the relation between motor and social development and for the more general mechanisms of change in development.

Experiment 1 showed that training three-month-old infants for two weeks using the simulated reaching paradigm (Needham, et al., 2002) encouraged object engagement, reaching, and grasping behavior. This experience also encouraged rapid orienting towards faces in a visual-preference task, suggesting a relationship between motor experience and face-preference behavior. Experiment 2 revealed that a connection between motor ability and face-preference behavior also exists in the absence of specific motor training. Components of the simulated reaching experience were isolated in separate comparison groups of Experiments 1 and 3 (observation of somebody acting on objects, external motivation to act, and experience of contingent arm and object movements). Results indicated that different training procedures were not as effective in

increasing manual-exploration or face-preference behavior. Finally, study 4 showed that the effects of simulated reaching experience at three months of age are still present nearly one year later.

Together, the results reported here suggest that self-produced motor experiences play an important role in infant development. However, the effectiveness of simulated reaching experience and its lasting influences on motor and social development raise further questions. Why should motor training be effective at all? What about the training experience encouraged face-preference behavior? How can motor experiences influence social development? And finally, given the observed long-term effects of motor training, what are the potential implications for future development? I will address each of these questions in the following.

7.1 Why does motor training affect development?

Why would we expect motor training to have any influences on infant development at all? In answering this question, it is useful to consider Vygotsky ideas about learning and development and his concept of the “zone of proximal development” (Vygotsky, 1978). The zone of proximal development (ZPD) describes the difference between what a child can do by herself and what a child can do with help from others. Learning creates the ZPD: learning precedes development and the processes by which learning occurs are subsequently converted into developmental processes. Vygotsky developed the ZPD with regard to preschool children, but it applies here as well. At three months of age, infants are not yet able to reach for and grasp objects on their own. But with some help from an adult, who places the toy into the hand of the infant or who guides their arm to the toy, they can succeed. Reaching and grasping behaviors are within the ZPD for three-month-old infants. Training with motor experiences that lie

beyond the infant's ZPD would most likely not lead to changes in development. For example, attempts to teach three-month-old infants to walk independently will probably fail and not lead to any changes (neither in the motor domain nor in other domains). Simulated reaching experience is effective because it functions within the ZPD of three-month-old infants and enables infants to engage in learning processes they would normally engage in slightly later. According to Vygotsky's theory, the specific motor-learning processes associated with the simulated reaching experience are subsequently converted into more general developmental processes. The ZPD suggests that the simulated reaching experience is effective because it matches the state of current and potential development in three-month-old infants.

The ZPD can explain why we would expect reaching training to be effective around three months of age. However, the ZPD does not explain why only one of the four training methods used here (active training) was successful. Another theory that emphasizes the role of self-produced actions on development is the constructivist theory of Piaget (Piaget, 1954, 1970). Piaget's theory offers one potential explanation on why only the active-training experience was an effective training method. According to Piaget, infants progress from one stage of development to the next by repeatedly acting on objects and observing the effects of their own actions. Through their own actions, infants learn about the world around them and construct increasingly complex representations of the physical world. Three components are necessary for learning to occur: Perception of objects, coordination of actions on these objects, and observation of the outcomes of actions (the interaction between action and object). Object perception alone or action production and coordination alone are not sufficient for this

construction, additionally an interaction (the result of an action on objects) between object and action is required (Piaget, 1970).

The active-training paradigm combined the three components that Piaget identified as necessary for learning to occur. In contrast, all other training procedures had one or the other of these components missing or at least strongly reduced. The passive-training experience and encouragement experience only allowed for very limited amounts of action-outcome observations—the action-object interaction component was missing. The movement experience did allow for the observation of action outcomes but did not require infants to learn how to coordinate their own actions. Infants in this group did not experience how variations in their own actions changed the action outcome (e.g., successful vs. non-successful grasp). In each case, at least one of the required components for construction of new knowledge was missing. Therefore, neither the passive-training procedure nor the motivation or movement experiences were sufficient to encourage motor learning.

Together, the ZPD and Piaget's theory suggest that engaging in self-produced actions on objects can advance development in three-month-old infants. However, it should be noted that neither Piaget nor Vygotsky developed their theory with three-month-old infants in mind. Especially Piaget would be skeptical about the kind of new knowledge that three-month-old could generate from motor experiences. The fact that training can alter *motor* behavior is not surprising (e.g., McGraw, 1935). But Experiments 1-3 showed a connection between motor ability and *social* behaviors (i.e. face preference). What about the training experiences of Experiments 1 and 3 was responsible for the observed changes in face-preference behavior?

7.2 What experiences encourage face-preference behavior?

Experiment 1 has shown that the active-training procedure encouraged face-preference behavior in three-month-old infants. Of the remaining three training procedures, only the movement-experience paradigm seemed to influence face-preference behavior to some degree. What were the differences between the training procedures that caused only active training and movement experience to encourage a preference for faces? In Experiment 2, the temperament dimension “activity level” showed a negative relation with face-preference behavior. Infants who were rated lower on activity level may engage in fewer but slower and planned actions whereas infants rated higher on activity level may produce more but less controlled limb movements that are not directed at a particular target. Slow and object-directed arm movements are important for independent reaching (e.g., Thelen, et al., 1993). Therefore, the relation between activity level and face-preference behavior suggests that infants who have more control over their limb movements show a preference for faces. A similar distinction can be made regarding the training procedures of Experiment 1 and 3.

The training procedures of Experiments 1 and 3 differed along two main dimensions: First, the amount of attention that was directed towards the training toys. And second, the amount of manual control over the training toys experienced by the infant. The AT procedure would be rated high on both dimensions. Parents directed infants’ attention towards the toys and infants were able to control the movement of the training toys following manual contact while wearing the sticky mittens. The PT procedure would be rated high on the attention dimension and low on the control dimension. Parents encouraged attention to the training toys, but infants were never allowed to move the toys on their own. The EE procedure would be rated high on the

attention dimension and intermediate on the control dimension. Parents again directed attention towards the training toys, but the infant had to successfully grasp the training toys herself in order to experience control over the toy's movement. At three months of age, successful grasping without help occurs rarely and infants in the EE group probably experienced only occasional control over the training toys. Finally, the ME procedure would be rated low on the attention dimension and high on the control dimension. Parents did not direct infants' attention towards the toy but attached the toy to the infants' hand. Infants in the ME group were able to control the movement of the training toys on all occasions when the toy was attached to their hand.

Considering the attention and control dimensions described above, the four training procedures of Experiment 1 and 3 can be placed into a Cartesian system with the amount of attention drawn to the training toys on the y-axis and the amount of experienced control over the training toys on the x-axis. Figure 22 shows the face-preference scores of all four training procedures from Experiment 1 and 3 placed on their corresponding positions in such a coordinate system.

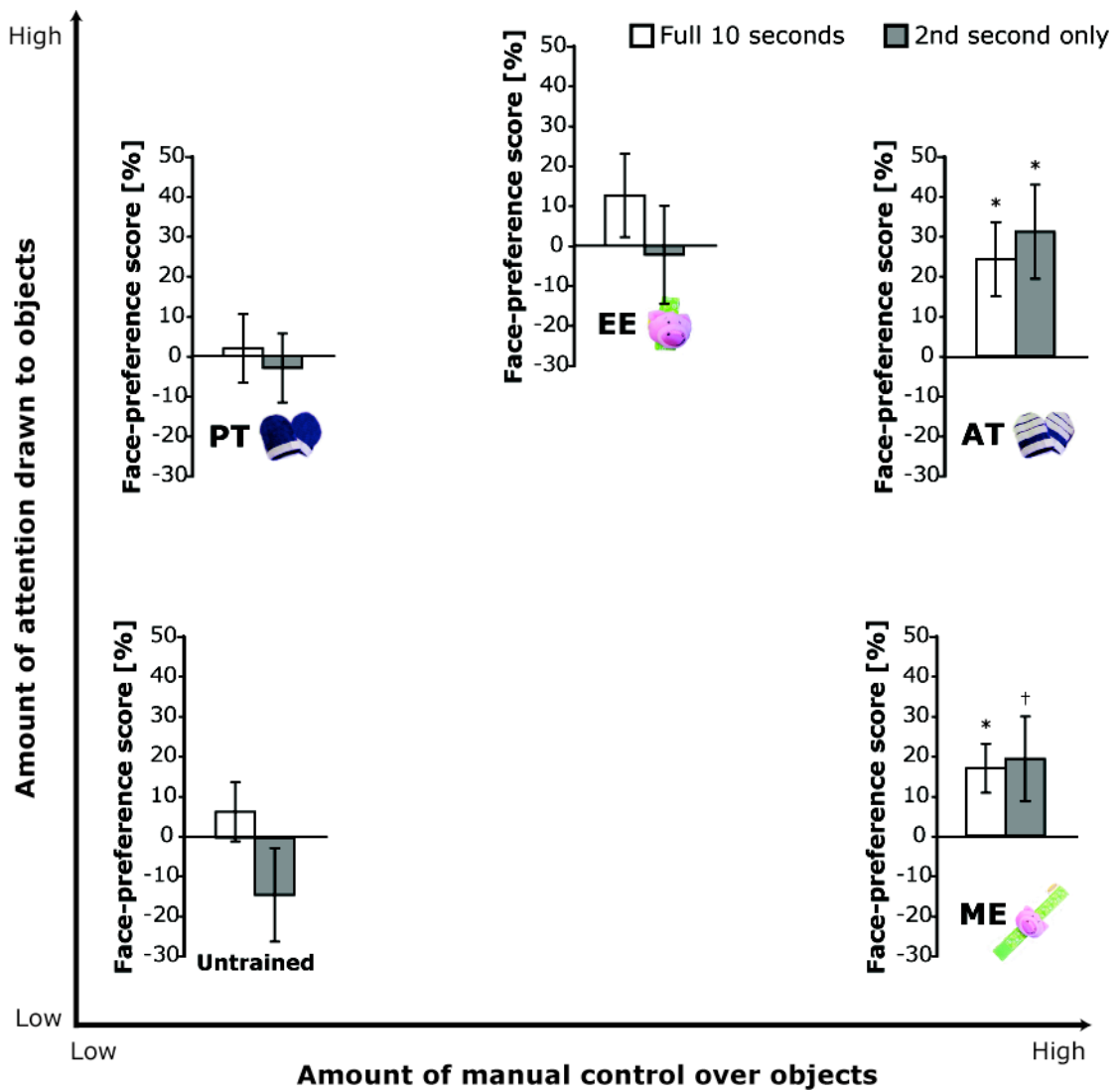


Figure 22: Face-preference scores by amount of manual control and attention drawn to objects during the training experiences. Face preference scores from Experiments 1 and 3 are reported for all training groups. Untrained group is taken from Experiment 1. Error bars are SEM. * $p < .05$. † $p = .087$.

The patterns visible in Figure 22 suggest that the amount of manual control over the training objects had a strong impact on face-preference behavior. In contrast, the amount of attention drawn to the training toys had little or no impact on infants' preference for faces. Therefore, experiencing the outcome of self-produced actions and

the corresponding movements of external objects seems to encourage infants' face-preference behavior. A preference for faces, in turn, provides infants with additional exposure to social and communicative information and may influence future social development, providing a link between motor experiences and social development.

Previously, the importance of motor experiences for development across several domains—in particular perceptual development—has been noted (e.g., Bertenthal, et al., 1994; Bushnell & Boudreau, 1993; Eppler, 1995; Gibson, 1988; Sommerville, et al., 2005). However, how and why motor experiences should influence social development remains an open question. Possible answers to this question will be discussed in the next section.

7.3 How are motor abilities and social cognition related?

The rich opportunities for learning that are present in the active-training procedure provide one potential answer to the question of why motor experiences seem to influence social cognition. While infants engage in self-produced reaching actions, they can actively learn about object properties, object affordances, and intentional actions of themselves and others (Gibson & Pick, 2000; Needham, et al., 2002; Sommerville, et al., 2005). Together, these learning processes may cause the observed changes in social orienting behavior by changing infants' understanding of themselves or of others (or both) as intentional agents and may make other agents and their faces more salient to the infant. This notion is similar to Piaget's theory of infants' construction of the physical world but now applied to infants' construction of the social world. Through their own actions, infants learn about themselves and others as intentional agents. Again, Piaget himself would probably have disagreed that already three-month-old infants were capable of learning about others as intentional agents.

However, Piaget tended to underestimate the abilities of young infants and learning about others as intentional agents can build on earlier emerging self-other discrimination abilities. By two months of age, infants have already learned to discriminate themselves from others through a process of active self-exploration (Rochat, 2001). Therefore, by two months of age infants seem to have some rudimentary conception of themselves and others that can be modified by new experiences such as self-produced reaching.

Another somewhat related reason for the influences of motor ability on face-preference behavior comes from motor theories of social cognition. Darwin was the first to suggest a relation between motor and social behaviors by noting that social displays, such as smiling or crying, may have evolved from basic motor actions (Darwin, 1873). The key idea here is that adaptive motor actions, such as defensive reactions, have evolved into social displays because of their ability to influence the behavior of the observer (Graziano, 2009). The discovery of so-called “mirror neurons” in the premotor cortex (di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992) and parietal lobe (e.g., Gallese, Fadiga, Fogassi, & Rizzolatti, 2002) of macaque monkeys has added further support for an involvement of motor abilities in social cognition. Mirror neurons are neurons that become active during both action production and action observation. Using indirect brain-imaging techniques (e.g., PET, fMRI), several studies have provided neurophysiological evidence for a similar mirror-neuron system (MNS) in humans (for review see Rizzolatti & Craighero, 2004). More recently, invasive depth electrode recordings also suggested that individual neurons with mirror properties exist in the human frontal cortex (Iacoboni, 2008). Because the MNS seems to be involved in both action production and action observation, it has been hypothesized to play a major role

in action understanding abilities via “mental simulation” or direct matching onto our own motor repertoire (Gallese, et al., 2009). This matching mechanism has been referred to as a “sense” for actions (Shapiro, 2009) and would provide a direct link between motor behavior and social understanding.

When in development does this proposed action sense emerge? While it has been suggested that a rudimentary action-matching system is present in infants already from birth (Lepage & Theoret, 2007; Meltzoff & Decety, 2003), this system is also shaped by experience and becomes tuned for actions with high levels of familiarity and expertise in the observer (Buccino, et al., 2004; Calvo-Merino, Glaser, Grezes, Passingham, & Haggard, 2005; Calvo-Merino, Grezes, Glaser, Passingham, & Haggard, 2006). Two studies have provided neurophysiological evidence for a functional MNS in six- to seven-month-old infants. The first study recorded brain activity in six- to seven-month-old infants using near-infrared spectroscopy (NIRS) and observed a stronger NIRS signal over sensorimotor areas during observation of a person performing actions when compared to observation of a rolling ball (Shimada & Hiraki, 2006). The second study investigated mu-rhythm activity using electroencephalography (EEG). The mu rhythm is an EEG response that can be measured over somatosensory areas and shows a similar frequency as the alpha rhythm with a peak around 10 Hz (Kuhlman, 1978). Mu-rhythm activity of the brain is suppressed during action production and during action observations, suggesting that it represents an EEG marker for mirror-neuron activity (Gastaut & Bert, 1954; Muthukumaraswamy, Johnson, & McNair, 2004). Similar to adults, six-month-old infants showed mu-suppression during observation of actions but not during observation of a moving dot (Nystrom, 2008). Both infant studies noted some differences in sensitivity of the neural responses between infants and adults, suggesting

that the infant MNS is still immature. Further, at six months of age, infants have already acquired reaching and grasping skills. It remains unclear whether infants would show evidence for a functional MNS at a younger age when they cannot perform object-directed arm movements themselves yet.

It is possible that an action-matching system is present only for actions that are within the motor repertoire of the infant. Experiment 1 has shown that the active-training procedure encouraged infant's own reaching and grasping attempts. Experiencing reaching and grasping on their own during the active-training procedure may jump-start the emergence of an action-matching system for reaching actions. Consequently, trained infants may attend more to faces because they recognize that people have the potential to act and this ability makes people more interesting compared to objects.

7.4 How long lasting are the effects of early motor training?

Experiment 4 has shown that reaching experiences at three months of age lead to changes in manual exploration and attention that seem to persist for at least one year. While these results are encouraging, one has to be careful to interpret them as suggesting that the trained infants have a permanent advantage over their untrained peers. In McGraw's study of the twins Jimmy and Johnny, one twin was trained on complex motor tasks such as climbing stairs while the other twin was not allowed to practice this skill. The trained twin mastered the skill earlier, as would be predicted, but the benefits of the training were only transient and eventually the untrained twin caught-up with his brother (McGraw, 1935). Similarly, Kagan observed infants who grew up in indigenous villages of Guatemala where they were rarely spoken to and had little opportunities for play (Kagan & Klein, 1973). The infants were described as

showing a strong “motoric passivity” and developmental delays. However, when Kagan observed 11-year-old children of the same villages, no signs of developmental retardation were present. Therefore, it seems that early positive or negative experiences do not necessarily have long-term consequences for development.

Long-lasting consequences for development have been observed following extreme experiences. For example, long-term consequences on cognitive and physical development have been observed following negative experiences in institutional settings with severe deprivation and lack of care (Smyke, et al., 2007). Institutional settings that provide adequate levels of stimulation and care did not show negative outcomes (Whetten, et al., 2009). The positive experiences associated with the active-training procedure used here did not constitute an extreme form of enrichment or training. Rather, the active-training procedure behavior that was well within the physical limits of the infant. As such, it is unlikely that the effects of simulated reaching experience at three months of age would continue much beyond the infant and possibly toddler period under normal circumstances.

In contrast, the implications and benefits of early reaching experience may be vastly different for infants who are at-risk for developmental delays, who follow an atypical developmental trajectory, or who grow up in a detrimental environment (such as a poor-quality institutional setting). In such a context, early motor training may make a significant difference and put these at-risk infants on an entirely different developmental trajectory. At this point, I can only speculate about the positive effects of early motor training for at-risk infants. Future studies should investigate this issue more closely.

8. Future directions

The results of Experiments 1, 3, and 4 indicate that providing non-reaching infants with simulated reaching experience (active training in Experiment 1) has a positive impact on both future motor and social development. However, it remains unknown how simulated reaching experience affects the developing brain and whether this form of motor training has value as a clinical intervention with infants at risk for motor or social deficits. In particular, three areas of research are of interest for future investigations.

First, are there any structural changes in the brain following simulated reaching experience? Previous studies have observed structural changes (increased gray and white matter) following motor training in the adult brain (Draganski, et al., 2004; Scholz, et al., 2009). No studies have investigated similar effects of motor training in human infants. The changes associated with motor training in adults were transient and followed an extensive training period (6-12 weeks) with a novel motor skill—juggling. It is possible that motor training in infants would have a similar but longer-lasting impact on the brain. The infant brain is still immature and may be more malleable by experience. Further, reaching continues to be practiced by the infant on a daily basis following the training period. In contrast, changes in the adult brain following juggling experience were likely transient because adults did not continue to practice their juggling skills following the conclusion of the training period. Learning about the structural changes that occur in the developing brain following beneficial interventions such as simulated reaching training would allow us to better understand how the brain is shaped by experience.

Second, does simulated reaching experience foster the development of a functional mirror-neuron system (MNS) in the human brain? Using single-cell recordings, neurons that become active both during action observation and action production have been discovered in the macaque brain (di Pellegrino, et al., 1992; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996) and more recently also in the human brain (Iacoboni, 2008). These so called “mirror neurons” and the corresponding MNS in humans are hypothesized to represent the biological basis for social cognition skills such as action understanding, empathy, and mental simulation of others’ intentions (Gallese, 2007; Rizzolatti & Craighero, 2004). The importance of the MNS for social cognition is supported by neuroimaging studies of patients with Autism Spectrum Disorders (ASD). Children and adults who suffer from ASD show impairments in social functioning and abnormal functioning of the MNS (Dapretto, et al., 2006; Oberman, et al., 2005). Further, it has been suggested that the MNS may represent a biological marker for the development of social competence in children (Pfeifer, Iacoboni, Mazziotta, & Dapretto, 2008). Therefore, information regarding the emergence and growth of the MNS is critical for our understanding of the normal and abnormal development of social interaction skills. However, little is known about the development of the MNS in humans and only few theories have addressed this issue (Del Giudice, et al., 2009; Gallese, et al., 2009; Lepage & Theoret, 2007). In particular, the importance of self-produced action experiences during early infancy remains poorly understood.

Findings from Experiments 1, 2, and 3 provide evidence that self-produced motor experiences can encourage face-preference behavior and potentially related social cognition skills (such as gaze following and action anticipation, see Experiment 2). Following brief training using the simulated reaching experience, three-month-olds

show an increased understanding of the goal of an observed action (Sommerville, et al., 2005). To date, a functional MNS has not been demonstrated in three-month-old infants. I predict that two weeks of simulated reaching experience would jump-start the emergence of a functional MNS for reaching actions in three-month-old infants and I plan to investigate this issue in the future.

And three, what is the practical value of the simulated reaching paradigm as clinical intervention for infants at-risk for social deficits? In Experiment 1, I quantified the influence of manual-exploration behavior on face-orienting behavior. The influence of motor experience on face-preference behavior appeared to be relatively small (accounting for only about 7.3% of the variation in face-preference behavior). Demographic variables showed a much stronger impact (accounting for about 20% of the variation). However, in contrast to demographic factors, the amount of manual-exploration experience and engagement can be actively modulated by experience and thus presents opportunities for intervention. Consequently, experiences that potentially encourage orienting to faces—such as the simulated reaching experience—would present a promising intervention for Autism Spectrum Disorders (ASD). Retrospective analyses of home videotapes suggest that children who were later diagnosed with ASD showed less attention to others during their first year compared to healthy children or children with cognitive impairments (Osterling, et al., 2002). Experiment 1 showed a positive effect of motor training on face-preference behavior in three-month-old infants. By encouraging face-preference behavior, simulated reaching training may be able to ameliorate some of the social deficits associated with ASD in at-risk infants. In a rat model for ASD, environmental enrichment has already been shown to reverse behavioral abnormalities associated with ASD (Schneider, Turczak, & Przewlocki, 2006).

Children with ASD are mainly characterized by striking impairments in social functioning but there is also evidence for fine and gross motor-skill deficits (Landa, 2008). The role of motor development in ASD is still unclear and it is possible that motor training is not effective as intervention for ASD. Rather, simulated reaching experience could be a marker for infants who are at-risk for ASD. The training procedures used in Experiments 1 and 3 are essentially motor-learning tasks with the simulated reaching experience providing the most supportive learning context among the four training paradigms. Using motor training as a marker task, infants who are trained with the simulated reaching paradigm but show no improvements in their reaching behavior or in their face-preference behavior may be at an increased risk to develop ASD. Infants identified in this way could then be selected for more in-depth assessments and earlier access to interventions.

In the future, I plan to investigate the three areas of research discussed here by studying the behavior of infants at-risk for ASD and by measuring brain function and development in healthy infants following motor-training experiences. Others agree that too little is known about the positive influences of motor training on the developing brain and call for more research on this issue: *“After more than 30 years of research on the negative effects [...] on the brain, it is now time to turn our attention to the potential positive impact of early interventions on brain development.”* (Lupien, McEwen, Gunnar, & Heim, 2009, p. 442)

References

- Adolph, K. E. (1997). Learning in the Development of Infant Locomotion. *Monographs of the Society for Research in Child Development*, 62(3), I-VI, 1-158.
- Adolph, K. E. (2000). Specificity of Learning: Why Infants Fall over a Veritable Cliff. *Psychological Science*, 11(4), 290-295.
- Adolph, K. E., & Berger, S. E. (2006). Motor Development. In D. Kuhn & R. S. Siegler (Eds.), *Handbook of Child Psychology: Vol 2: Cognition, Perception, and Language* (6th ed., pp. 161-213). New York: Wiley.
- Adolph, K. E., & Eppler, M. A. (1998). Development of Visually Guided Locomotion. *Ecological Psychology*, 10(3-4), 303-321.
- Adolph, K. E., & Joh, A. S. (2009). Multiple Learning Mechanisms in the Development of Action. In A. L. Woodward & A. Needham (Eds.), *Learning and the Infant Mind* (pp. 172-207). New York, NY: Oxford University Press.
- Adolph, K. E., Young, J. W., Robinson, S. R., & Gill-Alvarez, F. (2008). What Is the Shape of Developmental Change? *Psychological Review*, 115(3), 527-543.
- Aita, M., & Goulet, C. (2003). Assessment of Neonatal Nurses' Behaviors That Prevent Overstimulation in Preterm Infants. *Intensive and Critical Care Nursing*, 19(2), 109-118.
- Arabin, B., Bos, R., Rijlaarsdam, R., Mohnhaupt, A., & vanEyck, J. (1996). The Onset of Inter Human Contacts: Longitudinal Ultrasound Observations in Early Twin Pregnancies. *Ultrasound in Obstetrics & Gynecology*, 8(3), 166-173.
- Bahrack, L. (2003). Development of Intermodal Perception. In L. Nadel (Ed.), *Encyclopedia of Cognitive Science* (Vol. 2, pp. 614-617). London: Nature Publishing Group.
- Bahrack, L. E., Flom, R., & Lickliter, R. (2002). Intersensory Redundancy Facilitates Discrimination of Tempo in 3-Month-Old Infants. *Developmental Psychobiology*, 41(4), 352-363.
- Bahrack, L. E., & Lickliter, R. (2000). Intersensory Redundancy Guides Attentional Selectivity and Perceptual Learning in Infancy. *Developmental Psychology*, 36(2), 190-201.
- Baillargeon, R. (1999). Young Infants' Expectations About Hidden Objects: A Reply to Three Challenges. *Developmental Science*, 2(2), 115-132.

- Baillargeon, R. (2004). Infants' Physical World. *Current Directions in Psychological Science*, 13(3), 89-94.
- Baldwin, D. A., Baird, J. A., Saylor, M. M., & Clark, M. A. (2001). Infants Parse Dynamic Action. *Child Development*, 72(3), 708-717.
- Banks, M. S., & Salapatek, P. (1978). Acuity and Contrast Sensitivity in 1-Month-Old, 2-Month-Old, and 3-Month-Old Human Infants. *Investigative Ophthalmology & Visual Science*, 17(4), 361-365.
- Baron-Cohen, S. (1994). How to Build a Baby That Can Read Minds: Cognitive Mechanisms in Mindreading. *Cahiers De Psychologie Cognitive-Current Psychology of Cognition*, 13(5), 513-552.
- Barrett, T. M., & Needham, A. (2008). Developmental Differences in Infants Use of an Object's Shape to Grasp It Securely. *Developmental Psychobiology*, 50(1), 97-106.
- Barrett, T. M., Traupman, E., & Needham, A. (2008). Infants' Visual Anticipation of Object Structure in Grasp Planning. *Infant Behavior & Development*, 31(1), 1-9.
- Bertenthal, B. I., Campos, J. J., & Barrett, K. C. (1984). Self-Produced Locomotion: An Organizer of Emotional, Cognitive, and Social Development in Infancy. In R. N. Emde & R. J. Harmon (Eds.), *Continuities and Discontinuities in Development* (pp. 175-210). New York: Plenum Press.
- Bertenthal, B. I., Campos, J. J., & Kermoian, R. (1994). An Epigenetic Perspective on the Development of Self-Produced Locomotion and Its Consequences. *Current Directions in Psychological Science*, 3(5), 140-145.
- Bertenthal, B. I., Proffitt, D. R., & Cutting, J. E. (1984). Infant Sensitivity to Figural Coherence in Biomechanical Motions. *Journal of Experimental Child Psychology*, 37(2), 213-230.
- Bertenthal, B. I., Proffitt, D. R., & Kramer, S. J. (1987). Perception of Biomechanical Motions by Infants: Implementation of Various Processing Constraints. *Journal of Experimental Psychology: Human Perception and Performance*, 13(4), 577-585.
- Biringen, Z., Emde, R. N., Campos, J. J., & Appelbaum, M. I. (1995). Affective Reorganization in the Infant, the Mother, and the Dyad - the Role of Upright Locomotion and Its Timing. *Child Development*, 66(2), 499-514.
- Blackburn, S. (1998). Environmental Impact of the Nicu on Developmental Outcomes. *Journal of Pediatric Nursing*, 13(5), 279-289.
- Bourgeois, K. S., Khawar, A. W., Neal, S. A., & Lockman, J. J. (2005). Infant Manual Exploration of Objects, Surfaces, and Their Interrelations. *Infancy*, 8(3), 233-252.

- Bower, T. G. R. (1982). *Development in Infancy* (2nd ed.). San Francisco, CA: W.H. Freeman and Company.
- Bower, T. G. R., Broughton, J. M., & Moore, M. K. (1970). Demonstration of Intention in Reaching Behaviour of Neonate Humans. *Nature*, 228(5272), 679-&.
- Broekman, B. F. P., Chan, Y. H., Chong, Y. S., Quek, S. C., Fung, D., Low, Y. L., et al. (2009). The Influence of Birth Size on Intelligence in Healthy Children. *Pediatrics*, 123(6), E1011-E1016.
- Buccino, G., Lui, F., Canessa, N., Patteri, I., Lagravinese, G., Benuzzi, F., et al. (2004). Neural Circuits Involved in the Recognition of Actions Performed by Nonconspicuous: An fMRI Study. *Journal of Cognitive Neuroscience*, 16(1), 114-126.
- Buitelaar, J. K., Huizink, A. C., Mulder, E. J., de Medina, P. G. R., & Visser, G. H. A. (2003). Prenatal Stress and Cognitive Development and Temperament in Infants. *Neurobiology of Aging*, 24, S53-S60.
- Bushnell, E. W., & Boudreau, J. P. (1993). Motor Development and the Mind - the Potential Role of Motor Abilities as a Determinant of Aspects of Perceptual Development. *Child Development*, 64(4), 1005-1021.
- Calvo-Merino, B., Glaser, D. E., Grezes, J., Passingham, R. E., & Haggard, P. (2005). Action Observation and Acquired Motor Skills: An fMRI Study with Expert Dancers. *Cerebral Cortex*, 15(8), 1243-1249.
- Calvo-Merino, B., Grezes, J., Glaser, D. E., Passingham, R. E., & Haggard, P. (2006). Seeing or Doing? Influence of Visual and Motor Familiarity in Action Observation. *Current Biology*, 16(19), 1905-1910.
- Campos, J. J., Anderson, D. I., Barbu-Roth, M. A., Hubbard, E. M., Hertenstein, M. J., & Witherington, D. (2000). Travel Broadens the Mind. *Infancy*, 1(2), 149-219.
- Campos, J. J., Bertenthal, B. I., & Kermoian, R. (1992). Early Experience and Emotional Development - the Emergence of Wariness of Heights. *Psychological Science*, 3(1), 61-64.
- Campos, J. J., Witherington, D., Anderson, D. I., Frankel, C. I., Uchiyama, I., & Barbu-Roth, M. A. (2008). Rediscovering Development in Infancy. *Child Development*, 79(6), 1625-1632.
- Cancedda, L., Putignano, E., Sale, A., Viegli, A., Berardi, N., & Maffei, L. (2004). Acceleration of Visual System Development by Environmental Enrichment. *Journal of Neuroscience*, 24(20), 4840-4848.
- Carmichael, L. (1926). The Development of Behavior in Vertebrates Experimentally Removed from the Influence of External Stimulation. *Psychological Review*, 33(1), 51-58.

- Carpenter, M., Nagell, K., & Tomasello, M. (1998). Social Cognition, Joint Attention, and Communicative Competence from 9 to 15 Months of Age. *Monographs of the Society for Research in Child Development*, 63(4), V-143.
- Caspi, A., McClay, J., Moffitt, T. E., Mill, J., Martin, J., Craig, I. W., et al. (2002). Role of Genotype in the Cycle of Violence in Maltreated Children. *Science*, 297(5582), 851-854.
- Caspi, A., & Silva, P. A. (1995). Temperamental Qualities at Age 3 Predict Personality Traits in Young Adulthood: Longitudinal Evidence from a Birth Cohort. *Child Development*, 66(2), 486-498.
- Caspi, A., Sugden, K., Moffitt, T. E., Taylor, A., Craig, I. W., Harrington, H., et al. (2003). Influence of Life Stress on Depression: Moderation by a Polymorphism in the 5-HTT Gene. *Science*, 301(5631), 386-389.
- Clearfield, M. W., Osborne, C. N., & Mullen, M. (2008). Learning by Looking: Infants' Social Looking Behavior across the Transition from Crawling to Walking. *Journal of Experimental Child Psychology*, 100(4), 297-307.
- Corbetta, D. (2009). Brain, Body, and Mind: Lessons from Infant Motor Development. In J. P. Spencer, M. S. C. Thomas & J. L. McClelland (Eds.), *Toward a Unified Theory of Development: Connectionism and Dynamic Systems Theory Re-Considered* (pp. 51-66). Oxford, UK: Oxford University Press.
- Corkum, V., & Moore, C. (1998). The Origins of Joint Visual Attention in Infants. *Developmental Psychology*, 34(1), 28-38.
- Dapretto, M., Davies, M. S., Pfeifer, J. H., Scott, A. A., Sigman, M., Bookheimer, S. Y., et al. (2006). Understanding Emotions in Others: Mirror Neuron Dysfunction in Children with Autism Spectrum Disorders. *Nature Neuroscience*, 9(1), 28-30.
- Darwin, C. (1873). *The Expression of Emotions in Man and Animals*. New York, NY: D. Appleton and Company.
- Dawson, G., Sterling, L., & Faja, S. (2009). Autism: Risk Factors, Risk Processes, and Outcome. In M. de Haan & M. R. Gunnar (Eds.), *Handbook of Developmental Social Neuroscience* (pp. 435-458). New York, NY: Guilford Press.
- de Onis, M. (2006). Who Motor Development Study: Windows of Achievement for Six Gross Motor Development Milestones. *Acta Paediatrica*, 95, 86-95.
- de Vries, J. I. P., & Fong, B. F. (2006). Normal Fetal Motility: An Overview. *Ultrasound in Obstetrics and Gynecology*, 27(6), 701-711.
- Del Giudice, M., Manera, V., & Keysers, C. (2009). Programmed to Learn? The Ontogeny of Mirror Neurons. *Developmental Science*, 12(2), 350-363.

- Dennis, W. (1935). The Effect of Restricted Practice Upon the Reaching, Sitting, and Standing of Two Infants. *Pedagogical Seminary and Journal of Genetic Psychology*, 47(1), 17-32.
- Dennis, W., & Dennis, M. G. (1940). The Effect of Cradling Practices Upon the Onset of Walking in Hopi Children. *Pedagogical Seminary and Journal of Genetic Psychology*, 56(1), 77-86.
- di Pellegrino, G., Fadiga, L., Fogassi, L., Gallese, V., & Rizzolatti, G. (1992). Understanding Motor Events: A Neurophysiological Study. *Exp Brain Res*, 91(1), 176-180.
- DiPietro, J. A., Kivlighan, K. T., Costigan, K. A., & Laudenslager, M. L. (2009). Fetal Motor Activity and Maternal Cortisol. *Developmental Psychobiology*, 51(6), 505-512.
- Dodd, B. (1979). Lip Reading in Infants: Attention to Speech Presented in-Synchrony and out-of-Synchrony. *Cognitive Psychology*, 11(4), 478-484.
- Draganski, B., Gaser, C., Busch, V., Schuierer, G., Bogdahn, U., & May, A. (2004). Neuroplasticity: Changes in Grey Matter Induced by Training. *Nature*, 427(6972), 311-312.
- Driver, J., Davis, G., Ricciardelli, P., Kidd, P., Maxwell, E., & Baron-Cohen, S. (1999). Gaze Perception Triggers Reflexive Visuospatial Orienting. *Visual Cognition*, 6(5), 509-540.
- Eaton, W. O., & Enns, L. R. (1986). Sex Differences in Human Motor Activity Level. *Psychological Bulletin*, 100(1), 19-28.
- Eppler, M. A. (1995). Development of Manipulatory Skills and the Deployment of Attention. *Infant Behavior & Development*, 18(4), 391-405.
- Falck-Ytter, T., Gredeback, G., & von Hofsten, C. (2006). Infants Predict Other People's Action Goals. *Nature Neuroscience*, 9(7), 878-879.
- Fantz, R. L. (1963). Pattern Vision in Newborn Infants. *Science*, 140(356), 296-&.
- Farroni, T., Csibra, G., Simion, G., & Johnson, M. H. (2002). Eye Contact Detection in Humans from Birth. *Proceedings of the National Academy of Science U S A*, 99(14), 9602-9605.
- Farroni, T., Johnson, M. H., Menon, E., Zulian, L., Faraguna, D., & Csibra, G. (2005). Newborns' Preference for Face-Relevant Stimuli: Effects of Contrast Polarity. *Proceedings of the National Academy of Science U S A*, 102(47), 17245-17250.
- Farroni, T., Massaccesi, S., Pividori, D., & Johnson, M. H. (2004). Gaze Following in Newborns. *Infancy*, 5(1), 39-60.

- Ferrari, P. F., Visalberghi, E., Paukner, A., Fogassi, L., Ruggiero, A., & Suomi, S. J. (2006). Neonatal Imitation in Rhesus Macaques. *Plos Biology*, 4(9), 1501-1508.
- Fetters, L., & Todd, J. (1987). Quantitative Assessment of Infant Reaching Movements. *Journal of motor behavior*, 19(2), 147-166.
- Field, A. (2005). *Discovering Statistics Using Spss* (2 ed.). London: Sage Publications Inc.
- Fogel, A., Dedo, J. Y., & McEwen, I. (1992). Effect of Postural Position and Reaching on Gaze During Mother Infant Face-to-Face Interaction. *Infant Behavior & Development*, 15(2), 231-244.
- Fogel, A., Messinger, D. S., Dickson, K. L., & Hsu, H. C. (1999). Posture and Gaze in Early Mother-Infant Communication: Synchronization of Developmental Trajectories. *Developmental Science*, 2(3), 325-332.
- Frank, M. C., Vul, E., & Johnson, S. P. (2009). Development of Infants' Attention to Faces During the First Year. *Cognition*, 110(2), 160-170.
- Gallese, V. (2007). Embodied Simulation: From Mirror Neuron Systems to Interpersonal Relations. *Novartis Found Symp*, 278, 3-12; discussion 12-19, 89-96, 216-221.
- Gallese, V., Fadiga, L., Fogassi, L., & Rizzolatti, G. (1996). Action Recognition in the Premotor Cortex. *Brain*, 119 (Pt 2), 593-609.
- Gallese, V., Fadiga, L., Fogassi, L., & Rizzolatti, G. (2002). Action Representation and the Inferior Parietal Lobule. In W. Prinz & B. Hommel (Eds.), *Common Mechanisms in Perception and Action: Attention and Performance* (Vol. XIX, pp. 334-355). Oxford: Oxford University Press.
- Gallese, V., Rochat, M., Cossu, G., & Sinigaglia, C. (2009). Motor Cognition and Its Role in the Phylogeny and Ontogeny of Action Understanding. *Developmental Psychology*, 45(1), 103-113.
- Gastaut, H. J., & Bert, J. (1954). EEG Changes During Cinematographic Presentation; Moving Picture Activation of the EEG. *Electroencephalography and Clinical Neurophysiology*, 6(3), 433-444.
- Gauthier, I., & Nelson, C. A. (2001). The Development of Face Expertise. *Current Opinion in Neurobiology*, 11(2), 219-224.
- Gesell, A. (1934). *An Atlas of Infant Behavior* (Vol. 1). New Haven, CT: Yale University Press.
- Gibson, E. J. (1988). Exploratory Behavior in the Development of Perceiving, Acting and Acquiring of Knowledge. *Annual Review of Psychology*(39), 1-41.

- Gibson, E. J., & Pick, A. D. (2000). *An Ecological Approach to Perceptual Learning and Development*. New York: Oxford University Press.
- Gibson, E. J., & Walk, R. D. (1960). The "Visual Cliff". *Scientific American*, 202(4), 64-72.
- Goren, C. C., Sarty, M., & Wu, P. Y. K. (1975). Visual Following and Pattern-Discrimination of Face-Like Stimuli by Newborn-Infants. *Pediatrics*, 56(4), 544-549.
- Gramsbergen, A., & Mulder, E. J. H. (1998). The Influence of Betamethasone and Dexamethasone on Motor Development in Young Rats. *Pediatric Research*, 44(1), 105-110.
- Graziano, M. S. A. (2009). *The Intelligent Movement Machine: An Ethological Perspective on the Primate Motor System*. Oxford: Oxford University Press.
- Greenough, W. T., Black, J. E., & Wallace, C. S. (1987). Experience and Brain-Development. *Child Development*, 58(3), 539-559.
- Grossmann, T., & Farroni, T. (2009). Decoding Social Signals in the Infant Brain. In M. de Haan & M. R. Gunnar (Eds.), *Handbook of Developmental Social Neuroscience* (pp. 87-106). New York: The Guilford Press.
- Habek, D., Kulas, T., Selthofer, R., Rosso, M., Popovic, Z., Petrovic, D., et al. (2006). 3d-Ultrasound Detection of Fetal Grasping of the Umbilical Cord and Fetal Outcome. *Fetal Diagnosis and Therapy*, 21(4), 332-333.
- Hediger, M. L., Overpeck, M. D., Ruan, W. J., & Troendle, J. F. (2002). Birthweight and Gestational Age Effects on Motor and Social Development. *Paediatric and Perinatal Epidemiology*, 16(1), 33-46.
- Held, R., & Hein, A. (1963). Movement-Produced Stimulation in Development of Visually Guided Behavior. *Journal of Comparative and Physiological Psychology*, 56(5), 872-&.
- Hood, B. M., & Atkinson, J. (1993). Disengaging Visual Attention in the Infant and Adult. *Infant Behavior and Development*, 16(4), 405-422.
- Hood, B. M., Willen, J. D., & Driver, J. (1998). Adult's Eyes Trigger Shifts of Visual Attention in Human Infants. *Psychological Science*, 9(2), 131-134.
- Iacoboni, M. (2008). Mesial Frontal Cortex and Super Mirror Neurons. *Behavioral and Brain Sciences*, 31(1), 30.
- Johnson, M. H. (2005). Subcortical Face Processing. *Nature Reviews Neuroscience*, 6(10), 766-774.

- Johnson, M. H., Dziurawiec, S., Ellis, H., & Morton, J. (1991). Newborns Preferential Tracking of Face-Like Stimuli and Its Subsequent Decline. *Cognition*, 40(1-2), 1-19.
- Johnson, M. H., & Horn, G. (1988). Development of Filial Preferences in Dark-Reared Chicks. *Animal Behaviour*, 36, 675-683.
- Johnson, M. H., & Morton, J. (1991). *Biology and Cognitive Development: The Case of Face Recognition*. Oxford, UK: Blackwell.
- Johnson, S. P., Amso, D., & Slemmer, J. A. (2003). Development of Object Concepts in Infancy: Evidence for Early Learning in an Eye-Tracking Paradigm. *Proceedings of the National Academy of Science U S A*, 100(18), 10568-10573.
- Kagan, J., & Klein, R. E. (1973). Cross-Cultural Perspectives on Early Development. *American Psychologist*, 28(11), 947-961.
- Kagan, J., Snidman, N., Valikahn, & Towsley, S. (2007). The Preservation of Two Infant Temperaments into Adolescence. *Monographs of the Society for Research in Child Development*, 72(2), 1-+.
- Kail, R. V., & Ferrer, E. (2007). Processing Speed in Childhood and Adolescence: Longitudinal Models for Examining Developmental Change. *Child Development*, 78(6), 1760-1770.
- Keller, H., & Boigs, R. (1991). The Development of Exploratory Behavior. In M. E. Lamb & H. Keller (Eds.), *Infant Development: Perspectives from German-Speaking Countries*. Hillsdale, NJ: Lawrence Erlbaum Associates.
- Keller, H., & Zach, U. (1993). Developmental Consequences of Early Eye Contact Behaviour. *Acta Paedopsychiatrica*, 56, 31-36.
- Kikuchi, Y., Senju, A., Tojo, Y., Osanai, H., & Hasegawa, T. (2009). Faces Do Not Capture Special Attention in Children with Autism Spectrum Disorder: A Change Blindness Study. *Child Development*, 80(5), 1421-1433.
- Kleiner, K. A. (1987). Amplitude and Phase Spectra as Indexes of Infants Pattern Preferences. *Infant Behavior & Development*, 10(1), 49-59.
- Klin, A., & Jones, W. (2008). Altered Face Scanning and Impaired Recognition of Biological Motion in a 15-Month-Old Infant with Autism. *Developmental Science*, 11(1), 40-46.
- Klin, A., Lin, D. J., Gorrindo, P., Ramsay, G., & Jones, W. (2009). Two-Year-Olds with Autism Orient to Non-Social Contingencies Rather Than Biological Motion. *Nature*, 459(7244), 257-U142.
- Knudsen, E. I. (2004). Sensitive Periods in the Development of the Brain and Behavior. *Journal of Cognitive Neuroscience*, 16(8), 1412-1425.

- Kuhl, P. K., & Meltzoff, A. N. (1982). The Bi-Modal Perception of Speech in Infancy. *Science*, 218(4577), 1138-1141.
- Kuhlman, W. N. (1978). Functional Topography of Human Mu Rhythm. *Electroencephalography and Clinical Neurophysiology*, 44(1), 83-93.
- Kuhn, D. (1995). Microgenetic Study of Change: What Has It Told Us? *Psychological Science*, 6(3), 133-139.
- Landa, R. J. (2008). Diagnosis of Autism Spectrum Disorders in the First 3 Years of Life. *Nature Clinical Practice Neurology*, 4(3), 138-147.
- Lepage, J. F., & Theoret, H. (2007). The Mirror Neuron System: Grasping Others' Actions from Birth? *Dev Sci*, 10(5), 513-523.
- Lewkowicz, D. J. (2010). Infant Perception of Audio-Visual Speech Synchrony. *Developmental Psychology*, 46(1), 66-77.
- Libertus, K. (2008). Stopframecoding (Version 0.9) [Coding Software]. Durham, NC.
- Lobo, M. A., & Galloway, J. C. (2008). Postural and Object-Oriented Experiences Advance Early Reaching, Object Exploration, and Means – End Behavior. *Child Development*, 79(6), 1869-1890.
- Lomax-Bream, L. E., Barnes, M., Copeland, K., Taylor, H. B., & Landry, S. H. (2007). The Impact of Spina Bifida on Development across the First 3 Years. *Developmental Neuropsychology*, 31(1), 1-20.
- Lupien, S. J., McEwen, B. S., Gunnar, M. R., & Heim, C. (2009). Effects of Stress Throughout the Lifespan on the Brain, Behaviour and Cognition. *Nature Reviews Neuroscience*, 10(6), 434-445.
- Lynch, A., Lee, H. M., Bhat, A., & Galloway, J. C. (2008). No Stable Arm Preference During the Pre-Reaching Period: A Comparison of Right and Left Hand Kinematics with and without a Toy Present. *Developmental Psychobiology*, 50(4), 390-398.
- Macchi Cassia, V., Turati, C., & Simion, F. (2004). Can a Nonspecific Bias toward Top-Heavy Patterns Explain Newborns' Face Preference? *Psychological Science*, 15(6), 379-383.
- Maurer, D. (1985). Infants' Perception of Facedness. In T. M. Field & N. A. Fox (Eds.), *Social Perception in Infants*. Norwood, NJ: Ablex Publishing Corporation.
- McGraw, M. B. (1935). *Growth: A Study of Johnny and Jimmy*. New York, NY: D. Appleton-Century Company.

- McGraw, M. B. (1970). Major Challenges for Students of Infancy and Early Childhood. *American Psychologist*, 25(8), 754-8.
- Meltzoff, A. N., & Decety, J. (2003). What Imitation Tells Us About Social Cognition: A Rapprochement between Developmental Psychology and Cognitive Neuroscience. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences*, 358(1431), 491-500.
- Meltzoff, A. N., & Moore, M. K. (1977). Imitation of Facial and Manual Gestures by Human Neonates. *Science*, 198(4312), 75-78.
- Moll, H., Carpenter, M., & Tomasello, M. (2007). Fourteen-Month-Olds Know What Others Experience Only in Joint Engagement. *Developmental Science*, 10(6), 826-835.
- Moll, H., & Tomasello, M. (2007). How 14-and 18-Month-Olds Know What Others Have Experienced. *Developmental Psychology*, 43(2), 309-317.
- Moore, C. (2008). The Development of Gaze Following. *Child Development Perspectives*, 2(2), 66-70.
- Morton, J., & Johnson, M. H. (1991). Conspic and Concern - a Two-Process Theory of Infant Face Recognition. *Psychological Review*, 98(2), 164-181.
- Muthukumaraswamy, S. D., Johnson, B. W., & McNair, N. A. (2004). Mu Rhythm Modulation During Observation of an Object-Directed Grasp. *Brain Res Cogn Brain Res*, 19(2), 195-201.
- Myowa-Yamakoshi, M., & Takeshita, H. (2006). Do Human Fetuses Anticipate Self-Oriented Actions? A Study by Four-Dimensional (4d) Ultrasonography. *Infancy*, 10(3), 289-301.
- Myowa-Yamakoshi, M., Tomonaga, M., Tanaka, M., & Matsuzawaz, T. (2004). Imitation in Neonatal Chimpanzees (*Pan Troglodytes*). *Developmental Science*, 7(4), 437-442.
- Nation, K., & Penny, S. (2008). Sensitivity to Eye Gaze in Autism: Is It Normal? Is It Automatic? Is It Social? *Development and Psychopathology*, 20(1), 79-97.
- Needham, A. (2000). Improvements in Object Exploration Skills May Facilitate the Development of Object Segregation in Early Infancy. *Journal of Cognition and Development*, 1(2), 131-156.
- Needham, A., Barrett, T., & Peterman, K. (2002). A Pick-Me-up for Infants' Exploratory Skills: Early Simulated Experiences Reaching for Objects Using 'Sticky Mittens' Enhances Young Infants' Object Exploration Skills. *Infant Behavior & Development*, 25(3), 279-295.

- Nelson, C. A. (2001). The Development and Neural Bases of Face Recognition. *Infant and Child Development, 10*(1-2), 3-18.
- Nystrom, P. (2008). The Infant Mirror Neuron System Studied with High Density EEG. *Social Neuroscience, 3*(3-4), 334-347.
- Oberman, L. M., Hubbard, E. M., McCleery, J. P., Altschuler, E. L., Ramachandran, V. S., & Pineda, J. A. (2005). EEG Evidence for Mirror Neuron Dysfunction in Autism Spectrum Disorders. *Cognitive Brain Research, 24*(2), 190-198.
- Osterling, J. A., Dawson, G., & Munson, J. A. (2002). Early Recognition of 1-Year-Old Infants with Autism Spectrum Disorder Versus Mental Retardation. *Development and Psychopathology, 14*(2), 239-251.
- Pascalis, O., & Kelly, D. J. (2009). The Origins of Face Processing in Humans: Phylogeny and Ontogeny. *Perspectives on Psychological Science, 4*(2), 200-209.
- Pfeifer, J. H., Iacoboni, M., Mazziotta, J. C., & Dapretto, M. (2008). Mirroring Others' Emotions Relates to Empathy and Interpersonal Competence in Children. *Neuroimage, 39*(4), 2076-2085.
- Piaget, J. (1954). *The Construction of Reality in the Child*. London, England: Routledge and Kegan Paul Ltd.
- Piaget, J. (1970). Piaget's Theory. In P. H. Mussen (Ed.), *Carmichael's Manual of Child Psychology* (3rd ed., Vol. 1, pp. 703-732). New York, NY: John Wiley & Sons Inc.
- Pomerleau, A., & Malcuit, G. (1980). Development of Cardiac and Behavioral Responses to a 3-Dimensional Toy Stimulation in One-Month to 6-Month-Old Infants. *Child Development, 51*(4), 1187-1196.
- Putnam, S. P., Gartstein, M. A., & Rothbart, M. K. (2006). Measurement of Fine-Grained Aspects of Toddler Temperament: The Early Childhood Behavior Questionnaire. *Infant Behavior & Development, 29*(3), 386-401.
- Rader, N., Bausano, M., & Richards, J. E. (1980). On the Nature of the Visual-Cliff Avoidance Response in Human Infants. *Child Development, 51*(1), 61-68.
- Reid, V. M., & Striano, T. (2005). Adult Gaze Influences Infant Attention and Object Processing: Implications for Cognitive Neuroscience. *European Journal of Neuroscience, 21*(6), 1763-1766.
- Richards, J. E., & Rader, N. (1983). Affective, Behavioral, and Avoidance Responses on the Visual-Cliff: Effects of Crawling Onset Age, Crawling Experience, and Testing Age. *Psychophysiology, 20*(6), 633-642.
- Rizzolatti, G., & Craighero, L. (2004). The Mirror-Neuron System. *Annual Review of Neuroscience, 27*, 169-192.

- Rochat, P. (1989). Object Manipulation and Exploration in 2-Month-Old to 5-Month-Old Infants. *Developmental Psychology*, 25(6), 871-884.
- Rochat, P. (1992). Self-Sitting and Reaching in 5-Month-Old to 8-Month-Old Infants - the Impact of Posture and Its Development on Early Eye-Hand Coordination. *Journal of motor behavior*, 24(2), 210-220.
- Rochat, P. R. (2001). Social Contingency Detection and Infant Development. *Bulletin of the Menninger Clinic*, 65(3), 347-360.
- Rosenblith, J. F. (1992). *In the Beginning: Development from Conception to Age Two*. Newbury Park, CA: SAGE Publications.
- Rothbart, M. K. (1981). Measurement of Temperament in Infancy. *Child Development*, 52(2), 569-578.
- Rovee, C. K., & Rovee, D. T. (1969). Conjugate Reinforcement of Infant Exploratory Behavior. *Journal of Experimental Child Psychology*, 8(1), 33-&.
- Rovee-Collier, C. (1999). The Development of Infant Memory. *Current Directions in Psychological Science*, 8(3), 80-85.
- Rovee-Collier, C. K., Gekoski, M. J., Hayne, W. R., & Lewis, P. L. (1979). The Economics of Infancy: A Review of Conjugate Reinforcement *Advances in Child Development and Behavior* (Vol. Volume 13, pp. 195-255): JAI.
- Ruff, H. A., & Rothbart, M. K. (1996). *Attention in Early Development: Themes and Variations*. Oxford, UK: Oxford University Press.
- Sale, A., Berardi, N., & Maffei, L. (2009). Enrich the Environment to Empower the Brain. *Trends in Neurosciences*, 32(4), 233-239.
- Sangrigoli, S., & de Schonen, S. (2004). Recognition of Own-Race and Other-Race Faces by Three-Month-Old Infants. *Journal of Child Psychology and Psychiatry*, 45(7), 1219-1227.
- Schmidt, L. A., Fox, N. A., Perez-Edgar, K., & Hamer, D. H. (2009). Linking Gene, Brain, and Behavior: DRD4, Frontal Asymmetry, and Temperament. *Psychological Science*, 20(7), 831-837.
- Schneider, T., Turczak, J., & Przewlocki, R. (2006). Environmental Enrichment Reverses Behavioral Alterations in Rats Prenatally Exposed to Valproic Acid: Issues for a Therapeutic Approach in Autism. *Neuropsychopharmacology*, 31(1), 36-46.
- Scholz, J., Klein, M. C., Behrens, T. E. J., & Johansen-Berg, H. (2009). Training Induces Changes in White-Matter Architecture. *Nature Neuroscience*

- Schwartz, C. E., Wright, C. I., Shin, L. M., Kagan, J., & Rauch, S. L. (2003). Inhibited and Uninhibited Infants "Grown Up": Adult Amygdalar Response to Novelty. *Science*, 300(5627), 1952-1953.
- Shapiro, L. (2009). Making Sense of Mirror Neurons. *Synthese*, 167(3), 439-456.
- Shimada, S., & Hiraki, K. (2006). Infant's Brain Responses to Live and Televised Action. *Neuroimage*, 32(2), 930-939.
- Siegler, R. S., & Crowley, K. (1991). The Microgenetic Method: A Direct Means for Studying Cognitive Development *American Psychologist*, 46(6), 606-620.
- Simion, F., Regolin, L., & Bulf, H. (2008). A Predisposition for Biological Motion in the Newborn Baby. *Proceedings of the National Academy of Science U S A*, 105(2), 809-813.
- Smith, L., & Gasser, M. (2005). The Development of Embodied Cognition: Six Lessons from Babies. *Artificial Life*, 11(1-2), 13-29.
- Smyke, A. T., Koga, S. F., Johnson, D. E., Fox, N. A., Marshall, P. J., Nelson, C. A., et al. (2007). The Caregiving Context in Institution-Reared and Family-Reared Infants and Toddlers in Romania. *Journal of Child Psychology and Psychiatry*, 48(2), 210-218.
- Sommerville, J. A., Woodward, A. L., & Needham, A. (2005). Action Experience Alters 3-Month-Old Infants' Perception of Others' Actions. *Cognition*, 96(1), B1-11.
- Striano, T., & Reid, V. M. (2006). Social Cognition in the First Year. *Trends in Cognitive Sciences*, 10(10), 471-476.
- Striano, T., & Stahl, D. (2005). Sensitivity to Triadic Attention in Early Infancy. *Developmental Science*, 8(4), 333-343.
- Sugita, Y. (2008). Face Perception in Monkeys Reared with No Exposure to Faces. *Proceedings of the National Academy of Science U S A*, 105(1), 394-398.
- Sugita, Y. (2009). Innate Face Processing. *Current Opinion in Neurobiology*, 19(1), 39-44.
- Thelen, E. (1995). Motor Development - A New Synthesis. *American Psychologist*, 50(2), 79-95.
- Thelen, E., Corbetta, D., Kamm, K., Spencer, J. P., Schneider, K., & Zernicke, R. F. (1993). The Transition to Reaching: Mapping Intention and Intrinsic Dynamics. *Child Development*, 64(4), 1058-1098.
- Thelen, E., & Fisher, D. M. (1983). From Spontaneous to Instrumental Behavior - Kinematic Analysis of Movement Changes During Very Early Learning. *Child Development*, 54(1), 129-140.

- Thomas, J. R., & French, K. E. (1985). Gender Differences across Age in Motor Performance: A Meta Analysis. *Psychological Bulletin*, 98(2), 260-282.
- Tottenham, N., Tanaka, J., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., et al. (2009). The Nimstim Set of Facial Expressions: Judgments from Untrained Research Participants. *Psychiatry Research*, 168(3), 242-249.
- Troje, N. F., & Westhoff, C. (2006). The Inversion Effect in Biological Motion Perception: Evidence for A "Life Detector"? *Current Biology*, 16(8), 821-824.
- Turati, C. (2004). Why Faces Are Not Special to Newborns: An Alternative Account of the Face Preference. *Current Directions in Psychological Science*, 13(1), 5-8.
- Turati, C., Macchi Cassia, V., Simion, F., & Leo, I. (2006). Newborns' Face Recognition: Role of Inner and Outer Facial Features. *Child Development*, 77(2), 297-311.
- Vallortigara, G., Regolin, L., & Marconato, F. (2005). Visually Inexperienced Chicks Exhibit Spontaneous Preference for Biological Motion Patterns. *Plos Biology*, 3(7), 1312-1316.
- van den Boom, D. C. (1994). The Relationship between Attachment, Temperament, and Exploration. In H. Keller, K. Schneider & B. Henderson (Eds.), *Curiosity and Exploration* (1st ed.). Berlin, Germany: Springer.
- van der Fits, I. B. M., Klip, A. W. J., van Eykern, L. A., & Hadders-Algra, M. (1999). Postural Adjustments During Spontaneous and Goal-Directed Arm Movements in the First Half Year of Life. *Behavioural Brain Research*, 106(1-2), 75-90.
- van Praag, H., Kempermann, G., & Gage, F. H. (2000). Neural Consequences of Environmental Enrichment. *Nature Reviews Neuroscience*, 1(3), 191-198.
- von Hofsten, C. (1982). Eye-Hand Coordination in the Newborn. *Developmental Psychology*, 18(3), 450-461.
- von Hofsten, C. (1984). Developmental Changes in the Organization of Prereaching Movements. *Developmental Psychology*, 20(3), 378-388.
- von Hofsten, C. (2004). An Action Perspective on Motor Development. *Trends in Cognitive Sciences*, 8(6), 266-272.
- von Hofsten, C., & Ronnqvist, L. (1988). Preparation for Grasping an Object - a Developmental-Study. *Journal of Experimental Psychology-Human Perception and Performance*, 14(4), 610-621.
- Vygotsky, L. S. (1978). *Mind in Society: The Development of Higher Psychological Processes*. Cambridge, MA: Harvard University Press.

- Whetten, K., Ostermann, J., Whetten, R. A., Pence, B. W., O'Donnell, K., Messer, L. C., et al. (2009). A Comparison of the Wellbeing of Orphans and Abandoned Children Ages 6-12 in Institutional and Community-Based Care Settings in 5 Less Wealthy Nations. *PLoS ONE*, 4(12), e8169.
- Woodward, A. L. (1998). Infants Selectively Encode the Goal Object of an Actor's Reach. *Cognition*, 69(1), 1-34.
- Woodward, A. L. (2003). Infants' Developing Understanding of the Link between Looker and Object. *Developmental Science*, 6(3), 297-311.
- Woodward, A. L. (2009). Infants' Grasp of Others' Intentions. *Current Directions in Psychological Science*, 18(1), 53-57.
- Yonas, A., & Hartman, B. (1993). Perceiving the Affordance of Contact in Four- and Five-Month-Old Infants. *Child Development*, 64(1), 298-308.
- Zeanah, C. H. (2009). The Importance of Early Experiences: Clinical, Research, and Policy Perspectives. *Journal of Loss and Trauma*, 14, 266-279.
- Zebrowitz, L. A. (2006). Finally, Faces Find Favor. *Social Cognition*, 24(5), 657-701.
- Zoia, S., Blason, L., D'Ottavio, G., Bulgheroni, M., Pezzetta, E., Scabar, A., et al. (2007). Evidence of Early Development of Action Planning in the Human Foetus: A Kinematic Study. *Experimental Brain Research*, 176(2), 217-226.

Biography

I was born in Biberach an der Riß, Germany, on November 30th, 1979. In 2000, I graduated from Wieland-Gymnasium high school in Biberach an der Riß, Germany. Starting in 2001, I attended the University of Osnabrück, Germany, majoring in Cognitive Science and in 2003 I was a visiting exchange scholar at McGill University in Montréal, Canada. I received my B.Sc. from the University of Osnabrück, Germany, in 2004. In 2005, I started the PhD program at Duke University.

Publications

Needham, A., & **Libertus, K.** (2008). Neonativism. In M. M. Haith & J. B. Benson (Eds.), *Encyclopedia of Infant and Early Childhood Development* (Vol. 2, pp. 406-414). San Diego: Academic Press.

Brannon, E. M., Suanda, S., & **Libertus, K.** (2007). Temporal discrimination increases in precision over development and parallels the development of numerosity discrimination. *Developmental Science*, 10(6), 770-777.

Onat, S., **Libertus, K.**, & Konig, P. (2007). Integrating audiovisual information for the control of overt attention. *Journal of Vision*, 7(10).

Scholarships and Awards

2009: Society for Research in Child Development Travel Award
2008: James B. Duke Summer Research Fellowship
2007: Society for Research in Child Development Travel Award
2007 – 2009: Conference Travel Grants, Duke University
2006 – 2009: Summer Vertical Integration Scholarships, Duke University
2005 – 2006: German Academic Exchange Service Scholarship
2003 – 2010: e-fellows Scholarship

Memberships in Honorary Societies

2007 – present: Psi Chi, National Honor Society in Psychology