Walk this way, Talk this way.

Motor skills, spatial exploration, and the development of spatial cognition and language

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Motorische vaardigheden, ruimtelijke exploratie
en de ontwikkeling van ruimtelijke cognitie en taal
(met een samenvatting in het Nederlands)

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Content

Chapter 1

General Introduction

Anybody who is acquainted with parents of young infants knows that they eagerly wait for the moment their children start sitting, crawling, standing, or walking. Being able to sit or walk clearly impacts the child's physical functioning in the world, but does it also have consequences for psychological development? Let us consider what happens when an infant becomes able to sit independently. When infants can sit in an upright position for a longer time and no longer need to use their hands to support their posture, their world becomes much bigger. They can now not only see a lot more of the world around them, they can also do a lot more with it. As the hands are no longer needed for support, they can both be used to grab objects and manipulate them. Through manipulating objects children learn about the properties of objects such as shape, texture and weight (Rochat, 1992; Rochat & Goubet, 1995). Let us also consider what happens when the same infants start to walk. The world of walking infants is even bigger. Walking infants can change their own location in space, they can move towards a toy that interests them, and they can follow their parents around. More objects are within reach than before and children, therefore, start to pay attention to objects which are further away, being able to compare them with objects that are near, and seeing the spatial path between near and far (Campos et al., 2000). Walking infants can move around, into, between and behind large objects, and they can also carry objects from one place to another, and thus change the spatial arrangement of the room (Karasik, Adolph, Tamis-Lemonda, & Zuckerman, 2012). Every parent knows that the time at which children start walking is also the time to start making the house 'baby-proof'. Through these activities infants learn about spatial concepts such as *near* and *far*, *between, in front* and *behind*, and acquire skills such as mental rotation and using landmarks for navigation (Campos et al., 2000; Lehnung et al., 2003; Schwarzer, Freitag, Buckel, & Lofruthe, 2013). In this sense, the baby's first small steps are a big leap along the pathways of development.

Despite the large body of research on early precursors of linguistic and cognitive skills, the role of motor development as an early precursor of these skills has received little attention. However, in recent years theoretical papers have called for the study of cognitive and linguistic development in the context of movement and motor control (Gogate & Hollich, 2010; Hockema & Smith, 2009; Iverson, 2010; Rosenbaum, 2005), as part of a more comprehensive shift in the cognitive sciences towards embodied and situated models of human cognition (e.g., Glenberg, 2010; Shapiro, 2011). The relationship between motor development and cognitive-linguistic development is the topic of this dissertation. We address the question whether attainment of important motor milestones such as sitting and walking is a precursor of development in the domains of spatial cognition and general and spatial language, and we go into the question whether children's exploration behavior mediates the relationships between motor development, spatial cognition and language.

Embodied Cognition

The current dissertation is inspired by embodied cognition and ecological approaches to development. According to an embodied cognition view on development, cognition, including language, is grounded in real-time sensorimotor interactions between a person and his or her environment. The embodied cognition approach builds in many respects on the principles of ecological psychology, proposed by James Gibson and further elaborated by Eleanor Gibson, Ulric Neisser, and many others, stressing the central role of recurrent perception-action processes in development. Children, on the one hand, perceive information available in their environment, but on the other hand they also act in their environment and thereby change the information they can perceive (J. J. Gibson, 1979; E. J. Gibson & Pick, 2000; Thelen & Smith, 1994). In line with this idea, Hockema and Smith (2009) describe development as consisting of recurrent outside-in processes (children perceive information from the environment) and inside-out processes (children acting in the environment). For example, when children encounter toys, such as the nesting cups shown in Figure 1.1, they can see the toys and thus see their colors, edges, surfaces, shapes and textures, they can touch the toys and thus feel their textures, edges and shapes, they can pick up the toys and feel their weights relative to their own muscular strength, they can turn them around and perceive them from a different perspective, they can put them into their mouth and feel the fine-grained textures with their tongue, and they can bang them against the floor and listen to the sounds they make. All these activities involve outside-in processes as children receive visual, auditory and haptic information, *and* inside-out processes as children perform specific actions on the objects that generate new information to be perceived.

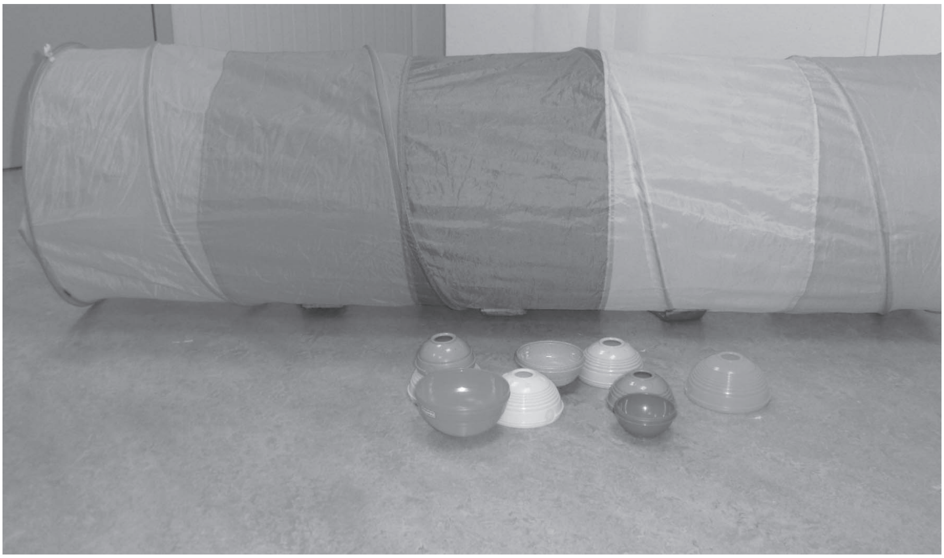

Figure 1.1 Example of toys

A key concept of the ecological embodied cognition approach is the concept of affordances, defined as the possibilities for action children have in their environment. Affordances are specified by both the physical properties of the environment relative to the properties of the child (such as weight, posture and neuro-muscular possibilities) and as such they imply complementarity of the child and the environment (J. J. Gibson, 1979). In the course of development children learn about affordances and develop the skills to recognize them and act upon them (E. J. Gibson, 1988). The attainment of motor milestones fundamentally changes the ways in which children perceive their world (outside-in process) *and* the ways in which they can act in the world (inside-out process). The central tenet of the current dissertation is that attaining particular motor milestones fundamentally changes the affordances children have and thus opens new learning opportunities. For example, the tunnel shown in Figure 1.1 is hollow inside and offers the affordance of crawling through it, and the opportunity to learn about spatial concepts such as *in* and *through*, but only for children who can already crawl. Following this, the first main hypothesis of the current dissertation is that attaining motor milestones, in particular sitting and walking, propels the development of spatial cognition and language.

The continuous perception-action cycles, or inside-out and outside-in processes, are the basis of the development of advanced cognitive-linguistic skills. What seem to be higher-level concepts, such as children's understanding of gravity and object permanence, are in fact concepts grounded in real life physical experiences. For example, children learn through repeated throwing of objects that, once you let go of an object, it will fall. They learn that, when you crawl behind the sofa, you cannot see mummy anymore, but when you crawl back, you can see her again. Similarly, when you put a toy in a box and close the lid, you cannot see the toy anymore, but once you open the lid, the toy is visible again. Thus, the knowledge that objects can fall and that objects continue to exist even if you don't see them, does not reside in the child's mind but rather is present in the world. Through interaction with the environment children discover the invariants of falling down and permanently existing across various situations and types of objects, leading to the emergence of knowledge of such seemingly abstract concepts as gravity and object permanence (E. J. Gibson & Pick, 2000; Thelen & Smith, 1994). These early experiences in the world lay the foundations for the development of advanced cognitive and linguistic skills later in childhood (Smith, Thelen, Titzer, & McLin, 1999; Smith & Gasser, 2005). In James Gibson's (1979) words, *knowledge* is the extension of direct perception as children learn to extract what is invariant from the constantly varying information they directly perceive.

In the ecological embodied cognition approach, children's exploration of the world has a special status. Through engaging in exploration children discover the affordances in their environment (E. J. Gibson, 1988). The new information obtained through exploration supports further cognitive development. In many ways exploration is the driving force of development (Adolph, Eppler, Marin, Weise, & Wechsler Clearfield, 2000; Smith & Gasser, 2005). When children attain a particular motor milestone, their exploration possibilities change (Soska & Adolph, 2014) and the change in exploration, in turn, contributes to their cognitive and linguistic development (Smith & Gasser, 2005). The second main hypothesis of the current study, therefore, is that exploration behavior mediates the relationships between attainment of motor milestones and cognitive-linguistic development.

In this dissertation, we focused on two forms of exploration that are related to the attainment of sitting and walking respectively, namely exploration of spatial-relational object properties such as the possibility of containing, stacking, ordering and so forth, and exploration of the larger space using self-locomotion. As these types of exploration are specifically related to the exploration of spatial relations between objects and of the wider layout of the space in which children move, they were hypothesized to be especially important for the development of *spatial* cognition and *spatial* language. In the following section we further describe these skills and their importance for further development and discuss how they are viewed from an embodied cognition perspective.

Spatial Cognition and Spatial Language

Spatial cognition is the ability to discover, process, and act upon spatial information (Landau, 2002). The broad domain of spatial cognition can be divided into several subdomains such as navigating through space, spatial processing (including mental rotation), and spatial memory. Most studies with young children have focused on spatial memory (often measured by the skill children show in retrieving objects that were hidden in sight of the child) and spatial processing (often measured with tasks involving mental rotation; Newcombe, 2002). Within the first years of life these skills show significant development (for examples, see Pelphrey et al., 2004; Pickering, 2001; Schwarzer et al., 2013). Spatial skills such as navigation are important for everyday functioning. However, spatial skills are also important for academic attainment in subjects such as science, mathematics, and language, as well as for complex social skills. For example, understanding of geometry requires knowledge of spatial concepts such as angle, line and surface. Similarly, recent research has shown that in order to understand how another person perceives a situation or reasons about it, one first needs to be able to take the other person's perspective in a literal sense (as a location in space) to become able to do so mentally (Creem-Regehr, Gagnon, Geuss, & Stefanucci, 2013; Landau & Hoffman, 2005; Newcombe, Uttal, & Sauter, 2013).

Within the domain of spatial skills, spatial language refers to the ability to comprehend and communicate about spatial information (Landau & Jackendoff, 1993). In the present study, we focused on a subset of Dutch spatial vocabulary, namely locative prepositions (such as *in, on, behind* and *between*), and verbs describing movement in a specific direction (such as *push, pull* and *climb*). While embodied sensorimotor knowledge of the concepts these words represent can already be found in infants younger than one year, direct (expressive) knowledge of spatial vocabulary is usually not demonstrated before the third year of life (Pruden, Hirsh-Pasek, Maguire, & Meyer, 2004). Spatial language is important for many aspects of communication and cognition. For example, according to influential theories, when listening to spoken discourse or reading a text, people create a so-called 'situation model' of the text in order to understand it. Spatial language plays an important role in the construction of the situation model and, therefore, is important for language comprehension (Kintsch, 2004; Wallentin, Ostergaard, Lund, Ostergaard, & Roepstorff, 2005). Moreover it has been suggested that once spatial language is acquired, it is important for the (re)structuring of spatial cognition. Indeed, studies show that correct production of spatial language is related to faster and more effective spatial processing (Hermer-Vazquez, Moffet, & Munkholm, 2001; Levinson, Kita, Haun, & Rasch, 2002; Pruden, Levine, & Huttenlocher, 2011).

In an embodied cognition view on development, both spatial cognition and spatial language are presupposed to be grounded in real-time body-environment interactions (just like any other form of cognition). Knowledge is not 'in' the child's mind or brain. Knowledge exists in the interaction between child and environment, and the knowledge and skills children show are variable and critically dependent on characteristics of the situation. Children may perform well on a task measuring spatial memory, but minor changes in the task or situation, for example when children have to search for a hidden object while standing in one condition and sitting in another condition, can dramatically alter children's performance (Thelen, Schöner, Scheier, & Smith, 2001).

A vivid demonstration of these notions is provided by studies into children's performance on the famous Piagetian A-not-B task, which is supposed to measure children's mastery of the concept of object permanence, a central concept in Piaget's theory of cognitive development. In this task, children attentively watch how an object is hidden by the experimenter at one of two identical locations (the A-location, which can be a hole in the table surface or a cloth under which the object is hidden) and then asked to search for the hidden object. From about age seven months children are able to find the hidden object at the A-location. The hiding and searching in the A-location is repeated several times. After children have found the object hidden at the A-location on several consecutive trials, the experimenter hides the object at location B, again while the child is attentively watching. Children who make the A-not-B error, continue to search for the object at the A-location, even though they have seen the object being hidden at the B-location. In the original version of the task, most children between ages seven and 12 months still make this error. From about age 12 months, searching becomes more robust and accurate, even when the object is hidden at the B-location. The A-not-B error has long been seen as indicating that children younger than 12 months do not yet know that objects continue to exist even though they are out of sight. According to the embodied cognition approach, however, the error is not about possessing the concept of object permanence or not, rather the error stems from properties of the sensorimotor memory, which is biased towards searching at the A-location due to the repeated reaching and grasping of the object at the A-location. Several variations of the A-not-B task have been studied, yielding different results, with children of the same age showing sometimes object permanence, but sometimes not. For example, when locations A and B are further apart, when the background is not neutral-gray but has patterns, or when the number of repetitions of hiding and searching at the A-location is smaller (creating a less strong motor memory trace), children are more likely to search at the right location B. Taken together, these results suggest that the concept of object permanence depends on the interplay of motor memory, perception and situation characteristics, fully in line with the ecological embodied cognition approach (Smith et al., 1999; Smith, 2009; Thelen et al., 2001).

A second example comes from language learning. Research has shown that when acquiring semantic categories, children use salient physical regularities, or invariants, such as the roundness of balls, of several objects that otherwise differ, to form categories (Samuelson & Smith, 2005). Children are also found to create such regularities themselves by sorting similar objects together and making easy visually recognizable groups, thereby further advancing their language learning. In this sense, semantic categories are not abstract but rather grounded in perceivable structures embedded in real world experiences (for a review, see Hockema & Smith, 2009; Sheya & Smith, 2011).

Exploration and Motor Development

Exploration is hypothesized to be one of the main mechanisms mediating the relations between motor milestone attainment and cognitive-linguistic development. Through exploration children learn about the affordances in their environment and develop the skill to act upon these affordances. In this dissertation, we focused specifically on spatial affordances. Learning about spatial affordances and developing the skill to act upon spatial affordances was hypothesized to underlie the development of spatial cognition, including spatial memory, spatial processing and spatial language. In addition, it was assumed that spatial affordances are specifically learnt through exploration of the spatial-relational properties of objects (such as the possibility of containing and stacking) and through the exploration of the larger space by self-locomotion (E. J. Gibson, 1988; Smith & Gasser, 2005).

Two motor milestones were thought to be especially important for the two forms of exploration that are the main focus of this dissertation, namely unsupported sitting and independent walking. When children learn to sit without needing to use their hands for support, their hands are free to grasp and manipulate objects and to explore their properties in a variety of ways, including properties that can be used to relate objects spatially (Rochat & Goubet, 1995). Attainment of walking enables children to change their location in space and therefore their perspective through self-movement. By experiencing the time-locked correlations between their own movement and the changing perception of the situation, children learn about spatial relations (Campos et al., 2000; E. J. Gibson & Pick, 2000; Thelen & Smith, 1994). Walking is different from other forms of self-locomotion such as crawling in that the upright posture enables children to easily keep track of, for example, the target in space towards which they are moving. Recent research shows that, unlike walking infants, crawling infants usually look at the floor while moving forward (Kretch, Franchak, Brothers, & Adolph, 2012). Walking also enables children, more than crawling, to carry objects from one location to another and thus to manipulate the spatial arrangement of the environment (Karasik et al., 2012). Several studies have found support for a relationship between motor development and exploration, on the one hand, and for a relationship between exploration and cognitive development, on the other hand (Needham, Barrett, & Peterman, 2002; Soska, Adolph, & Johnson, 2010; Soska & Adolph, 2014). However, to the best of our knowledge, a complete mediation model, with exploration mediating the relationships between motor development and cognitive development, has not yet been tested. Moreover, as most studies examined the relations between these variables within a relatively short period of time, evidence for medium, to long-term effects is lacking.

To summarize the main hypotheses of the current dissertation, (1) we expected that an earlier age of sitting and walking predicts better spatial cognition and a higher level of general and spatial language skills in the short and long term, and (2) that children's engagement in spatial exploration mediates these effects. In addition, as exploration is the main mediating mechanism studied in this dissertation, we also examined the development of exploration in the second and third years of life. Most studies to date (e.g., Galloway & Thelen, 2004; Soska et al., 2010) have focused on development of exploration in the first year of life and usually did not specifically examine exploration of spatial properties.

This Dissertation

In this dissertation four studies are reported that explore the links between motor development, exploration and cognitive-linguistic development. In Chapter 2, a study is reported that examines the medium to long-term effects of motor milestone attainment and spatial exploration in infancy and early toddlerhood on spatial memory at ages four and six years, using regression analysis. In Chapter 3, the relations of the attainment of unsupported sitting and independent walking with the development of productive vocabulary between ages 16 and 28 months are investigated, using latent growth modelling. In Chapter 4, a study is described which takes a closer look at the development of spatial exploration. Whereas in the study of Chapter 2 a retrospective measure of spatial exploration is used, Chapter 4 reports on direct observations of children's exploration behavior over time. Exploration development is modelled in an innovative way, using Item Response Theory in combination with latent growth modeling, in line with the theoretical notions leading this dissertation. The study reported in Chapter 5 examines the specific relations between motor development, exploration, spatial cognition and spatial language development. A mediation model is evaluated, using regression analysis and structural equations modelling, to test whether exploration indeed mediates the effects of motor milestones attainment on spatial cognition and spatial language. In Chapter 6 the results described in this dissertation are integrated and discussed, and directions for future studies are suggested.

The Current Samples

The studies in this dissertation used data from two samples. The first sample, reported on in Chapter 2, was part of a larger longitudinal study into language development as related to language exposure at home (Scheele, Leseman, & Mayo, 2010). This sample included 51 native Dutch children taking part in two measurement moments at ages four and six years. Information about attainment of motor milestones and exploration during infancy for this sample was obtained using retrospective reports by the parents. The sample involved in the studies reported in the Chapters 3, 4 and 5 consisted of two age-cohorts with 62 native Dutch-speaking children in all. The two age-cohorts took part in five measurement moments, with two overlapping measurements, and were analyzed following a cohort-sequential design. The 30 children belonging to the younger cohort were followed from age nine months to age 24 months and the 32 children belonging to the older cohort were followed from age 20 months to age 36 month. The two overlapping measurement moments took place at ages 20 and 24 months. See Figure 1.2 for a graphical display of the sample and a specification of the data that was used in the different studies reported in this dissertation.

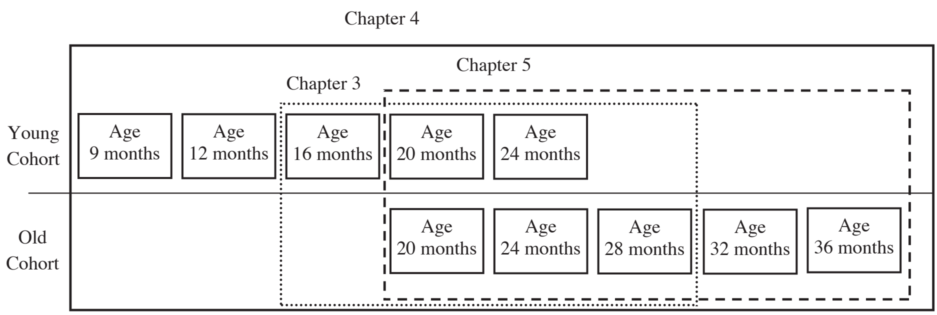

Figure 1.2. Cohort-sequential design of the current study, and division of data and corresponding chapters.

Chapter 2

Can infant self-locomotion and spatial exploration predict spatial memory at school age?

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Abstract

According to an embodied view of development sensorimotor activity plays a central role in cognitive development. Following this idea, we studied whether the age of achieving self-locomotion milestones and spatial exploration during the first years of life predict spatial memory at (pre)school age. Spatial memory was assessed in 51 children at ages four and six years. Parents reported retrospectively about ages of attainment of self-locomotion milestones and about the children's spatial exploration behavior during infancy and early toddlerhood. Results show that spatial exploration positively predicts spatial memory at both ages. The age of attainment of self-locomotion does not predict spatial memory at ages four and six. These findings extend previous work that showed a relation between exploration and spatial cognition over a short period of time. Results provide preliminary support to the hypothesis, suggesting that spatial exploration predicts spatial memory also over longer periods of time.

Introduction

According to an embodied view of development, movement and motor control are important for cognitive development. Cognition is thought to *emerge* in the real-time interactions between a person's *physical* body and a *physical* world (Smith, 2005). Children do not merely passively perceive information (that in a mysterious way "triggers" cognition), but they act upon their environment and thereby influence the sensory information they receive and what they can learn from it. By doing so, children learn increasingly more about the world (Sheya & Smith, 2011; Thelen, 2000a; Thelen, 2000b). Therefore, a relation between children's actions on the world and their cognitive development can be expected. Following these ideas, the current study conducted a preliminary investigation of these relations over time and examined to what extent motor development and spatial exploration during infancy predict spatial memory at (pre)school age.

Children are thought to learn through active interaction with (or exploration of) their environment. Through acting on their environment, children discover perceptual correlations and invariants, which are important for developing their cognition. They may, for example, discover that a mobile moves when they kick their legs against it, and therefore will increase their pace of kicking to make the mobile move faster. By doing so, infants discover the time-locked correlation between their own movement patterns and the movement patterns of the mobile (Smith & Gasser, 2005).

The attainment of self-locomotion dramatically changes infants' view on the world and widens their exploration scope to include the larger space around them. The ability to move over, by, into, and around objects expands the perceptual information infants can attend to. This new information draws their attention to spatial relationships between objects, themselves and the environment and enables infants to notice the variant and invariant aspects of the environment (e.g., you can push a chair forward but not a wall). Infants use these new cognitions to form spatial concepts (Sheya & Smith, 2011). Moreover, infants are increasingly able to modify spatial relations in their environment. Movement through the larger space and modifying spatial aspects of the environment, are referred to as *spatial* exploration. This kind of exploration is important for advances in spatial cognition as children attend to spatial aspects of the environment (Campos et al., 2000; E. J. Gibson, 1988). Thus, self-locomotion and spatial exploration are thought to be especially important for advances in spatial cognition.

To date, a number of studies have examined this topic suggesting that the onset of self-locomotion is consistently related to advances in spatial cognition over a short period of time. For example, infants aged 8-14 months with over six weeks experience with self-locomotion were more successful at searching for hidden toys in a large space than infants with less experience with self-locomotion (Clearfield, 2004). Various studies have shown that success in the A-not-B spatial-search task, where children have to find an object hidden in one of two identical locations, is obtained around 12 months and is strongly linked to the onset of self-locomotion (for a review see: Sheya & Smith, 2011; Thelen, Schöner, Scheier, & Smith, 2001). Similarly, success in a spatial-search task was related to the onset of self-locomotion in a group of 8 to 14-month-old infants suffering from Spina Bifida, both close to the age of onset and within two months of the onset of self-locomotion (Campos, Anderson, & Telzrow, 2009). Finally, nine-month-old infants who could crawl for at least two weeks were better at a mental rotation task than same-age non-crawling children (Schwarzer, Freitag, Buckel, & Lofruthe, 2013).

A number of studies demonstrated the importance of experience with exploration for cognitive advances. Soska, Adolph and Johnson (2010) showed that infants who were more experienced with visual-manual exploration of objects were more able to perceive an object as a complete 3D volume, despite seeing it only from a limited 2D viewpoint. Moreover, a number of studies with infants have demonstrated the importance of having actual *experience* with self-locomotion for advances in spatial cognition (for a review see: Campos et al., 2000; Clearfield, 2004). Similarly, primary-school children who were allowed to *actively* move through a space were better at spatial-search tasks than children who were pushed in a wheelchair through the same space (e.g., McComas & Dulberg, 1997).

Thus self-locomotion and spatial exploration appear to be important for the development of spatial cognition, at least within a relatively short period of time. The question remains, whether these effects are also visible over a longer period of time. Only a handful of longitudinal studies investigated similar relations. The trajectories of gross motor development during the first four years of life were found to positively predict performance on an intelligence test at school age (Piek, Dawson, Smith, & Gasson, 2008). Furthermore, the age of achieving self-locomotion was found to predict visual memory far into adulthood (Murray, Jones et al., 2006). To sum up, although theoretical notions suggest a *long-term* longitudinal relationship between self-locomotion, spatial exploration and spatial cognition, evidence is still limited. The current study, therefore, aims to provide further support for these ideas by utilizing data from an existing longitudinal study. The main question addressed was whether the age of attaining self-locomotion and spatial exploration during infancy can predict spatial memory at (pre) school age (ages four and six years).

Children's spatial memory was tested at two measurement occasions (ages four and six years). In addition, retrospective parental reports of the age of reaching self-locomotion milestones and spatial exploration were obtained. General fluid intelligence was used as a control variable in order to establish whether effects were specific to spatial abilities. Furthermore, characteristics such as the family's socioeconomic status (SES) and the child's gender have often been mentioned as predictors of spatial ability (e.g., Hart, Petrill, Deater Deckard, & Thompson, 2007; Spetch & Parent, 2006) and, therefore, were included as control variables.

The use of retrospective measures is not unproblematic as parents' memories may be distorted or influenced by concurrent child behavior. As the present study did not allow for a direct test of the reliability of parents' retrospective reports, data from an ongoing second study in a comparable sample were used to relate concurrent parent reports on children's early exploration behavior to retrospective parent reports, obtained several years later, on the same behavior.

Method

Participants

The data came from a subsample of Dutch children from a longitudinal study on early language development as related to language exposure at home (Scheele, Leseman, & Mayo, 2010). The sample included 51children (49% girls) growing-up in families with varied socioeconomic backgrounds (as measured by the level of parental education and occupation). The children were recruited using addresses made available by two middle-sized municipalities. Children with diagnosed developmental delays were excluded. The positive response rate was 65%. The current study used data from two measurement occasions: when children were about four years of age (*M* = 51.20 months, *SD* = 1.13) and when children were about six years of age (*M* = 71.17 months *SD* = 0.83). The children come from families with on average 2.10 children (*SD* = .69) and 62.8 % of the children were first born. Missing data regarding early sensorimotor development and exploration (about 8% data missing at random) were imputed using Relative Mean Substitution (Raaijmakers, 1999) and Multiple Imputation (Schafer & Graham, 2002).

Procedure

Information on reaching motor milestones and exploration in infancy was obtained through a structured personal interview with the main caregiver of the child (in this study always the mother) conducted by trained research assistants. Information about spatial memory and fluid intelligence was obtained by tests administered to the children at home by trained research assistants. Tests were administered in a fixed order using laptop computers. The children received a sticker after each test and the families were rewarded with a gift voucher of €10 and a small present for the children.

Measures

Age of achieving self-locomotion milestones

During the second measurement wave, the parents reported retrospectively about the age in months at which their children reached four developmental milestones related to self-locomotion: belly crawl (either with only arms and elbow moving or with both arms and legs moving and belly on the floor almost all the time), scooting or bottom shuffling (sitting right up and sliding forward), hands and knees crawl (using only hands and knees for support and the back is straight), walking unsupported (at least one step with each foot unsupported by an adult or by objects) and climbing stairs (moving up the stairs either by hands and knees crawl or by walking; Bodnarchuk & Eaton, 2004). Infant and toddler health clinics in the Netherlands provide parents with a log-book in which every 6 months growth measures and developmental milestones are registered. Parents were asked to use this log-book during the interview. A scale was constructed by calculating the mean of the reported ages. A small number of children were reported to have skipped the milestones of belly crawl and/or hands and knees crawl, and most children did not engage in scooting. For these children the composite score was computed using the mean of the ages of the milestones they did achieve.

Spatial exploration

The parents reported retrospectively about the engagement of their child in self-locomotion and spatial exploration play during the first two years of life, and about their housing conditions at that time, focusing on the opportunities for children to move around in their immediate environment. Together these reports were considered to give an indication of two components of spatial exploration, namely movement in space and exploration of spatial relations. A detailed description of all three subscales is given below and a test of the reliability of these measures is also described at the end of the method section. A composite score on this variable was calculated using the mean of the scores on all three subscales after *Z*-transformations were applied.

Frequency of self-locomotion

Parents were asked to rate the engagement of their children in four self-locomotion activities, namely belly crawling, crawling on hands and knees, unsupported walking and climbing stairs, relative to same-aged peers up to age two years. Answers were rated on a five-point Likert-type scale ranging from "much less frequently" to "much more frequently". A composite score was computed by calculating the mean of the four items. Cronbach's alpha for this scale was .75.

Spatial play

Parents were asked to rate the frequency with which their children engaged in five activities considered spatial play, allowing exploration of spatial relations such as *on* or *in* during the first two years of life. The activities included: playing with toys that can be stacked or nested (e.g., nesting cups or blocks); stacking objects; putting things together and taking them apart (e.g., building with Duplo® blocks); line up objects or toys; and spatially sorting objects. Answers about frequency of playing with blocks were given on a five-point Likert-type scale ranging from "much less frequently" to "much more frequently" than same-aged peers. Answers to the other questions were given on a three-point Likert-type scale ranging from never to daily. As items were scored on different scales, a composite score was computed by calculating the mean of the *Z*-transformations of the five items. Cronbach's alpha for this scale was .80.

Housing conditions

The parents reported whether three different features (having a garden, having stairs, and blocking the stairs with a gate) were present in their house when the children were two years or younger. These reports were used to assess the opportunities the child had for engaging in self-locomotion and spatial exploration. For example, a house with a garden was considered to enable self-locomotion and spatial exploration more than an apartment without a garden.

A score of two was given to conditions enabling self-locomotion and spatial exploration and a score of one to conditions limiting these behaviors. A composite score was computed by calculating the mean of the items. While these housing conditions are all related to opportunities for self-locomotion and spatial exploration, they are not necessarily inter-correlated leading to high internal consistency nor do they represent a homogenous underlying trait. Therefore, no Cronbach's alpha was computed for this scale.

Spatial memory

Children's spatial memory was assessed at ages four and six, using the dot matrix task from the Dutch version of the Automated Working Memory Assessment (AWMA; Alloway, 2007). Children were asked to remember the locations of a previously presented dot in a series of 4x4 matrices presented on a laptop screen. The number of locations gradually increased. Test-retest reliability of this task was .83 (Alloway, Gathercole, & Pickering, 2006).

Fluid intelligence

Raven's Colored Progressive Matrices (CPM; Raven, 1995) was administered at age four to measure nonverbal fluid intelligence. The test consists of 36 matching exercises in which the child is presented with a pattern and has to choose, out of six possible pieces, the piece which best completes the pattern. Each correct answer received a score of 1, yielding a total score between 0 and 36. The CPM has been found to have good reliability and validity (Raven, 1995).

Reliability of Retrospective Reports

To test whether retrospective reports on children's early play and exploration can be regarded as reliable, parents of 33 children (55% girls) between four and five years of age with similar socioeconomic backgrounds to the participants of the current study, participating in a second study were asked to answer retrospective questions (Oudgenoeg-Paz, Volman, & Leseman, 2012). These questions were identical in format and highly similar in content to the questions used in the present study (e.g., "How often did child play with blocks/ line up toys"). In a previous stage of the second study, when the children were aged between 20 and 24 months, these parents had kept detailed weekly logs of the child's spatial exploratory play for about 18 weeks, using pre-structured report categories similar to the retrospective questionnaire items of both the present and the second study (e.g., "child played with blocks/ stacked blocks"). Although measurement methods (weekly log vs. general questionnaire) and type of data (e.g., summary of scores for multiple days and weeks vs. assessment of overall frequency on Likert-scales) differed between the concurrent and retrospective report, and although the time that elapsed between log and retrospective report was two to three years (similar to the main study), Spearman correlations between the eight retrospective measures and corresponding concurrent variables based on the logs ranged between $r = .29$ and $r = .49$ (all ps < .10; all but two $p < .05$), suggesting satisfactory reliability.

In addition, data from the present study were used to determine correlations between parents' retrospective reports on children's play behavior at young age and reports on their current play behavior at age six. Spearman correlations were small to moderate, ranging from r =-.11 to r = .38 (only half of the coefficients were significant at $p < .05$), suggesting moderate developmental stability (e.g., J. S. Cohen & Mendez, 2009), but no strong confounding of parents' evaluation of the child's current play behavior and their retrospective report.

Analysis

Two multiple regression analyses were conducted to test whether the age of achieving self-locomotion milestones and the degree of spatial exploration predicted spatial memory at ages four and six years respectively, while controlling for fluid intelligence. The two other control variables (SES and gender) showed no relation with spatial memory and, therefore, were not included in the final analyses.

Results

Descriptive Analysis

Table 2.1 presents the means and standard deviations for all variables included in the analyses. The raw scores show that the children's spatial memory capacity increased from age four to six. This growth was statistically significant and had a large effect size ($t(50) = 4.5$, $p < .001$, $d = 1.27$).

Table 2.1 Means and standard deviations for model variables (N=51)

	Time 0[a]		Time 1[a]		Time 2[a]	
Variable	***M***	***SD***	***M***	***SD***	***M***	***SD***
Self-locomotion milestones	12.51	2.24				
Spatial exploration [b]						
Housing conditions	1.85	.25				
Frequency of self-locomotion	3.13	.56				
Frequency of spatial play [c]	.00	.74				
Spatial memory			9.98	3.40	12.49	4.23
Fluid intelligence			14.14	3.72		

Note .[a] Time 0 refers to infancy and early toddlerhood; Time 1 and Time 2 refer to the first and second measurement occasions respectively. [b] Here means and SD of the raw scores of the subscales are given. For each subscale a Z-transformation was computed and the total score is the mean of all three Z-transformations ($M = .00$, $SD = .60$). [c] This total score is the mean of the Z-transformations of the five individual items composing this subscale.

Table 2.2 Correlations table for model variables (N=51)

		1	2	3	4	5
1.	Self-locomotion milestones					
2.	Spatial exploration (infancy)	-.32*				
3.	Spatial memory age four	-.06	.28*			
4.	Spatial memory age six	-.11	.45**	.47***		
5.	Fluid intelligence (age four)	-.09	.22	.22	.29*	
6.	SES	.33*	.15	.18	.07	.46**

Note. *** $p < .001$ ** $p < .01$ * $p < .05$ † $p < .10$

The inter-correlations of all variables used in the final analyses are presented in Table 2.2. Spatial memory scores at ages four and six were moderately inter-correlated as was expected. The mean age of achieving self-locomotion milestones moderately correlated with SES, suggesting that children from families with lower SES achieved these milestones earlier, a finding reported before in the literature (Venetsanou & Kambas, 2010). Furthermore, Table 2.2 reveals a number of other interesting trends. The age of achieving self-locomotion milestones correlated negatively with spatial exploration, suggesting that children who achieved the milestones earlier explored more. SES did not correlate with spatial memory at age four nor at age six. Further analysis using *t*-tests revealed that there were no gender differences in spatial memory at neither age four ($t(49) = .94$, $p = .35$) nor age six ($t(49) = -1.11$, $p = .27$). Therefore both SES and gender were not included in the main analyses as control variables. Fluid intelligence correlated moderately with spatial memory at age six. The correlation between fluid intelligence and spatial memory at age four shows a trend supporting a positive link ($p = .12$). Finally, spatial memory was significantly correlated with the degree of exploration but not with the age of reaching self-locomotion milestones.

Main Analysis

To answer the research questions, two multiple regression analyses were conducted with the age of achieving self-locomotion milestones, degree of spatial exploration in infancy and early toddlerhood, and fluid intelligence as independent variables, and spatial memory at the ages of four and six years respectively as the dependent variables. The results are presented in Table 2.3.

Table 2.3 shows that spatial exploration is a marginally significant predictor of spatial memory at age four. Given the relatively small sample size, this can be considered a trend. Thus children who engaged in more spatial exploration during infancy had a marginally significant higher level of spatial memory at age four. This effect is medium sized (see J. Cohen, 1988). The age of achieving self-locomotion milestones, was not a significant predictor of spatial memory at that age.

Table 2.3 Summary of regression analysis for variables predicting spatial memory at ages four and six (N=51)

	R^2	*B*	*SE B*	*β*	*90% CI*
Predictors of Spatial memory age 4	.11				
Age of reaching self-locomotion milestones		.06	.22	.04	[-.32, .43]
Spatial exploration		1.41	.82	.26†	[.03, 2.80]
Fluid intelligence		.16	.13	.17	[-.06, .37]
Predictors of Spatial memory at age 6	.24				
Age of reaching self-locomotion milestones		.08	.25	.04	[-.35, .50]
Spatial exploration		2.88	.95	.42**	[1.29, 4.46]
Fluid intelligence		.23	.15	.20	[-.02, .48]

Note. *** p <.001 ** p <.01 * p <.05 † p <.10

Spatial exploration was also a significant predictor of spatial memory at age six, while the age of achieving self-locomotion milestones was not. Children who engaged more in spatial exploration during infancy and early toddlerhood had a higher level of spatial memory, with a large effect size. Thus, spatial exploration, but not the age of achieving self-locomotion milestones, positively predicted spatial memory at the ages of four and six years, while controlling for fluid intelligence. The effect of spatial exploration at age six appears larger than at age four. However, note that the 90%-confidence intervals of both regression coefficients overlap considerably, suggesting that the difference is not statistically significant.

Discussion

The objective of the current study was to examine whether the ages of achieving self-locomotion milestones and the degree of spatial exploration during infancy and early toddlerhood positively predict spatial memory at (pre)school age. Hypotheses about this relationship were derived from theoretical notions attributing a central role to sensorimotor activity in cognitive development (Smith, 2005; Thelen, 2000b). We expected to find that the age of achieving self-locomotion milestones and the level of spatial exploration during infancy and early toddlerhood would positively predict spatial memory a few years later, at (pre)school age. The results provide partial support for the hypotheses. We did not find support for our hypothesis suggesting that the age of attaining self-locomotion predicts spatial memory at school age. However, we did find initial support for our second hypothesis and could show that early spatial exploration positively predicts spatial memory at (pre)school age.

Contrary to our hypothesis, we did not find a direct effect of the age of achieving self-locomotion milestones on spatial memory. A possible explanation is that the age of attaining self-locomotion may be important for early spatial cognition, but the effects in the middle to long-term are indirect and mediated by exploration. The importance of early self-locomotion might mainly be that it enables children to engage in spatial exploration. Therefore, at a younger age, closer to the onset of self-locomotion, there might be an effect visible (this idea is also supported by the correlation we found between the age of achieving self-locomotion milestones and spatial exploration). However, with increasing age, the amount of experience with spatial exploration will be less dependent on the age of reaching self-locomotion and therefore, over time, experience with spatial exploration may become the most important factor. Longitudinal work following infants from a young age is needed in order to test this hypothesis.

Extending previous work (e.g., Campos et al., 2000; Clearfield, 2004) showing that self-locomotion and spatial exploration are positively related to advances in spatial cognition within a relatively short period of time, the current study provides evidence that this relation also exists over a longer period of time. Our results provide support for the hypothesis that spatial exploration positively predicts spatial memory at (pre)school age. Furthermore, by controlling for fluid intelligence, we provide evidence that this relation cannot be fully attributed to a shared underlying general cognitive ability. The details and especially the dynamics of this relation still require further investigation. Future studies should test dynamic models taking into account factors that might mediate this relation.

It is not clear from our results if the difference between the effects of spatial exploration on spatial memory at ages four and six is a real difference. On the one hand it could be that early experience with spatial exploration sets in motion a cascade of effects, which result in better spatial cognition over time. As these effects take time to accumulate, the effect at age six might be larger than the effect at age four. However, it is also possible that the difference is due to measurement issues. The instrument used to measure spatial memory was developed for children aged 4-11. Although no floor effect was visible at age four, the variance may be more restricted due to the young age of the children. Further work is needed to clarify this issue.

Several studies have reported that boys perform better than girls on spatial tasks (e.g., Spetch & Parent, 2006). We did not find such gender differences. While some researchers argue that gender differences in spatial ability are only detectable from age 10 onwards, others provide evidence for gender differences in children as young as three years (Levine, Vasilyeva, Lourenco, Newcombe, & Huttenlocher, 2005). Furthermore, several studies suggest that unlike other spatial abilities, there are no gender differences in spatial memory (e.g., Alloway et al., 2006). The same has been suggested with regard to the relation between SES and spatial memory (Noble, Norman, & Farah, 2005). Thus the age of the children and the measures used might explain the lack of relation with SES and gender. Further research is needed on this matter.

The current study suffered from a number of limitations. First, the sample size was rather small. However, as we expected medium to large effects, our design had sufficient statistical power. Second, only retrospective reports of the age of achieving self-locomotion milestones and children's early spatial exploration were available. Note that with respect to the self-locomotion milestones parents were encouraged to use the log-books of the infant and toddler health clinic. Previous empirical work has shown that motor development can be reliably reported retrospectively, especially when parents have memory aids (Langendonk et al., 2007). With respect to children's early spatial exploration play parents had to rely on their memory. Data from a second study were used to examine whether parents are indeed able to reliably report on children's play behavior several years earlier; the results were satisfactory. In addition, no confounding between parents' retrospective reports and the child's current behavior was apparent. Moreover, the use of retrospective reports on children's behavior has been proven to be valid and reliable in several related fields of study, such as social-emotional development (Wolke, Rizzo, & Woods, 2002) communicative development, play behavior and emerging symptoms of autism spectrum disorders (e.g., Clifford & Dissanayake, 2008). However, bias in the retrospective reports cannot be ruled out completely and prospective studies using concurrent measures of children's spatial exploratory behavior are clearly to be preferred. Nonetheless, when prospective data are not available, retrospective reports are an acceptable alternative.

Finally, due to the fact that we could only measure exploration retrospectively, we could only obtain a rough indication of the amount of spatial exploration in infancy and early toddlerhood. Future studies that study infants' exploration behavior directly will yield more detailed information and allow for fine-grained analysis of the different components of exploration behavior. Given the shortcomings of the current study, the results need to be replicated. However, the present results do provide important insights into the middle to long-term relations between motor development, spatial exploration and spatial memory and suggest new directions for future work.

The current work thus provides initial support for the idea that spatial memory emerges from engagement in spatial exploration. However, the full dynamics of this process still need to be studied in detail. Future research should use longitudinal designs with multiple measurement points following children from infancy to school age, and behavioral observations, yielding in-depth data about developmental processes over multiple timescales. Attention should be paid to the real-time processes taking place during exploration, as well as to the dynamics over time of the relationships between self-locomotion, spatial exploration and spatial memory.

Chapter 3

Attainment of sitting and walking predicts productive vocabulary between ages 16 and 28 months

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Abstract

Recent theories place movement and motor control as central factors in the developmental process and argue that cognition and language develop through active interaction between children and their environment. The attainment of developmental milestones, such as sitting and walking, might play an important role in this process as it dramatically changes the way children interact with their environment. While a few studies have related the attainment of these milestones to cognitive advances, empirical evidence relating these milestones to language is scarce. Therefore, we studied whether the age of achieving unsupported sitting and independent walking predicts overall level and growth in productive vocabulary between the ages of 16 and 28 months. Productive vocabulary was measured in 59 children between the ages of 16 and 28 months. Measurement waves took place every four months. Information on the age of attainment of motor milestones was also obtained. Using a longitudinal cohort-sequential Latent Growth Model, results revealed that an earlier age of attaining unsupported sitting predicted a higher intercept (or overall level) of productive vocabulary and an earlier age of attaining independent walking predicted a larger slope (or growth) of productive language. The attainment of independent walking seems to propel development of productive language between the ages of 16 and 28 months. The effect of unsupported sitting on overall level of productive vocabulary might reflect an earlier effect on growth. The results are in line with the notion of motor milestones being an important driving force in linguistic development.

Introduction

Motor and language development might be considered two distinct domains. After all what does walking have to do with talking? However, current theories link the two areas of development and place movement and motor control as central factors in the developmental process. The topic of movement and motor control is a neglected topic in developmental psychology and some even refer to it as the 'Cinderella' of (developmental) psychology (Iverson, 2010; Rosenbaum, 2005). Still, in recent years, interest in studying cognitive development in the context of sensorimotor activity is increasing (e.g., Adolph, Tamis-Lemonda, & Karasik, 2010; Sheya & Smith, 2011; Smith & Gasser, 2005; Thelen, 2000b). The current study followed this impetus and examined the relation between the age of attainment of two central developmental motor milestones and the development of productive vocabulary between the ages of 16 and 28 months.

The centrality of sensorimotor activity in development is a core hypothesis in theories such as the embodiment theory. According to this theory, cognition and other aspects of mental life (such as reasoning, emotion and language) *emerge* through interactions between a person's *physical* body and a *physical* world (Smith, 2005). Following ecological approaches, this theory stresses the active role children play in their development. Children act upon their environment and thereby influence the sensory information they receive and what they can learn from it. Through these ongoing perception-action couplings children learn increasingly more about the world (E. J. Gibson, 1994; Hockema & Smith, 2009; Sheya & Smith, 2011; 2005; Thelen, 2000a).

The attainment of sensorimotor milestones plays an important role in this process as it brings about a dramatic change in infants' perception of the world, in the opportunities they have for acting on their environment and in the input they elicit from their environment. For example, a child who gains the ability of engaging in self-produced locomotion experiences changes to vantage resulting in changes to the optic flow and changes to proprioceptive information. In addition, this child also has the ability to reach for and manipulate objects, which were previously out of reach. This child can now also carry objects from one location to another. At the same time this child also sees his or her environment from different angels and hears new linguistic input, such as 'do not crawl to the stairs, you might fall' (Campos et al., 2000; Clearfield, 2011; Gogate & Hollich, 2010; Karasik, Tamis-Lemonda, & Adolph, 2011; Tamis-Lemonda et al., 2008). Walking children are also better able to direct adults' attention to specific objects and are thus more likely to receive linguistic input pertaining to their current focus of attention (Clearfield, 2011). Thus, the attainment of motor milestones brings about changes in infants and in their environment, or put differently, changes in various perception-action systems. These changes open the door to advances in cognition and language (Sheya & Smith, 2011). Therefore the attainment of motor milestones should be an important driving force, propelling cognitive and linguistic development.

In the literature a few central developmental motor milestones have been related to cognitive developmental advances. The achievement of unsupported sitting frees the hands for manual exploration of toys and contributes to improvements in the quality of reaching movements (Rochat & Goubet, 1995). Postural and head control in sitting have also been related to attention in infants born preterm (Tribucci, Penedo-Leme, & Araújo Rodrigues Funayama, 2009; Wijnroks & Van Veldhoven, 2003). Finally, unsupported sitting has been related to better visual-manual exploration skills and success on a 3D completing task, which measures the extent to which infants perceive objects as volumes in 3D space despite the fact that the far sides of the objects are always occluded by the visible portions (Soska, Adolph, & Johnson, 2010).

The ability to engage in self-produced locomotion, which is usually acquired during the first or second year of life when infants begin to crawl or walk, has consistently been related to cognitive development (Campos et al., 2000). Studies have shown for instance that self-locomotion is related to: more effective and correct coding of spatial information (Lehnung et al., 2003; Thelen, Schöner, Scheier, & Smith, 2001); improved performance on a maze task; increased ability to make fine spatial discriminations (Clearfield, 2004); increased effectivity of spatial search; increased awareness of the results of one's own physical actions (Thelen et al., 2001); more effective updating of spatial information (Sheya & Smith, 2011) and various advances in social and emotional development (Campos et al., 2000). More specifically, walking has been related to more advanced forms of objects exploration (Clearfield, 2011; Karasik et al., 2011), success in a means-end task (James, Walle, & Campos, 2011) and various advances in social and emotional development (Clearfield, 2011; Karasik et al., 2011).

Moreover, few longitudinal studies have shown a relation between early motor development and later cognitive abilities at school age (Piek, Dawson, Smith, & Gasson, 2008; Schoon, Cheng, & Jones, 2010) and even into adulthood (Murray, Veijola et al., 2006). However, with regard to the relation with language development, empirical evidence is still scarce. While the theoretical notions discussed in this paper suggest that there should be a relation over time between the attainment of motor milestones and language development, most empirical evidence to date is cross-sectional. Several studies have shown cross-sectional correlations between motor and linguistic abilities in typically developing children (e.g., Alcock & Krawczyk, 2010) as well as in children with various developmental disorders (e.g., Hill, 2001; Müürsepp, Ereline, Gapeyeva, & Pääsuke, 2009).

A few recent studies also provide initial longitudinal evidence for a relation between the attainment of motor milestones and later language. In children with familial risk for dyslexia, slow motor development during the first year of life predicted poorer expressive language at ages three and half and five and half (Viholainen et al., 2006) and a significant delay in the age at which children take their first steps was found to predict lower receptive vocabulary at age four (Schultz & Eaton, 2011).

To sum up, the motor milestones of unsupported sitting and independent walking have been related to various cognitive advances. Based on embodiment theory, we expected attainment of these milestones to also be related to language development in typically developing infants. While a few theoretical papers suggest such a relation (e.g., Hockema & Smith, 2009; Iverson, 2010), developmental evidence in this field is scarce. Therefore, the main goal of the current study was to look at the relation between the age of attainment of the motor milestones of unsupported sitting and independent walking and productive language development. Effects on overall level and rate of growth were both tested. The choice of sitting and walking as the focus of the current study was made because both milestones have been related to cognitive advances (e.g., Clearfield, 2004; Soska et al., 2010) and because it allows us to study one postural control milestone and one self-locomotion milestone. Walking was preferred to crawling as a self-locomotion milestone because not all children engage in crawling. Furthermore, few recent studies indicate that the transition from crawling to walking brings about dramatic changes in infants' physical and social interactions with the environment (Clearfield, 2011; Karasik et al., 2011). However, although crawling will not be included in the main analysis, descriptive analysis regarding the age of crawling will be presented.

The age of attainment of unsupported sitting and independent walking was recorded in 59 healthy infants. Productive vocabularies were measured every four months from age 16 months to age 28 months. All of the hypotheses were tested using Latent Growth Modelling (LGM).

Method

Participants

For the current study we used part of the data of a larger longitudinal study in which children belonging to two age cohorts took part. The children belonging to the younger cohort (*N* = 28, 54% girls) were followed from age 9 to 24 months with measurement waves roughly every four months. The children belonging to the second cohort (*N* = 31, 58% girls) were followed from age 20 to 36 months with measurement waves taking place every four months. Both cohorts took part in five waves in total with two overlapping waves at ages 20 and 24 months. Recruitment to the study took place when the younger children were between the ages of 3 and 9 months and the older children were between the ages of 13 and 20 months.

For the current study data from three waves per cohort was used. For the younger cohort measurement waves conducted at ages 16, 20 and 24 months were used and for the older children waves conducted at ages 20, 24 and 28 months. Thus, data at age 16 months (*M* = 16.18 months, *SD* = .40) and at the age of 28 months (*M* = 28.07 months, *SD* = .40) were available only from the first and second cohort respectively. Data at the age of 20 months (*M* = 20.52 months, *SD* = .54) and the age of 24 months (*M* = 24.35 months, *SD* = .46) were available from both cohorts.

The participants were recruited through day care centers in the municipality of Utrecht (the Netherlands) and its surroundings and through an address list made available by the municipality of Utrecht. Response rate for the parents contacted via the address list was about 24%. However, as these families were selected based solely on the birth date of their children it is likely that at least some of these families did not meet the inclusion criteria for the study. The children were all Dutch speaking and had no serious medical or developmental disorders (as far as known at the time of the beginning of the study when the children were aged 9 or 20 months).

After close examination of the data, the data of four children were removed from the analysis. The first child had been treated for hip dysplasia and while the treatment did not impede her ability to engage in crawling or standing, it did impede her ability to engage in unsupported sitting. The data of the second child was removed as her parents filled in the questionnaires when the child was much older than the requested age (22.4 months instead of 20 months). The other two children had too many missing values on the variables of interest. This resulted in a total sample size of 55 children, divided into 27 (52% girls) in the younger cohort and 28 (57% girls) in the older cohort. Missing data, missing at random (about 2% for age of achieving motor milestones and about 5% for the language data) were imputed using multiple imputation (Schafer & Graham, 2002).

Procedure

The data were collected using parental reports. The questionnaire regarding the attainment of milestones was sent to parents at the time of enrolment to the study, so that they could keep track of their child's attainment of the milestones as it occurred. The language questionnaire was sent to the parents during each measurement wave. The parents then could fill in the questionnaire at their convenience and return it by post or by giving it to a researcher who visited their home as part of the larger study. Parents were encouraged to use their own kept records or the information they had from the Child and Infant Health Centre (Consultatiebureau) where this information could assist them in filling in the questionnaires. The families were rewarded with a small gift for their children during each measurement moment.

Measures

Age of achieving motor milestones

All parents filled in the Parental Checklist of Developmental Milestones (Bodnarchuk & Eaton, 2004). Parents were requested to keep track of their child's development and note the age in months at which their children achieved a few central motor developmental milestones. The list includes detailed criteria based on which the parents could determine if their child had achieved that milestone. The parents were given the list at the time of enrolment to the study (between ages 3 and 9 months for the younger cohort and between ages 13 and 20 months for the older cohort). For milestones that were achieved prior to enrolment to the study, parents were asked to fill in the age at which the child achieved the milestones based on records kept by the Child and Infant Health Centre (Consultatiebureau) or their own records (including own kept diaries, blog entries, e-mails and digital photos). If the parents had no record of these ages the data were considered to be missing.

For the current study information was used regarding the age of sustained unsupported sitting (baby sits up alone, not supported by a pillow or chair, without using hands for support for at least 30 seconds), hands and knees crawl (the baby uses only hands and knees for support, the back is straight, the knees are under the hips and the elbows under the shoulders) and sustained walking (walking unsupported across the room. The baby uses walking as the main means of getting around). Bodnarchuk and Eaton (2004) have shown that parents can reliably report the age of attainment of these milestones using this list.

In the total sample the parents of three children had no records of the age at which their child achieved sustained unsupported sitting and the parents of two of these children had also no records of the age of attainment of hands and knees crawl. The two children with missing data for sitting and crawling are the children who were excluded from the analysis due to too many missing data. Remaining missing data were imputed using multiple imputation (Schafer & Graham, 2002). In addition four children did not engage in hands and knees crawl. These children were excluded from (descriptive) analyses regarding this milestone.

Productive vocabulary

The children's productive vocabulary was measured using the Dutch version of the McArthur-Bates Communicative Developmental Inventories (CDI) – short version (NCDI; Zink & Lejaegere, 2002). During each measurement wave the parents were asked to indicate on a list of 112 words if their child already says this word. A total score was computed by counting the words the child produced. Missing data (about 5%) were imputed. At the age of 16 months the parents filled in the earlier version of the NCDI, namely the NCDI-I – short version. However, as standard scores are available for both the NCDI-I-short version and the NCDI-II- short version at the age of 16 months, the raw scores of the children on the NCDI-I-short version were transformed into raw scores on the NCDI-II-short version using their respective standard scores. Both the NCDI-I-short version and the NCDI-II-short version have been shown to have good reliability and validity (Zink & Lejaegere, 2002).

Analysis Plan

LGM was used to model the change in productive vocabulary over time. This is a powerful and flexible method used to model individual change in repeated observations of a single variable over time (Duncan, Duncan, & Strycker, 2006). Development in LGM is represented by two latent factors, the intercept and the slope. The intercept of the model represents the overall level of the measured construct across measurement points. The slope represents the rate of growth in the measured construct across measurement points. In the current study a sequential-cohort (or accelerated) design was applied to model the development of productive vocabulary from age 16 to 28 months. This design includes limited repeated measurements of independent age cohorts. This technique provides a way to link the data from the separate cohorts on the basis of temporarily overlapping measurement waves in order to determine the existence of a common growth curve. This enables researchers to approximate a long-term longitudinal study by simultaneously conducting and linking several short-term longitudinal studies of independent age cohorts (Duncan et al., 2006). Accelerated LGM with the statistical software AMOS™ (Arbuckle, 2008) was used to combine the two age cohorts in a single model of children's productive vocabulary development spanning the age range from 16 to 28 months. The means and variances of the intercept and slope were estimated, as well as the effects of the predictors on the intercept and slope. To evaluate model fit, the chi-square (χ^2), the root mean square error of approximation (RMSEA), the comparative fit index (CFI) and the Tucker Lewis Index (TLI) were used. As a rule of thumb, a non-significant χ^2 indicates good model fit, RSMEAs below .05 indicate good fit and below .08 reasonable fit, and CFI or TLI greater than .95 can be considered a good fit and values greater than .90 indicate an acceptable fit (Kline, 2005).

In the first stage a growth model was fitted to the data of productive vocabulary development. Regression weights for the intercept were fixed to 1 and regression weights for the slope were fixed to reflect the actual measurement time. Using the multiple group option in AMOS™ the weight for the first measurement (at 16 months) was fixed to -1 and the weights for the following waves were fixed to 0, 1 and 2 respectively. As children's scores at the age of 16 months were still low (see Table 3.1 in the results section), the distribution of scores was somewhat skewed at this age. Therefore, the second measurement (20 months) was used to represent the intercept by fixing the slope regression weight to zero. Fixing the intercept at the second time-point does not influence the calculation of the slope. In addition the measurement error of the measures taken during the overlapping measurement times (ages 20 and 24 months), the mean and variance of the intercept and slope and the covariance between the intercept and slope were all constrained to be equal for both cohorts. Parameters were then set free to see if this provides a significant improvement in the model fit. In addition, nonlinear growth was tested by using an unspecified accelerated LGM (Duncan et al., 2006). In this model the slope regression weight of the first and last measurement points (i.e. the first measurement for the young cohort and the last measurement for the older cohort) was set free while the other two weights were kept constant. This method allows for modelling higher order polynomial growth such as quadratic or cubic growth. See Figure 3.1 for an illustration of the combined accelerated LGM.

In the second stage predictors (age of achieving the milestones of unsupported sitting and independent walking) were added to the model, while keeping the growth part of the model constant. Structural paths from the predictors to both intercept and slope and the covariance between the predictors were specified and constrained to be equal for both cohorts. These structural paths were then set free to test if this provides a significant improvement in the model fit.

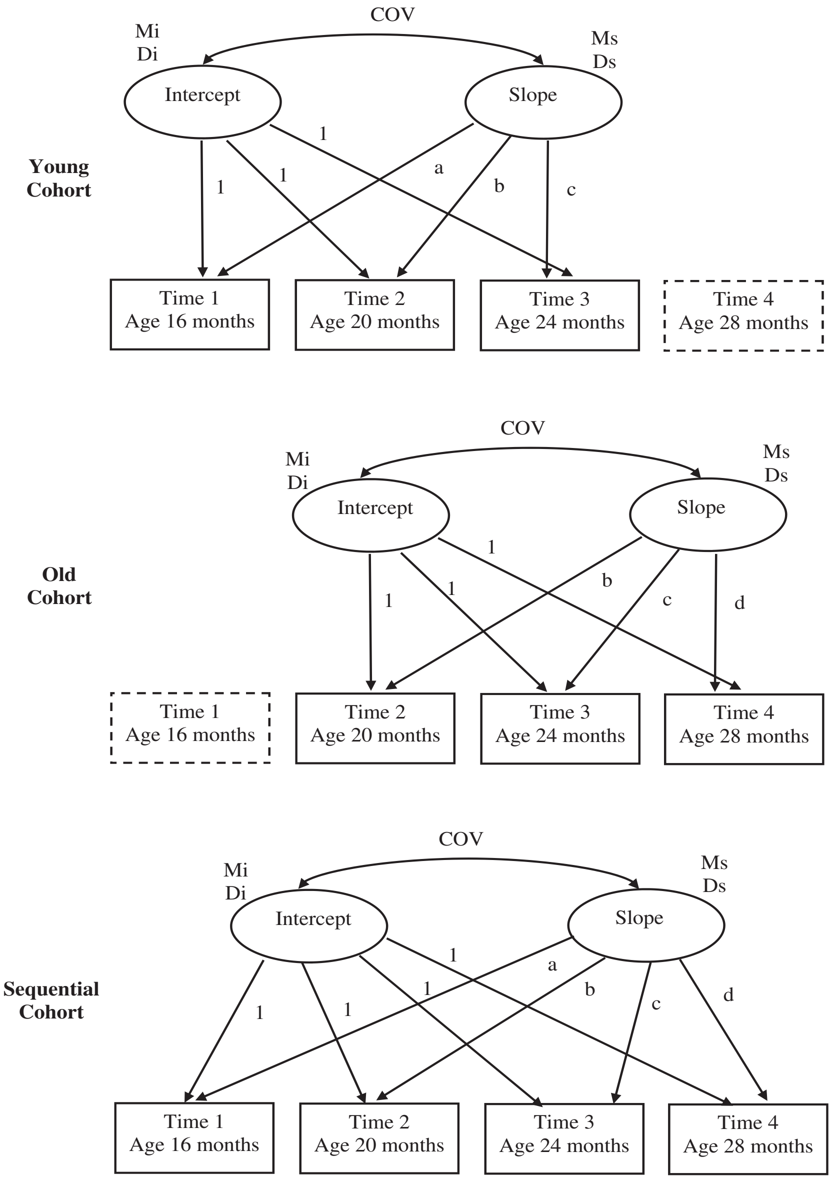


Figure 3.1. Description of the combination of the two age cohort into one cohort-sequential LGM.
Note. Mi = Mean intercept, Di = Disturbance intercept, Ms = Mean slope, Ds = Disturbance slope, Cov = Covariance

Results

Descriptive Analysis

The descriptive statistics of all variables included in the analyses can be found in Table 3.1. Even though the age of attainment of crawling was not included in the analysis, it was included in the descriptive statistics in order to give an impression of how it relates to the relevant variables. As outliers can have a large effect on the results in a relatively small sample, extra care was taken. Most variables had no values beyond two standard deviations from the mean. The age of attainment of walking had one value which was more than two standard deviations above the mean (but less than three), this value was adjusted to the value of the next closest extreme value plus one (Tabachnik & Fidell, 2007). It is important to notice that at 16 months the level of productive language is still very low (as scores on the scale range from 0 to 112) and thus almost approaching a floor effect. However the skewness value of the distribution of scores at this age does not exceed the acceptable limit of 3. Another important point is that at 28 months at the group level, there is no visible ceiling effect. Using ANOVA, no significant differences were found between the two cohorts on any of the variables. The mean age of attainment of the milestones might seem a bit late, but these ages are within the norm for children in the Netherlands (see for example Laurent de Angulo et al., 2005; Ruiter, 2007).

Table 3.1 Means and standard deviations for all variables

	Total			Young Cohort			Old Cohort		
Variable	***N***	***M***	***SD***	***N***	***M***	***SD***	***N***	***M***	***SD***
Sitting unsupported	55	8.18	1.51	27	8.35	1.52	28	8.02	1.51
Hands and knees crawl	51	9.97	1.88	25	10.34	2.09	26	9.62	1.62
Walking unsupported	55	14.96	2.36	27	15.02	2.64	28	14.91	2.10
Productive vocabulary 16 months	27	9.16	9.30	27	9.16	9.30	-	-	-
Productive vocabulary 20 months	55	29.36	20.30	27	26.59	19.57	28	32.04	20.99
Productive vocabulary 24 months	55	61.23	27.60	27	59.84	30.23	28	62.57	25.28
Productive vocabulary 28 months	30	83.16	25.74	-	-	-	28	83.16	25.74

In Table 3.2 the correlations between all variables included in the analyses are presented and in Table 3.3 the correlations per cohort are shown. As can be expected, the ages at which the children achieved the various milestones correlate strongly with each other and the correlations between the measures of productive vocabulary at the different ages are also large. Overall, the correlations are similar between the two age cohorts, with a couple of exceptions. The correlation between the age of attainment of independent walking and productive vocabulary at age 20 months is lower for the younger cohort in comparison to the older cohort. This is due to two cases in the younger cohort that form multivariate outliers (even though none of the two is a univariate outlier). When these two cases are removed, the correlation for the younger

Table 3.2 Correlations table for all variables (total sample)

		1	2	3	4	5	6
1.	Sitting unsupported						
2.	Hands and knees crawl	.48***					
3.	Walking unsupported	.29**	.70***				
4.	Productive vocabulary 16 months	-.28	.13	.07			
5.	Productive vocabulary 20 months	-.42**	-.27†	-.27*	.83***		
6.	Productive vocabulary 24 months	-.34**	-.21†	-.28*	.71***	.83***	
7.	Productive vocabulary 28 months	-.26	-.34†	-.43**	-	.60***	.77***

Note. *** p <.001 ** p <.01 * p <.05 † p <0.10

Table 3.3 Correlations table for all variables (above diagonal younger cohort below diagonal older cohort)

		1	2	3	4	5	6
1.	Sitting unsupported		.47*	.35†	-.28	-.36†	-.36†
2.	Hands and knees crawl	.48**		.75***	.13	-.09	-.16
3.	Walking unsupported	.26	.59**		.07	-.17	-.31
4.	Productive vocabulary 16 months	-	-	-		.83***	.71***
5.	Productive vocabulary 20 months	-.45*	-.45*	-.39*	-		.88***
6.	Productive vocabulary 24 months	-.30	-.28	-.24	-	.80***	
7.	Productive vocabulary 28 months	-.26	-.34†	-.43*	-	.60***	.77***

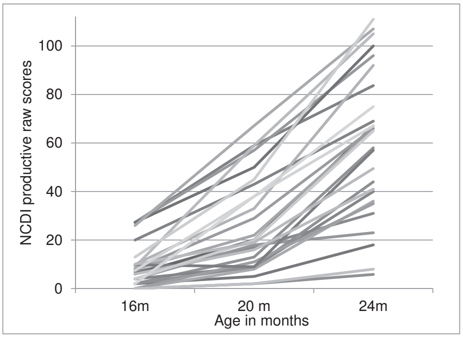
Note. *** p <.001 ** p <.01 * p <.05 † p <0.10

cohort is much larger (r = -.38, p = .06). However, as there is no reason to believe that these two cases are not part of the population they were kept in the analysis (Tabachnik & Fidell, 2007). The correlations between the age of attainment of crawling and productive vocabulary are smaller in the younger cohort. This is again due to two multivariate outliers. These two cases belong to a small group (13.5% of total sample) of children who engage in cruising before they engage in crawling. This group is relatively larger in the younger cohort where 19% of the children belong to this group in comparison to 7.5% in the older cohort. It is possible that this group of children follows a different trend of motor development, with regard to crawling and should possibly be analyzed separately. However, as crawling was not part of analysis, this issue was not further explored.

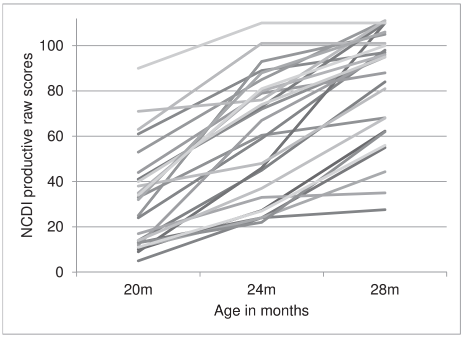
Generally the age of attainment of the motor milestones correlated negatively with the level of productive vocabulary. The negative effects indicate that children who achieve unsupported sitting and independent walking earlier score higher on productive vocabulary. These correlations are generally moderate to large and vary somewhat between the milestones and the ages. Productive vocabulary at age 16 months does not correlate with the milestones, probably due to the overall low level of productive vocabulary at this age.

Testing the Growth Model

Figure 3.2 shows the individual growth curves for children in both the younger (Figure 3.2a) and the older (Figure 3.2b) cohort. The growth curves show that most children grow constantly on their productive vocabulary. However different children show larger growth spurts or periods of accelerated growth at different points. The lower scores and lower distribution of scores at 16 months is also visible.



2 a. Younger cohort



2 b. Older cohort

Figure 3.2. Individual growth curves of productive language in both cohorts

Another trend that becomes visible in Figure3. 2b is the small group of children in the older cohort who seem to reach a ceiling effect. These children score already at age 24 very close to the maximum score of 112. Therefore they do not grow in their score between ages 24 and 28 months. This tendency represents a systematic measurement error, which will have to be accounted for in the final model. In order to account for this systematic error, the covariance between the intercept and slope was allowed to vary between the two cohorts. As can be seen from Figure 3.2, in the older cohort some children who start higher have a lower slope due to the ceiling effect, but at the same time other children in this group and in the younger cohort seem to show a positive correlation between intercept and slope, as children who start higher seem to also grow more in productive vocabulary. Setting the covariance between intercept and slope free will allow the model to account for this systematic measurement error.

Model selection proceeded in four steps; fit indices of the models tested are presented in Table 3.4. First, the fit of a linear model was tested. This model did not fit the data well. Next, the parameters were set free between the two cohorts, but this did not provide a significant improvement in the model fit. Third, an unspecified LGM was tested in order to test for non-linear growth. This model provided good fit for the data. The model reflected a weak cubic trend (regression terms for the slope converged at -.70, 0, 1 and 1.70). Figure 3.3 presents the growth curves based on the observed and implied means and shows that while the level of productive vocabulary grows constantly between ages 16 and 28 months, this growth is slightly faster between ages 20 and 24 months. This trend reflects the fact that more children have a

Table 3.4 Fit indices for accelerated LGM (*N*= 55)

Model	χ^2 *(df)*	*CFI*	*TLI*	*RMSEA*	$\Delta\chi^2$*(df)*
1. Linear growth parameters constrained	18.24(8)*	.91	.93	.16	-
2. Linear growth parameters free	17.11(4) **	.88	.82	.25	1.13(4)[a]
3. Unspecified growth parameters constrained	5.95(6)	1.00	1.00	.00	12.29(2) **a
4. Unspecified growth parameters free	4.62(2) †	.98	.93	.16	1.33(4)[b]
5. Same as # 3 with both milestones as predictors	19.87(16)	.97	.96	.07	-
6. Same as #5 structural parameters free	19.24(12) †	.94	.91	.11	.63(4)[c]

Note. *** p <.001 ** p <.01 * p <.05 †p <0.10 [a] models compared to model 1. [b] model compared to model 3. [c] model compared to model 5. *CFI* = Comparative Fit Index, *TLI* = Tucker Lewis Index, *RMSEA* = Root Mean Square Error of Approximation.

period of accelerated growth in productive vocabulary between the ages of 20 and 24 months compared to the other periods. Finally, the parameters of the unspecified LGM were set free but this did not provide a significant improvement in model fit. Therefore the more parsimonious constrained model was maintained.

The parameter estimates for the growth only model can be found in Table 3.5. In LGM the intercept reflects the height of the line, or the general level of productive vocabulary of each child throughout the study and the slope reflects the average growth between measurement moments. The significant mean of the slope and the intercept (see Table 3.5) show that there is significant growth in the scores on productive vocabulary between ages 16 and 28 months. The significant variances of the slope and intercept indicate that there is substantial variance

Table 3.5 Model parameters for unspecified growth only model and model with covariates (*N*= 55)

	Unstandardized estimates	**Standardized estimates**
Growth only model		
Mean Intercept (SE)	30.35 (2.56)***	-
Mean Slope (SE)	31.04 (2.22) ***	-
Variance Intercept (SE)	233.16 (58.04) ***	-
Variance Slope (SE)	118.20 (37.92) **	-
Covariance Intercept-Slope (SE) Young/Old[a]	147.15 (40.99) *** / 21.68 (51.32)	.89 / .13
Model with two Predictors		
Effects on intercept (SE)		
Sitting	-2.65 (1.17) *	-.26
Walking	-1.08 (.77)	-.17
Effects on slope (SE)		
Sitting	-1.00 (.98)	-.13
Walking	-2.15 (.64) ***	-.45
Covariance sitting-walking (SE)	1.13 (.65) †	.33

Note. *** p <.001 ** p <.01 * p <.05 †p <0.10 [a] covariance values for the young and older cohort respectively between individual children in their level of productive vocabulary and in the level of their growth. As was expected the covariance between the intercept and slope is not significant in the older cohort (due to the previously mentioned systematic measurement error) and positive and large for the younger cohort.

Testing the Effect of the Milestones

In the next stage the ages at which the children achieved the motor milestones of unsupported sitting and independent walking were added into the model as covariates in order to test if these variables predicted the intercept and the slope of productive vocabulary. The fit statistics and the regression weights of this model can be found in Tables 3.4 and 3.5, respectively. From Table 3.4 it can be seen that the model has a good to acceptable fit to the data. Setting the structural part of the model free between the two cohorts did not provide a significant improvement in model fit (see Table 3.4). Therefore the more parsimonious constrained model was kept.

As can be seen from Table 3.5 the age of achieving unsupported sitting predicted the intercept and the age of achieving independent walking predicted the growth in productive vocabulary between the ages of 16 and 28 months. The negative regression weights suggest that children who achieve unsupported sitting and independent walking earlier show a higher overall level and a quicker growth in productive vocabulary, respectively. The effects were medium to large.

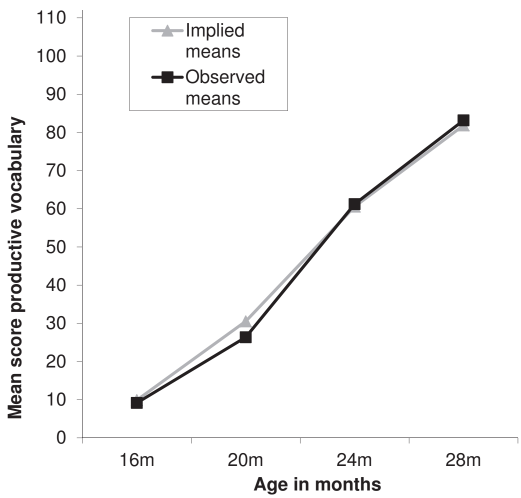


Figure 3.3. Growth in productive languag as shown by the implied and observed means, showing a weak cubic trend.

To sum up, the models presented here have shown that children's growth on productive vocabulary between the ages of 16 and 28 months can best be described by a weak cubic trend (see Figure 3. 3), where most children demonstrate a period of accelerated growth between ages 20 and 24 months. The models further show that children who achieve unsupported sitting at an earlier age have an overall larger productive vocabulary between age 16 and 28 months and that children who attain independent walking at an earlier age show a quicker rate of growth in productive vocabulary during the same period.

Discussion

The main goal of the present study was to determine whether the age of attainment of the milestones unsupported sitting and independent walking predict the development of productive vocabulary between ages 16 and 28 months. Theoretical views, such as embodiment theory, argue that perception and action play an important role in the development of cognition and language (Gogate & Hollich, 2010; Hockema & Smith, 2009). Furthermore, the attainment of motor milestones sets advances in various perception-action systems in motion and thus propels further cognitive and linguistic development (Sheya & Smith, 2011). Therefore, we expected earlier attainment of the motor milestones unsupported sitting and independent walking to be related to higher overall level of productive vocabulary and to a quicker rate of growth.

Results indicated that children who achieved unsupported sitting at an earlier age had an overall higher level of productive vocabulary between the ages of 16 and 28 months. Moreover, children who achieved independent walking at an earlier age grew more quickly on productive vocabulary in this age period. These results are in line with the hypothesis. In addition, results also indicated that the growth in productive vocabulary followed a weak cubic trend. This trend might reflect a real trend, but it might also be a result of the instrument used (with possible floor and ceiling effects). More work with a larger sample is needed in order to establish conclusions regarding the shape of development in this domain and therefore we will not discuss this trend any further.

Before we discuss in detail the difference between effects on overall level and effects on growth, it is important to recall the time scale of the current study. We examined the effect of the age of achievement of unsupported sitting (on average about 8 months) and independent walking (on average about 15 months) on the overall level and growth in productive vocabulary between the ages of 16 and 28 months. Thus the model shows growth between ages 16 and 28 months and the predictors of this growth are events that took place several months earlier.

The effect of sitting on overall level suggests that children who were more advanced than peers in their sitting skill at a younger age are also more advanced than peers in productive vocabulary later on. The effect on growth suggests that children who achieved independent walking earlier than peers showed a quicker growth in productive vocabulary later on but not necessarily a higher overall level. This effect, especially, is in line with the notion of milestones propelling linguistic development.

The attainment of independent walking has been shown to bring about advances in various perception-action systems and was related to qualitative and quantitative changes in children's interaction with the environment and in the linguistic input they receive (Clearfield, 2011; Karasik et al., 2011; Walle & Campos, 2011). The onset of independent walking sets a series of changes, at different levels, in motion. Walking infants perceive the world from a different angle, which changes the visual input they receive, and can manipulate the environment in a different more sophisticated manner. They can, for example, carry objects from one location to another more easily (Campos et al., 2000; Karasik et al., 2011). Walking infants also interact more with their mothers and are therefore more likely to receive more linguistic input from them. Moreover, as walking infants actively draw their mother's attention to specific objects, they are also more likely to receive linguistic input that is relevant to the object they are currently involved with (Clearfield, 2011). Finally, the kind of input infants receive also changes with their changing motor abilities. Walking infants, for instance, hear more prohibiting phrases, compared to crawling infants (Walle & Campos, 2011). This might be because their new motor abilities make them susceptible to dangers that did not exist earlier (Gogate & Hollich, 2010). For example, a walking infant might walk to the kitchen table and pick up a sharp knife lying there, whereas a crawling infant will probably not reach the table at all.

The set of processes set in motion by the attainment of independent walking, bring about changes in infants and their environments and thus cause a change in the interaction between infants and their environment. Put differently, the onset of independent walking brings about changes in multiple perception-action systems. As infants learn language through this active interaction with the environment, taking place at many levels (Gogate & Hollich, 2010; Hockema & Smith, 2009), the attainment of independent walking can be expected to propel growth in language. Our results support this notion. In time this effect might manifest itself also in an effect on overall level, but at first, primarily an effect on growth is expected.

In our data, the effect of the age of attainment of unsupported sitting is manifested in an effect on the overall level and not on the growth. We suggest that this is due to the time that has passed since unsupported sitting has been achieved. As one might recall, at the time when the productive vocabulary was measured, between 16 and 28 months, all children could already engage in unsupported sitting for a while (the latest age of sitting in the current sample was 11 months, five months before the first measurement of productive vocabulary took place). Therefore, should unsupported sitting have an effect on the growth rate of productive vocabulary, this effect might manifest itself in a younger age range, closer to the onset of unsupported sitting. In the age range examined in the current study all children have gained sufficient experience with sitting and therefore the attainment of unsupported sitting might no longer propel the development of productive language. Nonetheless, the effect of unsupported sitting on overall level of productive vocabulary might be a result of an effect on growth in productive vocabulary evident at an earlier age. Further work with younger children is needed in order to test this hypothesis.

The use of LGM adds an extra dimension on top of using simpler correlational analysis. In the current study the correlations are not as large as the effects we find in LGM. Correlations reflect the relation between the ages of attainment of the motor milestones and level of productive vocabulary at each measurement point separately. As can be seen from the model tested the effect of the milestones on the overall level is moderate at best. However, the main finding of the current study, namely the effect of walking on the slope of productive vocabulary cannot be seen from the correlations as they only reflect effects on general level per measurement point.

The results of the current study also shed new light on previous work (Schultz & Eaton, 2011; Viholainen et al., 2006). This work has found mainly effects of motor *delay* on linguistic development at (pre)school age, suggesting that possibly over longer periods of time the effects of the age of attainment of motor milestones become smaller and it is only children with severe motor delays who do not catch up. Our results suggest that while at the long term the correlation between the age of attainment of milestones and language might be rather small, this does not mean that these milestones do not play a role in the developmental process of productive language. When examined more closely, the onset of motor milestones is related to language development, as our results show.

We believe that once motor milestones are achieved the child's exploration behavior, what he or she actually does in the world, plays a much larger role than the actual attainment of the milestones. Furthermore, other paths to language, not going through motor milestones, are also possible. Think for example about children who due to a physical disability do not engage in many of these milestones. These children also develop productive vocabulary. The milestones are thus not sufficient nor necessary in the process of language acquisition (Iverson, 2010). However, we believe that what is common to all of the alternative paths, is that they allow the child to engage in some form of exploration of his or her environment. While this exploration might take many forms (even through a proxy), it might itself be the essential component in the way to language development. This hypothesis is, however, beyond the scope of the current study. It is also evident that children demonstrate some linguistic abilities before they can sit or walk. However our results suggest that the attainment of walking propels a period of accelerated growth in productive vocabulary.

Some might argue that the results of the current study simply reflect the existence of some 'general developmental factor', which accounts for why some children develop quicker than others. Many suggestions have been made for what this domain general mechanism might be. A few examples are: processes of brain maturation, processing speed, lower level or higher level cognitive structures such as statistical learning or executive functions and environmental factors (for a review see: Rhemtulla & Tucker-Drob, 2011). Let us follow this idea and consider such a general developmental factor. In our case this factor should then account on the one hand for a correlation between earlier motor development and overall levels of productive vocabulary. Then children who score higher on this general factor would be expected to score higher on motor and linguistic development as well.

On the other hand this factor should also account for (differential) effects on growth. In this case, besides a domain general factor which is responsible for both motor and linguistic development, we also require a domain general factor, which accounts for the order or 'plan' of development. This factor should explain why a growth spurt in one domain follows right after growth in another domain. Thus, although we cannot rule out the existence of such a general factor, it seems preferable to choose for the more parsimonious idea of motor milestones propelling linguistic development.

The current study has a few limitations worth mentioning. First and foremost is the relatively small sample size. However, the application of a sequential-cohort design allowed us to increase the power of the analysis and as the expected (and indeed found) effects where all moderate to large, the power of the study seems sufficient. Another limitation is the use of parental reports to measure both productive language and age of attainment of motor milestones. While the use of other sources of information is recommended for future work, the used instrument were both validated against instruments taken by researchers and practitioners and found to provide a reliable and valid picture of the children's motor and linguistic level (Bodnarchuk & Eaton, 2004; Zink & Lejaegere, 2002).

The use of LGM might be considered a strong point of the current study. This technique allowed us to model and predict individual differences in growth and reveal effects on growth, which are not easily discovered using more traditional methods. The use of individual growth curves rather than measures of central tendency allowed us to study development at the individual level and attempt to tap into the fine dynamics of the developmental process. Finally, the design of the current study, while it did not allow for causal conclusions, did allow us to study development in depth within a relatively short period of time. Using this design, we were not able to study developmental mechanisms directly. However, we were able to look closely at the effects of the attainment of two motor milestones on productive vocabulary during the second and beginning of the third year of life and provide initial evidence pertaining to these mechanisms. Further (experimental) work is necessary in order to study the suggested developmental mechanisms more directly.

To sum up, the results of the current study provide important insights regarding the role the attainment of unsupported sitting and independent walking might play in the development of productive vocabulary. The results are in line with hypotheses stemming from embodiment theory suggesting that the attainment of motor milestones opens new worlds to infants and enables them to develop on many levels, including language. Further work is needed in order to study these developmental mechanisms in detail, replicate our findings and examine possible implications to clinical practice. Nonetheless, the current study adds to the growing body of evidence suggesting that researchers and practitioners must no longer neglect motor development when studying cognitive and linguistic development.

Chapter 4

Development of exploration of spatial-relational object properties in the second and third year of life

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Manuscript under revision.

Abstract

Within a perception-action framework, exploration is seen as a driving force in young children's development. Through exploration children become skilled in perceiving the affordances in their environment and acting upon them. Using a perception-action framework, the current study examined the development of children's exploration of the spatial-relational properties of objects, such as the possibility of containing or stacking. Sixty-one children, belonging to two age cohorts were followed from 9 to 24 months and from 20 to 36 months respectively. Exploration of a standard set of objects was observed in five home visits in each cohort, conducted every four months. A cohort-sequential augmented growth model for categorical data, incorporating assumptions of Item Response Theory, was constructed that fitted the data well, showing that the development of exploration of spatial-relational object properties follows an overlapping waves pattern. This is in line with Siegler (1996) who suggested that skill development can be seen as ebbing and flowing of alternative (simple and advanced) behaviors. While the probability of observing the more complex forms of exploration increased with age, the simpler forms did not disappear altogether but only became less probable. Findings support a perception-action view on development. Individual differences in observed exploration as related to gender and spatial memory, as well as future directions for research are discussed.

Introduction

According to perception-action views, children play an active role in their own development. They perceive information that elicits actions and these actions, in turn, provide new information to be perceived, specifying new actions. Children's growing knowledge of the world and their increasing ability to act adaptively and skillfully in it are grounded in these continuously recurring perception-action loops, referred to as exploration (Adolph, Eppler, Marin, Weise, & Wechsler Clearfield, 2000; J. J. Gibson, 1979; E. J. Gibson, 1988; E. J. Gibson & Pick, 2000).

Exploration is in many ways the key to development. Extensive empirical work shows that young children's exploration behavior is related to advances in several domains of development (e.g., Needham, 2000; Needham, Barrett, & Peterman, 2002; Soska, Adolph, & Johnson, 2010). Exploration of the spatial properties of objects and of the spatial relations between objects (henceforth, spatial-relational object properties) is a special kind of exploration, referring to the perceiving of and acting upon properties of objects, such as the possibility of containing, stacking, fitting into each other, pulling out and so forth. Evidence suggests that the exploration of objects and spaces is strongly related to the development of spatial cognition (Campos et al., 2000; Campos, Anderson, & Telzrow, 2009; Clearfield, 2004; Oudgenoeg-Paz, Leseman, & Volman, 2014). Spatial cognition, in turn, has been shown to be highly relevant for success in various academic disciplines such as science, mathematics and language as well as for complex social behaviors involving perspective-taking (Creem-Regehr, Gagnon, Geuss, & Stefanucci, 2013; Gathercole, Alloway, Willis, & Adams, 2006; for a review see: Newcombe, Uttal, & Sauter, 2013).

Research on the development of object exploration has predominantly focused on the exploration of single objects during the first year of life (e.g., Eppler, 1995; Galloway & Thelen, 2004; Soska et al., 2010). Less is known about the development of object exploration after the first year of life. Moreover, research into children's object exploration has rarely focused on exploration of the spatial-relational properties of objects and the possibilities of combining objects entailed by these properties. The current study adds to the evidence by examining the development of children's exploration of the spatial-relational properties of objects from the end of the first year into the third year of life.

Studies investigating single object exploration in infants have mainly focused on actions such as fingering, mouthing and shaking that enable infants to acquire different kinds of information about the objects through different sensory modalities (e.g., Eppler, 1995; Lobo & Galloway, 2008; Ruff, 1984). Exploration of multiple objects simultaneously (e.g., holding two objects together) has been reported to appear in infants as young as seven to eight months, but this seems to become an established part of the behavioral repertoire of typically developing children only from the age of 11 months onwards (Kotwica, Ferre, & Michel, 2008). In the second year of life, once two or more objects can be manipulated together, exploration becomes gradually more complex as infants start to explore the spatial relations between objects and become increasingly skilled in making combinations of increasing complexity (e.g., inserting an object into another object, pulling an object out of another object, stacking objects). Exploration of spatial-relational properties is displayed to a greater extent when infants are presented with objects with complementary spatial properties that afford such combinations, suggesting that the information structures in the environment play a critical role in the development of exploration (Fagard & Jacquet, 1989; Kimmerle, Ferre, Kotwica, & Michel, 2010; Ramsay, 1985; for a review see: Greaves, Imms, Krumlinde, Dodd, & Eliasson, 2012).

In line with Lockman (2000), who applied a perception-action perspective to tool-use development, we argue here that the development of exploration from exploring single to exploring multiple objects without combining them and to combining objects requires detecting the spatial-relational affordances of single objects as well as detecting what Lockman calls *affordance relations* between objects and which we will refer to as *relational affordances*. For example, discovering the affordance of insertion requires perception of the elementary affordances of the separate objects first (e.g., having an opening and size relations enabling containment). Through perception-action routines infants discover the actions that separate objects afford. By performing the actions specified by elementary affordances repeatedly, also with similar objects in different situations, infants become increasingly skilled in acting upon these affordances. This process sets the stage for discovering new, more complex affordances that, in turn, specify more complex actions such as spatially combining objects (E. J. Gibson, 1988; E. J. Gibson & Pick, 2000).

The affordances to be discovered are specified by the interaction between the child's abilities and the information structures in the environment. Therefore, development of object exploration in this view is driven by recurrent perception-action cycles leading to increasing skill and discovery of increasingly complex affordances, *and* by the information structures in the environment (J. J. Gibson, 1979; E. J. Gibson, 1988). In addition to these driving forces, the development of object exploration is obviously constrained by the neuromuscular development of hand skills (e.g., ability for grasping, in-hand manipulation and bimanual manipulation of objects; Greaves et al., 2012), and by (changes in) body-scaled relations for grasping (e.g., does the size of an object affords the child to grasp it with one hand or is grasping with two hands needed; Van der Kamp, Savelsbergh, & Davis, 1998). These constraints are important to bear in mind, but they are not the main focus of the present study.

Support for the perception-action view on development of object exploration comes from a cross-sectional study by Bourgeois, Khawar, Neal and Lockman (2005) into the development of object-surface combinations. The findings of this study suggest that complex actions in which children establish relations between objects and surfaces emerge from previous exploration of the properties of these objects and surfaces separately, resulting in detecting affordances that specify a relation between object and surface, leading to action (i.e., exploiting the relational affordance by making the object-surface combination). For instance, 6-months-old infants explored object properties (e.g., softness and hardness of objects by squeezing and scratching) and surface properties (e.g., liquidity, discontinuity, flexibility and rigidness by slapping, pressing, rubbing and picking), but they hardly related objects to surfaces. Interestingly, 10-months-old infants also explored object and surface properties separately when presented with a new set of objects. However, the 10-months-olds also related objects to surfaces much more frequently (e.g. pressing objects into different surfaces, rubbing objects on surfaces and banging objects on surfaces), with the particular action shown depending on the specific properties of both the objects and the surfaces. The youngest infants always started with either separate object or surface exploration and only occasionally ended with object-surface relational exploration. The oldest infants mostly still started with separate object or surface exploration, but soon changed to exploration of the relations between the two within the session (Bourgeois et al., 2005). Note that the affordances explored in the Bourgeois et al. study are spatial-relational in the sense that they involve relations such as *on*, *in*, *against* and *through*. Similar results were reported in a longitudinal study by Takeshita et al. (2005), who investigated the development of spatial-relational object exploration in infant chimpanzees. The results showed that the infant chimpanzees followed a developmental trajectory from the exploration of the spatial-relational properties of single objects and surfaces to the exploration of combinations of objects and surfaces (i.e., detecting and exploiting the relational affordances). These results closely match the results of Bourgeois et al.. Longitudinal evidence pertaining to the development of spatial-relational object exploration in human infants, taking a perception-action perspective, however, is still lacking.

The development of spatial-relational object exploration and mainly the use of combinations has also been studied within a play development perspective, in which play development is considered as a succession of stages of increasing cognitive complexity. Object exploration (including among others the making of combinations) in this research is seen as an early stage-to-pass in play development, with symbolic play as the cognitively most complex level towards which development is heading (e.g., Belsky & Most, 1981; Schneider, 2009; Van Schijndel, Singer, Van der Maas, & Raijmakers, 2010). A typical and widely discussed problem of stage theories is how to explain intra-individual variability, that is, the frequently observed temporary regressions to a previous, less advanced stage and temporary progressions to a future, more advanced stage (Fischer & Bidell, 2006; Siegler, 1996; Van Dijk & Van Geert, 2007; Van Geert & Van Dijk, 2002). The perception-action account may provide an alternative perspective on this issue. In this view (seemingly) higher order behaviors or concepts are thought to be situated and emerge or be 'softly assembled' from the (simple) perception-action loops constituting every specific activity. Therefore, for instance, temporary regressions can occur when well-learned affordances pertaining to extensively explored objects (children showing skill in their actions with these objects) are to be discovered again if new objects are encountered with slightly different physical properties or if these objects are encountered in a new constellation with other objects. In these cases, the context of the task and the child's previous experience do not (yet) support the emergence or soft assembly of the more advanced forms of behavior and therefore simpler forms are used. Developmental progress can occur if extensively explored objects are encountered in a constellation in which children can perceive more complex relational affordances that specify more complex actions. In this view, simple perception-action routines do not disappear in the course of development but rather continue to provide the basis on which new, more complex perception-action routines can emerge (Fischer & Bidell, 2006; Lockman, 2000; Siegler, 1996, Thelen & Smith, 1994). Therefore, the emergence of complex and developmentally more advanced behaviors (such as making object-object combinations), can be expected to go together with increased variability of skill at the point of emergence, showing both temporary regressions and progressions, and gradually increasing stability of the higher level skill the more the complex affordance structure is explored (Lockman, 2000; Siegler, 1996; Thelen & Smith, 1994; Van Geert & Van Dijk, 2002).

Following this line of reasoning, Siegler (1996) suggested, as an alternative to stage-theories, that the development of particular skills can be described as the ebbing and flowing of alternative behaviors, with changes over time in the likelihood that certain behaviors will be observed. Developmental progress is marked by a decrease in the observed frequency of less mature behaviors and an increase in the observed frequency of more mature behaviors, resulting in the typical pattern of overlapping waves. Until recently, Siegler's model was only used as a metaphor, but not statistically tested. Using recent advances in latent growth modelling and Item Response Theory, Van der Ven, Boom, Kroesbergen and Leseman (2012) successfully modelled the development of mathematical problem-solving strategies in eight-year-olds' multiplication learning as overlapping waves, fully in line with Siegler's (1996) theoretical proposal. The current study applied this approach to the development of young children's exploration of spatial-relational object properties. It is however, important to note, that while Siegler's model refers to the choice between alternative strategies, which are internally represented in the child's mind, the choice between alternative behaviors in our model is not seen as internal process. The behaviors we observe are not assumed to be the result of internal representation; they are thought to emerge in real-time as a result of the interaction between multiple factors, such as task constraints, previous experience of the child with these or similar tasks, the child's posture, motivation and so forth.

The present study examined the development of young children's exploration of spatial-relational object properties over a period from age 9 to 36 months. In order to cover this extended age-range, an augmented cohort sequential approach was used involving two age cohorts (Duncan, Duncan, & Strycker, 2006). The study focused specifically on children's exploration of the properties of objects that afford spatial combinations. Exploration behaviors of different levels of complexity observed at different time points were modelled as overlapping waves, with the shapes of the waves and their timing being a function of the complexity of the affordances explored and children's growing skill to pick up and exploit these affordances. A clear advantage of this approach is that it allows examining both the development of group means, as in the study of Bourgeois et al. (2005), *and* children's individual developmental trajectories, including intra-individual variability (see Van Geert & Van Dijk, 2002 for a discussion on the importance of studying intra-individual variability). Moreover, using this approach, developmental trajectories can be related to background variables which have been shown to predict exploration and spatial cognition, in particular gender and socioeconomic status (Hart, Petrill, Deater Deckard, & Thompson, 2007; Levine, Vasilyeva, Lourenco, Newcombe, & Huttenlocher, 2005), and to concurrent measures of spatial cognition to evaluate the validity of the current approach.

In the present study, children were observed while exploring a standard set of objects that was carefully selected to enable a variety of spatial-relational affordances of different complexity (for a review on the importance of object selection see: Greaves et al., 2012). In contrast to most previous studies of exploration behavior (e.g., Bourgeois et al., 2005; Eppler, 1995; Soska et al., 2010), observations in the current study were conducted at children's homes rather than in a lab setting. Children were allowed to play on the floor and move around while exploring. This setting was chosen in order to elicit behavior that optimally resembles children's natural exploration behavior, thereby increasing the ecological validity of the study.

Method

Design and Participants

The participants belonged to two cohorts. Both cohorts took part in five measurement moments ranging from age 9 to 24 months for the younger cohort (N = 30, 53% girls) and from 20 to 36 months for the older cohort (N = 32, 56% girls). Measurement moments took place at intervals of four months, with the exception of the first interval in the younger cohort, which lasted three months. The two cohorts had overlapping measurement moments at ages 20 and 24 months. The participants were recruited through day care centers in the municipality of Utrecht (the Netherlands) and through an address list made available by the municipality of Utrecht. Only children from Dutch speaking families with no serious medical or developmental disorders were included in the study. Informed consent was obtained for all children.

Two children in the younger cohort and one child in the older cohort only took part in the first two measurements. In addition, some of the observation data was missing due to technical problems or to children's occasional unwillingness to cooperate. This resulted in 5.3% of the observation data missing. Five children missed data from one measurement moment and one child missed data from two measurement moments. Details about the total number and mean age of the children at each measurement moment can be found in Table 4.1. Finally, two children refused to do the spatial memory task during the third measurement moment and data on SES was missing for four children due to incomplete questionnaires.

Table 4.1 Sample size, mean children's age and standard deviations divided by cohort for all measurement moments

	Young cohort		Old cohort		Total	
Measurement	***N***	***MAge*[a] *(SD)***	***N***	***MAge*[a] *(SD)***	***N***	***MAge*[a] *(SD)***
9 months	30	9.21 (.47)	-	-	30	9.21 (.47)
12 months	29	12.16 (.47)	-	-	29	12.16 (.47)
16 months	27	16.05 (.37)	-	-	27	16.05 (.37)
20 months	27	20.26 (.29)	31	20.75 (.61)	58	20.52 (.54)
24 months	28	24.12 (.33)	30	24.14 (.30)	58	24.13 (.31)
28 months	-	-	29	27.92 (.38)	29	27.92 (.38)
32 months	-	-	31	32.14 (.33)	31	32.14 (.33)
36 months	-	-	29	36.05 (.25)	29	36.05 (.25)

Note. [a] Age in months.

Procedure

Exploration was observed during home visits. Children were filmed while exploring a standard set of objects, brought along by the researcher, for eight minutes. The objects included a transparent container with foam blocks in different sizes and shapes, which can be fitted into each other, plastic building blocks and nesting cups. See Figure 4.1 for a photo of the objects used. The films were edited to remove interruptions (such as stopping for changing

Figure 4.1.Objects used in the observations.

or drinking). Exploration behavior was scored based on the first four minutes of uninterrupted play. Spatial memory was also measured during the home visits, using a test administered by trained research assistants. Background information such as gender and SES was obtained through parental questionnaires. The families were rewarded with a small gift for the child at each measurement moment.

Measures

Exploration of spatial-relational object properties

Exploration of spatial-relational object properties was scored based on four minutes video recordings. Each four minutes recording was divided in 24 intervals of 10 seconds each. Per interval the activities of the child and duration of each activity were noted. Next, a score was given to each interval based on the most dominant (longest enduring) activity. *No exploration* was scored when the child was not engaged with any of the objects (also not looking at any of the objects). *Exploration involving a single object* was scored when the child was manipulating and/or looking at a single object (i.e., looking without manipulation and manipulating without looking were also considered as exploration). A few examples of this kind of exploration are: picking up, rotating, mouthing, hitting (all of these performed with a single object). *Exploration involving multiple objects* was scored when the child was manipulating or looking at two or more objects, for example when objects were lying next to each other, but was not trying to combine the objects. Examples of this kind of exploration are: holding one object while manipulating another, holding or mouthing one object and looking at another, looking at two or more objects simultaneously, picking up multiple objects, throwing or putting down few objects at once (without ordering them according to shape or size), mouthing two objects simultaneously. *Exploration involving combinations of objects* was scored when the child was bringing two or more objects in relation to one another. Examples of this kind of exploration are: inserting an object into another object, stacking, fitting an object into another object, removing objects out of other objects containing them, ordering objects according to shape (e.g., letting the flat ends touch) or according to size rather than randomly putting objects in the vicinity of each other. If two or more activities lasted equally long during an interval, the score representing the (theoretically) more complex activity was assigned to that interval. Thus, for each four-minute video observation, each of the 24 intervals received a score of either 1 (no exploration), 2 (exploring a single object), 3 (exploring multiple objects) or 4 (exploration using combinations). The video fragments were scored by trained coders. 19.6% of the fragments were independently scored by two coders. Cohen's kappa ranged between .67 and .76 with a mean value of .71 (SD = .02) (all kappa values but one were above .70).

Spatial memory

Spatial memory was assessed using an adaptation of the memory for location task developed by Caravale and colleagues (Caravale, Tozzi, Albino, & Vicari, 2005). Children were presented with a row of identical cups and viewed a toy being hidden under one of the cups. After a short delay, while being distracted by the experimenter, children were asked to search for the toy. To make the task more difficult, the number of toys (1 or 2), number of cups (4 or 6), and the length of the delay (1 to 11 seconds) were manipulated. The level of difficulty of the items was determined in pilot testing and the results can be found in Table 4.2. Testing started with a fixed starting item that varied per age group (see Table 4.2). If children failed the starting item they were given a second identical item. If they were successful on the starting item, in either the first *or* second attempt, they were given a next item of one difficulty level up. If they passed this item (again on the first *or* second attempt) they were again given an item of one difficulty level up until they either failed an item twice or until they completed the item with the highest level of difficulty. If children failed both attempts of the starting item they were given a next item of one difficulty level down until they were successful (again on the first *or* second attempt) or until the lowest difficulty level was reached. The final score was the highest level of difficulty completed with success. To shorten testing time, items involving two toys were not administered at 16 months, as pilot testing indicated this was too difficult for this age. The score range was therefore 0-9 at 28 months and 0-6 at 16 months.

Table 4.2 *Items in order of difficulty in memory for location task*

Difficulty level	Number of cups/ number of toys hidden / delay (in seconds)
1	4/1/1
2	4/1/4
3[a]	6/1/1
4	6/1/5
5	4/1/9
6	6/1/11
7[b]	6/2/1
8	6/2/5
9	6/2/11

Note. [a] Starting item at 16 months. [b] Starting item at 28 months.

Socioeconomic status

SES was based on the highest completed education level of both parents scored on a 7-point scale ranging from 1 (elementary school) to 7 (university degree) and the status of their current occupation on the Dutch national job index list ranging from 1 (elementary vocation level) to 5 (academic profession level; Centraal Bureau voor de Statistiek, 2001). SES was computed as the mean of both parents' education and occupation levels after *Z*-transformation (Cronbach's $\alpha = .73$).

Analysis

The first step of the analysis involved a close examination of the patterns in the raw data. For each measurement occasion, the frequencies of the four different forms of exploration that were observed in the 24 intervals per four-minute observation were calculated. One of the assumptions underlying the model, based on Items Response Theory (IRT), is that the distinguished forms of exploration constitute an ordinal scale. Therefore, we expected to find clear peaks signaling the form of exploration the child uses most frequently at a particular point in time. Figure 4.2 presents examples from the raw data. Figures 4.2A to 4.2C show clear peaks in accordance with the IRT assumption. In order to correct for measurement error caused by the fact that some actions carried over from one to the next 10 seconds interval, whereas others ended or started in the middle of an interval, only differences in frequencies larger than 10% of the intervals were considered meaningful; in case of smaller differences, the frequency counts were treated as being equal. Note that it is possible to find two adjacent exploration forms as equally frequent without violating the IRT assumption (see Figure 4.2B). However, finding two

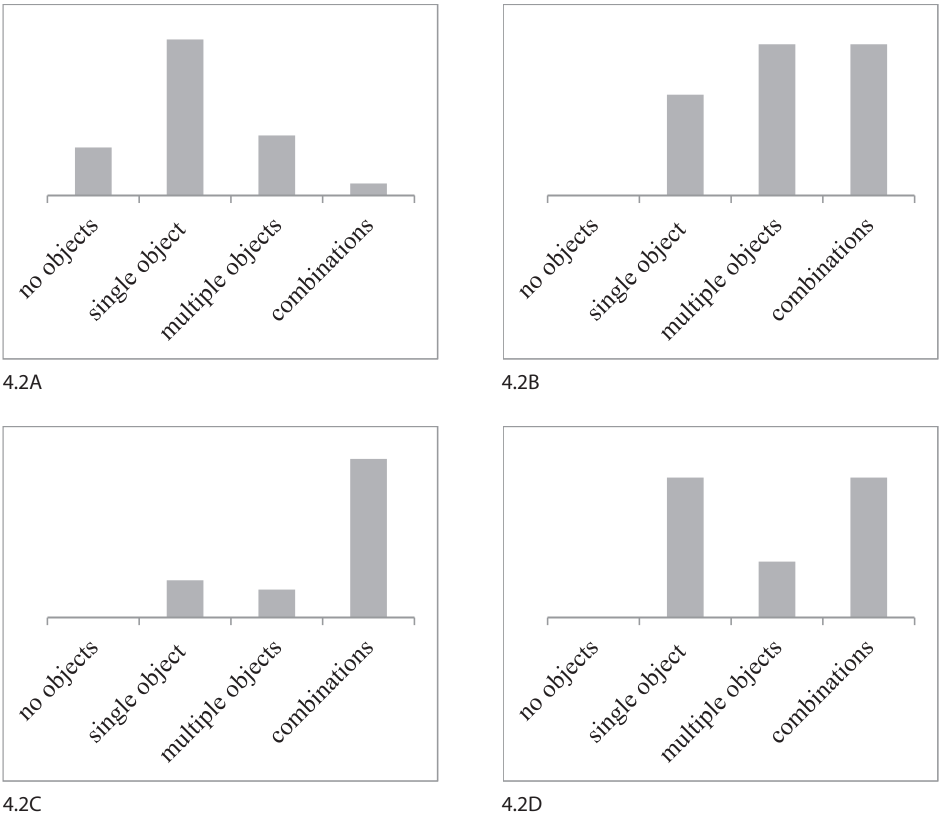

Figure 4.2. Raw data of individual children demonstrating the patterns of frequency of forms of exploration within four minutes observation

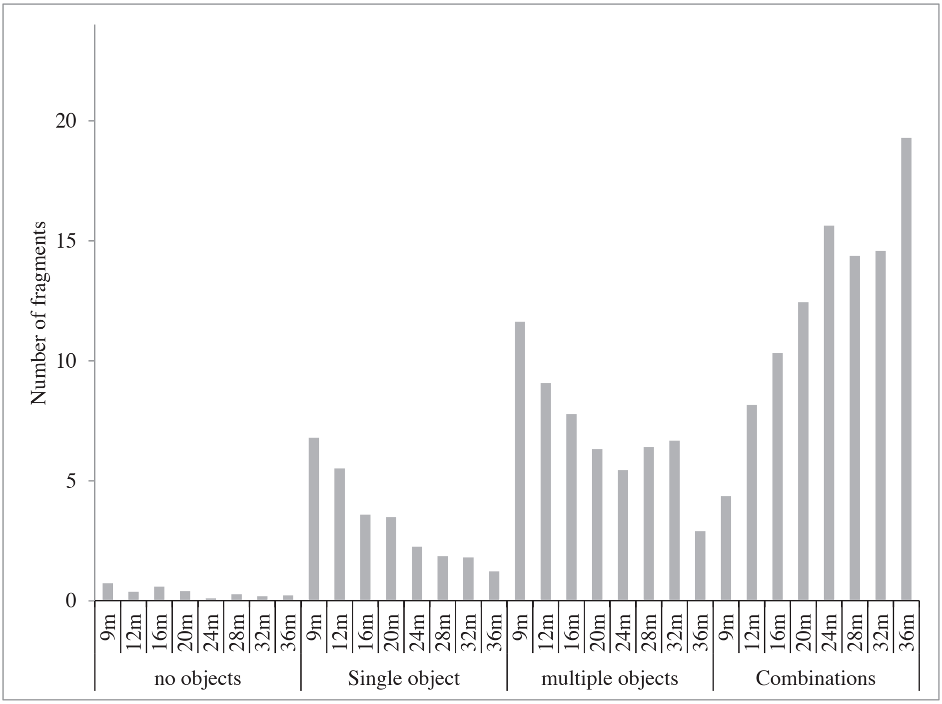

Figure 4.3. Mean number of intervals scored per exploration form per age group.

non-adjacent forms as both most frequent is inconsistent with the IRT assumption (see Figure 4.2D). Two observations (out of a total of over 250) showed this pattern (one child at 12 months and one child at 20 months). These observations were considered as erroneous and treated as missing data.

Figure 4.3 shows the frequency of each form of exploration per age group, revealing that at the younger ages children showed single object or multiple objects exploration most frequently. With increasing age, however, combinations gradually became the most frequent form of exploration. *No exploration* was never the most frequent form of behavior in the current sample. Therefore this level was not informative for the current purpose and not included in further analyses in order to keep the model as parsimonious as possible. Furthermore, at the oldest age a ceiling effect was manifest; almost all children showed mainly combinations during exploration, indicating that combining objects is a well-established skill at this age for almost all children in the current sample. Due to the ceiling effect and the resulting severely limited variance in scores, the data from the last measurement moment at 36 months could not be used in further analyses. In summary, close examination of the data confirmed that coding in terms of the most frequent form of exploration would be appropriate for this data set. Exploration was coded as a categorical value ranging from exploration with single objects (coded as 2) to the making of combinations (coded as 4), for each child, at each measurement occasion.

When two adjacent forms were both the most frequent forms and roughly equally frequent (within 10% difference), the lower score was awarded to avoid overestimation of children's level of exploration.

To model the longitudinal change in the frequencies of the different exploration forms, a latent growth model (LGM) for categorical data was used. LGM can be used to estimate the mean level (across ages) of a developing ability in a particular sample (intercept), the mean growth of this ability over time (slope), and the inter-individual variances in level and growth, which represent inter-individual differences in developmental trajectories. For the present purpose, the mean of the intercept is not of interest as the numerical values of the latent ability scale are arbitrarily chosen (see below). The focus is on the development of children's exploration ability (reflected in the slope) and on the inter-individual differences in developmental trajectories (reflected in the variances of the intercept and the slope). Model building included a second assumption based on IRT, stating that there is an underlying continuous and developing latent ability that can predict the probability of using each form of exploration at a given age and ability level. The higher a child is on the latent ability scale, the greater the chance he or she will display a more complex form of exploration. Using a basic version of a multi-category IRT model known as the Graded Response Model (Embretson & Reise, 2000), mapping the probability of use of a particular exploration form to the latent ability leads to a graphical display as in Figure 4.4. In this figure the X-axis represents the latent ability scale and the Y-axis represents the probability of engaging in each form of exploration. Individual children as well as group means are assumed to progress on the X-axis to the right towards a higher ability level over time. This increase in the latent ability is modeled by the LGM part of the overall model. Note that Figure 4.4 represents data that are generated by the Graded Response Model using

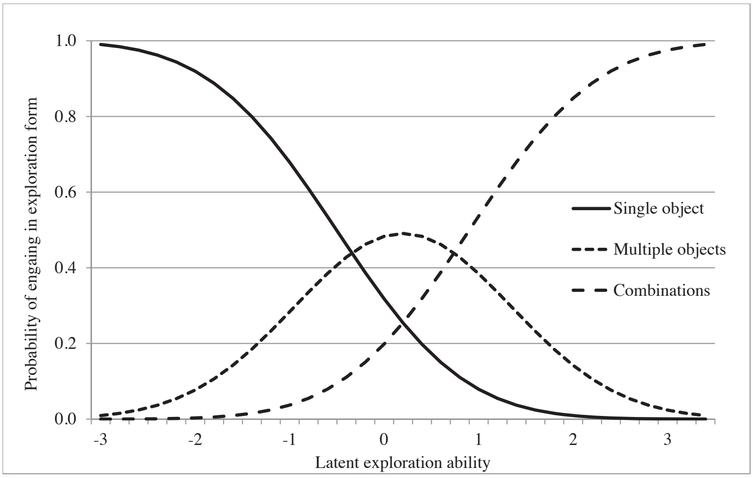

Figure 4.4. Overlapping waves model for the development of exploration of spatial-relational properties based on the Graded Response Model.

the estimated regression coefficients for each measurement occasion generated by LGM part of the model. The actual data of the present study do not cover the whole scale. Children's scores at the first measurement point are distributed around the zero point on the X-axis (which represents the average ability at age 9 months; see also Figure 4.5 below).

The shape of the curves in Figure 4.4 is fixed and the middle point of the scale (which is arbitrarily set to zero) predicts the probability of all exploration forms at the first measurement point at age 9 months. The only parameters to be estimated in this case are the two thresholds that represent the points where curve 1 and 2 respectively curve 2 and 3 intersect. Together these two parameters suffice to define the model. More complex models are possible, but the present study opted for the most parsimonious model. The shapes of the curves of the overlapping waves were constrained to remain the same over time, reflecting the assumption of measurement invariance over time.

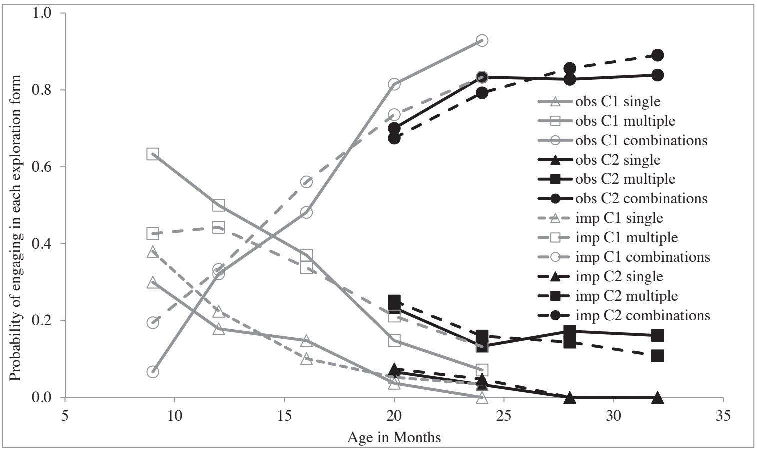

Figure 4.5. Observed versus implied trends in children's spatial-relational object exploration from age 9 to 32 months.
Note. obs=observed, imp=implied, c1=younger cohort, c2=older cohort.

Data from both age cohorts were combined into a single growth model, using a cohort-sequential accelerated design. In an accelerated design, data from different age cohorts drawn from the same population can be combined on the basis of overlapping measurements to estimate a single growth model, creating a virtual longitudinal cohort that spans the whole age range of the two cohorts together (Duncan et al., 2006). Estimation was done with Mplus version 7.11 (Muthén & Muthén, 1998-2010, see example 6.4). Using the two-group option of Mplus the factor loadings and measurement errors of measurements at the two overlapping measurement moments were constrained to be equal in the two cohorts. For the technically interested reader we provide further details about the model in the Appendix. Fit of the final model was evaluated using Bayesian estimation. In this approach the informative fit statistic is the Posterior Predictive Probability value (*ppp* value) and a *ppp* value of around .50 indicates good model fit. For each estimated parameter value a credibility interval is computed. For a 90% credibility interval, there is 90% probability that the population value is within this interval (for a detailed explanation see Van de Schoot et al., 2013). We did not specify any informative priors, but only used the default priors specified in Mplus (Muthén & Muthén, 1998-2010). If the model fits the observed data well, the *ppp* value should be around .50 and separate curves should arise for each form of exploration, with partial overlap.

Finally, variables were added to the model as predictors of the variances in intercept and slope. Given the small sample size, in order to limit the number of variables in the model, two separate models were tested. First, a model was estimated with two background variables, gender and SES, as predictors. Second, a separate model was estimated with the measurement of children's spatial memory at the third measurement moment (ages 16 and 28 months for the younger and older cohorts respectively) as predictor. In order to reduce the chance of type II error, a significance level of $\alpha = .10$ was used.

Results

The descriptives of the observation data are presented in Figure 4.3 and were already discussed in the Methods section. The descriptives for spatial memory and SES are presented in Table 4.3. Table 4.3 shows that most parents in the current sample had completed higher vocational or academic education and had jobs at the professional or academic level.

Table 4.3 Descriptive statistics of model variables

	M	*SD*
Spatial memory age 16 months	5.63	1.60
Spatial memory age 28 months	7.93	1.05
SES[a]	-.01	.78
Education level mother[b]	6.30	1.02
Education level father[b]	5.96	1.27
Occupation level mother[c]	4.05	.95
Occupation level father[c]	4.18	.95

Note. [a] SES is the mean of *Z* transformations of the scores on parental educational and occupational level. [b] Education level was measured on a 7-point scale. [c] Occupation level was measured on a 5-point scale.

Overlapping Waves Model

The results of the LGM showed good model fit (*ppp*-value = .45). Table 4.4 presents the model parameters. The significant mean of the slope indicates that there is significant development in

Table 4.4 Model parameters for overlapping waves model showing the development of exploration

	Unstandardized value (*SD*)[a]	Standard value	90% CI[b]
Mean Slope[c]	.62 (.09)***	-	[.49,.77]
Mean Intercept[c]	-.31 (.18)†	-	[-.60,-.01]
Variance Slope	.12 (.05)***	-	[.07,.22]
Variance Intercept	.27 (.22)***	-	[.11,.74]
Covariance intercept-slope	-.07 (.08)	-.42	[-.26,.01][d]
Factors predicting the intercept[e]			
Gender	.60 (.38)†	.60	[.05,1.25]
Spatial memory 16 months	-1.67 (2.99)	-.27	[-5.73,3.94]
Spatial memory 28 months	-.36 (2.16)	-.10	[-3.71,3.38]
Factors predicting the slope[e]			
Spatial memory 16 months	6.51 (3.29)*	.72	[1.36,12.18]
Spatial memory 28 months	1.09 (1.94)	.20	[-1.98,4.32]

Note. † $p < .10$ * $p < .05$ ** $p < .01$ *** $p < .001$
[a] SD = posterior standard deviation. [b] CI = credibility interval around unstandardized parameter value. [c] As the scale is arbitrary standard values for these parameters are meaningless. [d] Standard 90% confidence interval: [-.74, .05]. [e] Only factors included in final models (after model trimming) are reported.

children's skill to exploit spatial-relational affordances during exploration. As mentioned above, the mean of the intercept (the overall level on the latent scale) is arbitrary and should not be interpreted. The significant variances of both intercept and slope indicate that children vary significantly in both the overall level of exploration ability and in the rate of growth over time. The correlation between the intercept and the slope is not significant. Figure 4.4 has already been discussed in the method section and shows a representation of the resulting overlapping waves model using the results of the LGM analysis. Figure 4.5 graphically displays the trends implied by the model versus the actually observed trends in children's spatial-relational object exploration (created in Microsoft Excel), showing that the model indeed fits the data well as the lines representing the observed and implied trends largely coincide. Note that Figure 4.5 corresponds to the right part of Figure4. 4, showing the same overlapping waves pattern. Both Figures 4.4 and 4.5 show that, over time, exploration involving single and multiple objects becomes less probable, whereas exploration involving combinations becomes more probable.

Figure 4.6 presents a few examples of individual developmental trajectories from the raw data. The Y-axis represents the relative frequency of each form of exploration within each observation. Figures 4.6A and 4.6C show a relatively stable increase of the frequency of combinations and a decrease of the frequency of single object and multiple objects exploration with only small fluctuations. Figures 4.6B and 4.6D, on the other hand, show a less stable pattern. The frequency of combinations, for example, drops and then rises again. Thus, Figure 4.6 shows that the growth trajectories of individual children, on which the model is based, indeed show progressions *and* regressions.

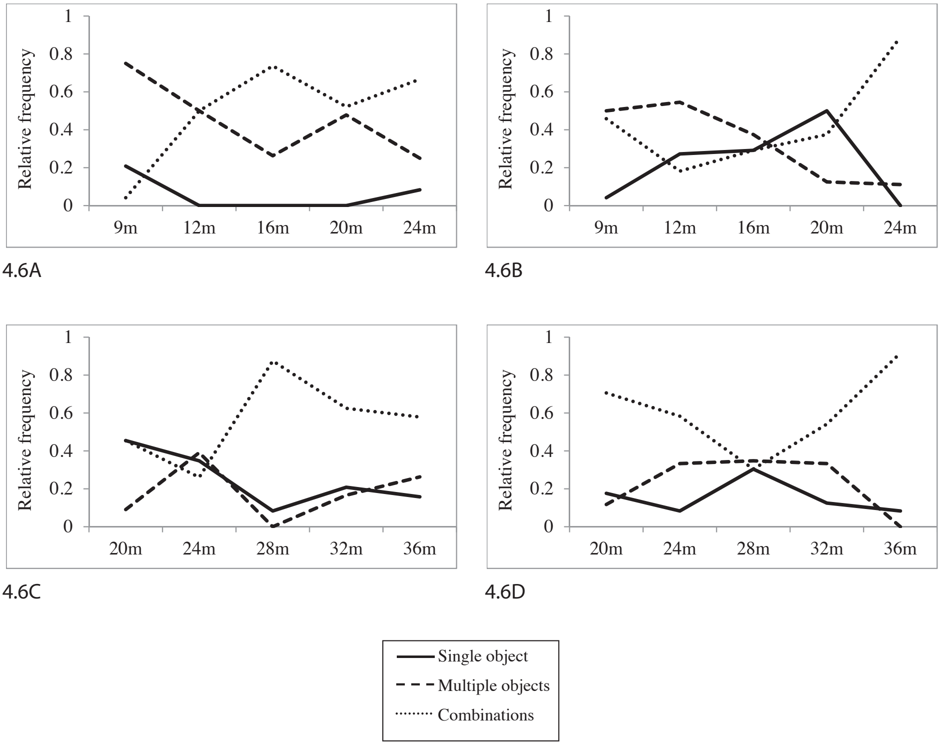

Figure 4.6. Examples of individual growth trajectories. On the top trajectories from the younger cohort and on the bottom trajectories from the old cohort.

Relations with Child Characteristics and Demographic Background

Next, a model was built with SES and gender as predictors of the intercept and slope variance. The initial model had acceptable fit (*ppp* value = .37). However, removing non-significant paths resulted in a better fitting model with only an effect of gender on the intercept variance (*ppp* value = .41). The results are presented in Table 4.4. Gender significantly predicted the intercept (p = .078) and this effect is large. The negative effect means that girls show a higher overall level of exploration ability. There were apparently no effects of SES.

Finally, a model was tested with spatial memory measured at the third measurement moment (age 16 months and 28 months for the younger and older cohort respectively) as predictor of the intercept and slope. Good model fit was obtained by allowing the effects of the predictor to vary between the two cohorts (*ppp* value = .47). As can be seen from Table 4.4 only the effect of spatial memory on the slope of the younger cohort was significant, suggesting that children with better spatial memory at age 16 months grow more rapidly in exploration ability. The effect size is large. No effect was found in the older cohort.

Discussion

The current study examined the development of young children's exploration of the spatial-relational properties of objects within a perception-action theoretical framework. Following Siegler's (1996) theoretical proposal, we could confirm that the development of children's exploration of spatial-relational object properties indeed follows a pattern of overlapping waves. Children progressed from exploring mainly single and multiple objects without combining them to exploring objects mainly by making combinations, while using the spatial-relational properties of objects that specify actions such as insertion, pulling out, or stacking. Although with age the probability of engaging in more complex forms of exploration increased, and the probability of simpler forms decreased, the simpler forms were still observed at later ages. This finding is in line with a perception-action approach viewing development as a dynamic process of becoming increasingly skilled, in which the formation of complex skills builds on and is grounded in lower level, more simple skills (Fischer & Bidell, 2006; E. J. Gibson, 1988; Lockman, 2000; Thelen & Smith, 1994).

Our findings are consistent with the findings of Bourgeois et al. (2005) who studied the development of exploration of object-surface combinations. Similar to our findings, Bourgeois et al. showed in a cross-sectional study that younger children display more single object (or surface) exploration and older children engage more in object-surface combinations. Furthermore, 'less mature' behaviors were still observed in the older children, but less frequently. The current study extends the findings of Bourgeois et al. by providing supportive evidence using a longitudinal design.

The present study shows that children's exploration of spatial-relational object properties over time can be represented on a 'latent ability' scale. A question is what the latent scale actually measures and to what extent the common (statistical) notion of *latent* is applicable. We suggest that the latent growth factor in our model actually is a measure of children's *observable* increasing skill to pick up and exploit the spatial-relational affordances of (constellations of) objects. Although it is tempting to interpret the observed growth as pointing to an internal ability that matures with age, we propose, in line with the perception-action framework, that it rather represents children's increasing skill to perceive and act upon what is there in the environment. The developmental process of becoming increasingly skilled cannot be reduced to mere bodily growth and motor development. While this process is obviously constrained by the children's maturing physical possibilities and neuromuscular motor skills, the development of this skill is primarily driven by children's continuously recurring engaged exploration on the one hand *and* the information structures available for them in the environment on the other hand (see also Greaves et al., 2012). In the current study, the available information structures were the spatial-relational properties of the particular set of objects that was presented to the children.

The pattern of overlapping waves that was observed contributes to the understanding of intra-individual variability in development. Temporary regressions (behavior of a previous stage is observed) constitute a well-known problem for stage theories of development, because of the assumption that once a child has reached a certain stage all behavior should conform to the epistemological constraints of that stage (see Van Geert & Van Dijk, 2002). The use of newly developed statistical techniques enabled us to account for this intra-individual variability, in the development of spatial-relational object exploration. As the different forms of exploration are interdependent (i.e., only one form can be presented at any given moment) they were regarded as outcomes of the same variable representing the continuously developing skill in exploiting spatial-relational affordances. The overlapping waves model then enabled us to model regressions and progressions in this skill. The present results, in line with the perception-action account, suggest that the observed use of more simple forms of exploration should be regarded as an indication that later developing, more complex skills still build on earlier developing, less complex skills (Fischer & Bidell, 2006; Lockman, 2000). For example, the discovery of the complex spatial-relational affordance of stacking objects in a multiple objects constellation requires the perception of the elementary affordances of single objects (e.g., flat solid surface) first. We propose that becoming skilled means becoming increasingly able to very rapidly discover and use the elementary affordances of objects, which opens the possibility of discovering affordances that specify more complex actions.

We further examined relationships of the observed exploration development with child and demographic background characteristics. We found, a relation with gender, suggesting that, overall, girls show a higher level of exploration with this set of objects than boys. Previous work (Pomerleau, 1992; Servin, Bohlin, & Berlin, 1999) has also shown gender differences in exploratory behavior from an early age. Girls, for example, were shown to engage more than boys in pinching and object displacement. These studies, however, did not examine gender differences in exploration of spatial-relational properties of objects as in the current study. The relationship of the growth in exploration with spatial memory at the age of 16 months was strong, indicating construct validity of the model, and confirming findings in a different study that showed long-term relations between exploration in infancy and spatial memory at school age (Oudgenoeg-Paz et al., 2014). Contrary to the expectations, no significant relation was found with spatial memory in the older cohort at the age of 28 months. This is probably due to the ceiling effect in exploration in the older cohort, meaning that for this cohort the variance to be explained was much smaller. Furthermore, no significant relations with SES were found, unlike previous studies. A likely explanation is the restricted variance in SES in the present study. The vast majority of the children in the current sample came from middle to high SES families

Given the composition and small size of the sample, the results of the present study should be interpreted with caution. More research is needed to further examine the generalizability and validity of the model developed in the present study. Future research could investigate the exploration of spatial-relational object properties as a predictor of future abilities, as well as extend the current work by focusing on other aspects of spatial-relational exploration, such as the complexity of the combinations made in terms of the different types of relations explored. Extending the current approach to other kinds of spatial exploration behavior, such as exploration of larger spaces through self-locomotion, is also recommendable. Another interesting direction for future research is to examine more closely the dynamics of exploration at the micro-level, within a given task. Micro-level research can reveal whether similar developmental patterns as found in the current macro-level study characterize micro-development, with changes from more simple to more complex forms of exploration from the beginning towards the end of a task. This can contribute to the understanding of the relationships between developmental processes taking place on different time-scales (see Van Geert & Steenbeek, 2005 for a discussion of the relations between development on the micro and macro time scale). Finally, the present study proposed two basic driving forces of individual development: engagement in exploration and information structures in the environment. If these factors are indeed driving forces in development, examining individual differences in engagement and basic personal characteristics underlying engagement, such as temperament, is a highly relevant research topic. In addition, individual differences in the available information structures, for example in the form of play material and opportunities to explore this material are another relevant research topic. Future studies should examine the effects of relatively impoverished versus enriched environments on development of exploration, as related to the family's SES or to the quality of the day care provision used.

A clear limitation of the study was the relatively small sample size. This had consequences for the power of the study. This limitation was partially compensated for by the multiple measurement moments employed in the study increasing the total number of data points and by the use of a sequential cohort design increasing the degrees of freedom of the model (Duncan et al., 2006). In addition, Bayesian estimation was used to assess model fit. This method is suitable for small samples as it increases the confidence in the parameter estimations obtained with small samples (Van de Schoot et al., 2013). Finally, the use of children's home environment as setting to conduct the observations offered less possibility for standardization and control. However, due to this setting the present study can be considered ecologically more valid than other studies on exploration and spatial development that used lab settings.

Despite these limitations, the current study contributes to the knowledge of child development in both a theoretical and methodological respect. First, the present findings support a perception-action approach to development by showing that the development of more complex spatial-relational object exploration skill builds on and is grounded in less complex spatial-relational object exploration. Second, the study contributes to the repertoire of analytical methods for research in child development, by showing the feasibility of combining latent growth modeling for categorical data with assumptions of Item Response Theory to model development as a series of overlapping waves, as suggested by Siegler (1996) and Van der Ven et al. (2012). This approach can be a powerful tool for studying development over multiple measurement moments, as it can account for the general level of an ability or skill, the average developmental trajectory of a particular sample, the inter-individual differences in developmental trajectories and the frequently observed intra-individual variability in development. Individual differences in the parameters of a model as used in the present study can be examined and related to other characteristics of the child and the environment, and the parameters can be used to predict future abilities in domains such as spatial cognition, language and social-emotional competence.

Appendix-Technical Specification of the Model

The constructed model was a latent growth model with categorical data. In addition, as the current study applied cohort-sequential design, a two group-model was used to combine data from the two age cohorts. For the two-group model a mixture analysis with known classes had to be used; for the categorical part of the model a PROBIT link was used; as estimators we used both maximum likelihood (MLR) and Bayesian estimation. MLR was used because it could handle the required constraints on the thresholds (the sum of threshold one and two had to be constrained to be zero). The Bayesian estimator was used (with threshold values imported from the MLR) because it performs better with small samples and in particular the distribution of variance parameter estimates is more accurate (Van de Schoot et al., 2013).

Chapter 5

Exploration as a mediator of the relation between the attainment of motor milestones and the development of spatial cognition and spatial language

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Abstract

According to the embodied-cognition approach, cognition and language are grounded in daily sensorimotor child-environment interactions. Following this approach, the attainment of motor milestones is expected to play a role in cognitive-linguistic development. Early attainment of unsupported sitting and independent walking indeed appear to predict better spatial cognition and language at later ages. However, evidence pertaining to the relation of these milestones with the development of *spatial* language and to factors that might mediate this relation is scarce. The current study investigated whether exploration of spatial-relational object properties (e.g., the possibility of containing or stacking) and exploration of the space through self-locomotion mediate the effect of, respectively, age of sitting and age of walking on spatial cognition and spatial language. Sixty-two Dutch children took part in a longitudinal study. A combination of tests, observations and parental reports was used to measure motor development, exploration behavior (age 20 months), spatial memory (age 24 months), spatial processing (age 32 months) and spatial language (age 36 months). Results show that attainment of unsupported sitting predicted spatial memory and spatial language, but spatial-relational object exploration did not mediate these relations. Attainment of independent walking predicted spatial processing and spatial language, and exploration through self-locomotion (partially) mediated these relations. Finally, an explorative analysis suggested that a shared predictor, namely exploration through self-locomotion, could explain the relation between spatial processing and spatial language. These findings extend previous work and provide partial support for the hypotheses about the mediating role of exploration.

Introduction

In the first years of life children make huge strides in their development on multiple domains. The rapid development of cognition and language takes place in the context of other major changes in the domain of motor development. Recent research has called for studying the co-development of motor abilities and cognitive-linguistic skills to better understand the developmental mechanisms at work (Adolph, Tamis-LeMonda, & Karasik, 2010; Hockema & Smith, 2009; Iverson, 2010; Rakison & Woodward, 2008; Smith, 2010). One possible mechanism linking motor and cognitive development might be children's exploratory behavior. While using motor skills to explore their environment, children receive and generate sensory information that sets the stage for acquiring new cognitive and linguistic skills (E.J. Gibson, 1988; Smith & Gasser, 2005). Following these ideas, the current study examined the relations between the attainment of the major motor milestones 'unsupported sitting' and 'independent walking' and the development of spatial cognition and spatial language, and investigated the role of exploration as a factor mediating these relations.

The theory of embodied cognition offers a framework in which cognitive-linguistic development is grounded in sensorimotor development. The theory argues that cognition (including language) emerges in real-time through the interaction of a child's physical body and the physical world (Smith, 2005). Children perceive information that is available in the environment and at the same time children make changes in their environment (by acting in it) and thus generate new information to be perceived. By doing so, they experience the time-locked correlations between their own movements and the perceived changes in the environment, thereby laying the foundations for further development involving the discovery of more complex relations between the child and the environment (E.J. Gibson & Pick, 2000; Smith & Gasser, 2005; Thelen & Smith, 1994).

The attainment of particular motor milestones is an important factor in this process because it provides children with completely new possibilities for perceiving and acting in the world, and thus fundamentally changes the information children receive from their environment. The current study focused on the milestones of unsupported sitting and independent walking as these milestones are widely seen as particularly important for cognitive and linguistic advances (e.g., Campos et al., 2000; Soska & Adolph, 2014). Attaining the milestone of unsupported sitting stimulates the child to focus on information in the environment that is functionally needed for maintaining this new posture, such as information for maintaining balance (Bertenthal & von Hofsten, 1998). Attainment of unsupported sitting also frees the hands for manual exploration of objects and, therefore, enables infants to gain better knowledge of object properties (Rochat & Goubet, 1995; Soska, Adolph, & Johnson, 2010). Important properties of objects explored by infants when they can sit are the spatial-relational properties of objects. Spatial-relational object exploration refers to the perceiving of and acting upon properties enabling spatial relations between objects, such as the possibility of containing, stacking, and so forth. When children start to engage in *self-locomotion* they learn to focus their attention on information that is needed for successful navigation in the environment (for a review, see Campos et al., 2000). Engagement in self-locomotion draws infants' attention to the spatial relationships in their environment and enables exploration of the wider space by moving around. For example, children can crawl behind the sofa or between the sofa and the table, and learn about the spatial relations *behind* and *between*. When engaging in exploration through self-locomotion children shift from an egocentric to an allocentric view of the world and learn to perceive their environment from multiple perspectives. Infants engaging in self-locomotion can also manipulate the spatial relationships in the larger environment by carrying objects from one place to another. These interactions with the environment contribute to the formation of spatial concepts (Campos et al., 2000; Newcombe, 2002; Sheya & Smith, 2011).

Research has found support for relations between the attainment of motor milestones, exploratory behavior and advances in spatial cognition. Attainment of unsupported sitting has been related to better visual-manual object exploration which in turn is related to (among others) the ability to: perceive objects as three dimensional (Soska et al., 2010), recognize similarities between objects (Woods & Wilcox, 2013), process dynamic multimodal events involving visual information, sound and action (Baumgartner & Oakes, 2013), improved mental-rotation skills (Möhring & Frick, 2013), and better spatial memory at ages four and six years (Oudgenoeg-Paz, Leseman, & Volman, 2014). Attainment of self-produced locomotion (i.e., crawling or walking) and (self-generated) locomotor experience have been related to success on spatial search tasks (Campos, Anderson, & Telzrow, 2009; Clearfield, 2004), better coding of spatial information and increased awareness of the results of one's own actions (Lehnung et al., 2003; Thelen, Schöner, Scheier, & Smith, 2001), more effective updating of spatial information (Sheya & Smith, 2011), more flexible memory retrieval (Herbert, Gross, & Hayne, 2007), and success in a mental-rotation task (Frick & Möhring, 2013; Schwarzer, Freitag, Buckel, & Lofruthe, 2013). Finally, attainment of independent walking has been specifically related to more advanced object exploration (Clearfield, 2011; Karasik, Adolph, Tamis-Lemonda, & Zuckerman, 2012; Karasik, Tamis-Lemonda, & Adolph, 2011) and the ability to predict action effects (Cignetti, Zedka, Vaugoyeau, & Assaiante, 2013).

Besides the contribution to the development of spatial cognition, attainment of motor milestones and the resulting exploratory behavior are also hypothesized to play a role in language development, as language is also thought to be grounded in sensorimotor child-environment interactions (Gogate & Hollich, 2010; Hockema & Smith, 2009; Iverson, 2010). Several cross-sectional studies have shown correlations between motor and linguistic abilities in both typically developing children (e.g., Alcock & Krawczyk, 2010) and in children with developmental disabilities (e.g., Hill, 2001; Müürsepp, Ereline, Gapeyeva, & Pääsuke, 2009). A number of recent studies have examined these relationships longitudinally, providing further support for the presupposed developmental relations. A previous analysis involving the same sample as in the current study has shown that early attainment of unsupported sitting was related to a higher level of productive vocabulary between ages 16 and 28 months, and that early attainment of independent walking was related to a faster rate of growth in productive vocabulary in this age period (Oudgenoeg-Paz, Volman, & Leseman, 2012). Attainment of walking also appears to be related to an increase in receptive vocabulary (in addition to productive vocabulary), and a higher amount of self-locomotion during free play (crawling and walking) has been found to be associated with a larger receptive vocabulary (Walle & Campos, 2014). Finally, children's motor skills at 12 months of age have been found to be related to their productive language abilities at 16, 20 and 23 months of age (Longobardi, Spataro, & Rossi-Arnaud, 2014). While these studies have focused mainly on general language abilities, it can be expected, given the link between attainment of sitting and walking and development of *spatial* cognition, that attaining these motor milestones is especially important for the development of *spatial* language. Evidence for such a specific relation between the attainment of motor milestones and spatial language would provide additional support for the main tenets of the embodied cognition approach. However, to the best of our knowledge such evidence is still lacking.

In sum, the attainment of unsupported sitting and independent walking has been related to advances in both spatial cognition and language. However, more evidence is needed with regard to the relation of these milestones with spatial language. Moreover, the process through which motor development can promote spatial language development, through which mediating mechanisms, is not well understood. Several studies point to spatial exploration (i.e., exploration of spatial-relational object properties and exploration of the larger space through self-locomotion) as a possible mediating factor. For example, evidence reveals a relation between attainment of sitting and walking and spatial exploration on the one hand, and between spatial exploration and spatial cognition and language on the other hand. However, to the best of our knowledge no study to date explicitly examined in a single design to what extent spatial exploration mediates the relationship between attainment of motor milestone and spatial language development. Therefore, in the current study, it was hypothesized that exploration of objects and space mediates the relation between motor milestone attainment and advances in spatial cognition and spatial language. More specifically, the current study examined (1) to what extent spatial-relational object exploration mediates the relation between attainment of unsupported sitting and the development of spatial cognition and spatial language; and (2) to what extent exploration involving self-locomotion mediates the relation between attainment of independent walking and the development of spatial cognition and spatial language. The study focused on a subset of spatial vocabulary, namely locative prepositions, such as *in* and *on,* and verbs indicating movement in a particular direction, such as *push* and *climb* (Landau & Jackendoff, 1993). As measures of children's spatial cognition we used two different tests, measuring spatial memory and spatial processing respectively, as previous work suggests that spatial memory and spatial processing can be differently related to predictors and outcome variables (e.g., Newcombe, Uttal, & Sauter, 2013; Robert & Savoiea, 2006; St Clair-Thompson & Gathercole, 2006).

Studying the early predictors of spatial cognition and spatial language is important as evidence shows that spatial cognition is important for achievement in technology, mathematics and science, as well as for complex social behaviors requiring perspective-taking (Creem-Regehr, Gagnon, Geuss, & Stefanucci, 2013; for a review see: Newcombe et al., 2013), whereas spatial language enables children to accurately convey complex scenarios, an ability which is important for narrative comprehension and production (Wallentin, Ostergaard, Lund, Ostergaard, & Roepstorff, 2005).

In the current study, 62 children belonging to two age cohorts were followed from 9 to 36 months. Measures of motor milestones attainment, exploration behavior, spatial memory, spatial processing and spatial language were obtained in a series of home visits. For measures taken after the age of 24 months, data was only available for 30 children. In the analyses using these measures (concerning spatial processing and productive spatial language), data from measurements at ages 32 and 36 months were used. Although the entire study included measures of these variables at other ages as well, for the present purpose we focused on a limited set of measures in order to keep the analysis parsimonious, while still including data on advanced spatial cognition and language abilities.

Method

Design and Participants

The sample consisted of 62 typically developing children belonging to two age cohorts. Participants were recruited through daycare centers in the municipality of Utrecht (the Netherlands) and through a list of addresses made available by the municipality. All children came from Dutch speaking families and had no known developmental disabilities or delays. Most families were of medium to high socioeconomic status (SES) as indicated by the level of parental education and the status of their occupations. Informed consent from the parents was obtained for all children. All children took part in five measurement moments ranging from age 9 to 24 months for the younger cohort (*N* = 30, 53% girls) and from 20 to 36 months for the older cohort (*N* =

Table 5.1 Sample size, mean children's age and standard deviations divided by cohort for all measurement moments

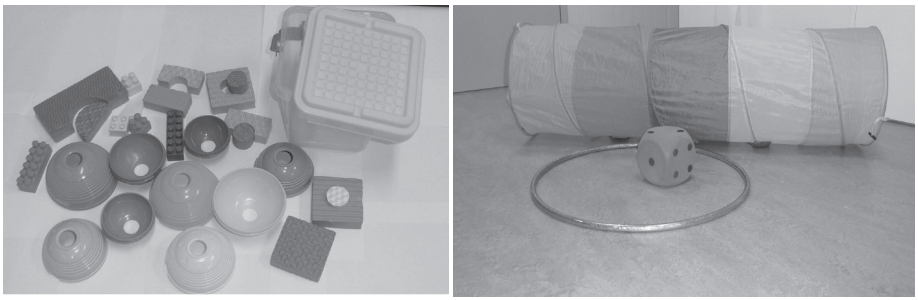
	Young cohort		Old cohort		Total	
Measurement	***N***	***MAge*[a] *(SD)***	***N***	***MAgea (SD)***	***N***	***MAge*[a] *(SD)***
20 months	27	20.26 (.29)	31	20.75 (.61)	58	20.52 (.54)
24 months	28	24.12 (.33)	30	24.14 (.30)	58	24.13 (.31)
32 months	-	-	31	32.14 (.33)	31	32.14 (.33)
36 months	-	-	29	36.05 (.25)	29	36.05 (.25)

Note. [a] Age in months.

32, 56% girls). Measurements took place at the children's homes roughly every four months with two overlapping measurement moments at ages 20 and 24 months. Table 5.1 presents the mean ages of the children at each measurement moment.

Procedure

At each measurement moment children were visited at home twice. Exploratory behavior was measured at age 20 months. During each of the two visits at this measurement moment the children were filmed while they were exploring a standard set of objects for eight minutes. Two different sets of objects were used, one for each home visit. See Figure 5.1 for photos of the objects used. The first set was used to elicit spatial-relational object exploration and included a transparent container with foam blocks in different shapes that could be fitted into each other, plastic building blocks and nesting cups (see panel A of Figure 5.1). The second set was used to elicit spatial exploration involving self-locomotion and included a play tunnel made of polyester (150cm length and 45cm diameter), a large foam dice (15x15x15cm), and a hoop (70cm diameter; see panel B of Figure 5.1). The video recordings of children's play with the objects were edited to remove interruptions (such as stopping for toileting or drinking). Exploration behavior of each child was scored based on the first four minutes of uninterrupted play. Spatial memory, spatial processing and spatial language were also measured during the home visits, at respectively age 24 months, 32 months and 36 months, using playful tests administered by trained research assistants. Tests were administered in a fixed order. A laptop computer was used to administer the test of spatial language. Age of attainment of motor milestones was measured by parental questionnaires. The families were rewarded with a small gift for their child at each measurement moment.



5.1A Small objects

5.1B Large objects

Figure 5.1. Objects used in the observations.

Measures

Age of attaining motor milestones.

Parents filled out the Parental Checklist of Developmental Milestones (PCDM; Bodnarchuk & Eaton, 2004). The list was given to the parents at the time they enrolled their children in the study (between ages 3 and 9 months for the younger cohort and between ages 13 and 20 months for the older cohort). The list included detailed descriptions of each milestone to help parents with determining if and at which age their child had achieved a particular milestone. Regarding milestones that were not yet attained, parents were asked to keep close track of children's motor development and to note the age at which these milestones were attained. For milestones attained prior to enrolment in the study, parents were asked to use the records kept by the Child and Infant Health Centre or their own records (such as diaries, blog entries, emails and digital photos) to obtain a reliable report of the age at which these milestones were reached. Only two parents could not reliably report the age at which their child started sitting or walking. In addition, one parent reported that the child could not easily sit before age 10 months as she was being treated for hip dysplasia. These data were considered as missing. In the current study we specifically focused on two central milestones: unsupported sitting (baby sits up alone, not supported by a pillow or chair, without using hands for support for at least 30 seconds), and independent walking (walking unsupported across the room; the child uses walking as the main means of moving around). Bodnarchuk and Eaton (2004) have shown that parents can reliably report the age of attainment of these milestones using the PCDM.

Exploration behavior

Children's spatial-relational object exploration and spatial exploration through self-locomotion were scored based on the four minutes video recordings of both types of exploration. Each four minutes recording was divided in 24 intervals of 10 seconds each. Per interval, the activities of the child and the duration of each activity in seconds were noted. Next, a score was given to each interval based on the dominant (longest enduring) activity. Trained observers scored children's spatial-relational exploration behavior for the first set of toys (including the container, blocks and cups) and children's exploration of the larger space through self-locomotion for the second set (with the tunnel, dice and hoop). In total 15.6% of the data were independently scored by two coders. The mean Cohen's kappa for coding of spatial-relational object exploration was .72 (SD = .09) with almost all kappa values (but two) above .70. For exploration through self-locomotion the mean kappa was .75 (SD = .12) with almost all kappa values (but two) not lower than .65.

For *spatial-relational object exploration* the score per interval ranged from 1 to 4: (1) *No exploration* was scored when the child was not engaged with or looking at any of the objects; (2) *Exploration involving a single object* was scored when the child was manipulating (e.g., mouthing, picking up, rotating) and/or looking at a single object; (3) *Exploration involving* *multiple objects* was scored when the child was manipulating or looking at two or more objects (for example when objects were lying next to each other), but was not attempting to combine the objects. This included, for example, holding or mouthing one object and looking at another, picking up multiple objects, throwing or putting down a few objects at once (without ordering them according to shape); (4) *Exploration involving combinations of objects* was scored when the child was bringing two or more objects in relation to each other. Examples of this kind of exploration were: stacking, fitting an object into another object, ordering objects according to shape (e.g., letting the flat ends touch or grouping according to size rather than randomly putting objects in the vicinity of each other). A previous analysis of children's exploration involving the current sample (Oudgenoeg-Paz, Boom, Volman, & Leseman, submitted) has shown that the four forms of exploration constitute an ordinal scale with combining objects as the most complex form in the current age range. Based on the previous study, the use of combinations was expected to differentiate best among children at age 20 months. Therefore, the proportion of using combinations during exploration was used as a measure of children's exploration of spatial-relational object properties.

For *exploration through self-locomotion* each 10 seconds interval was given a score of either stationary (0) or engaged in self-locomotion (1). Stationary activities involved object exploration in a stationary position (i.e., not changing location). Examples are sitting and playing with the dice and standing by the tunnel and banging on it. Exploration involving self-locomotion was scored when the child changed location by self-movement, for example by crawling or walking towards an object, crawling through the tunnel, kicking the dice and running after it. If in a single interval both stationary exploration and self-locomotion were observed, the score was based on the activity that was present most of the time. If both behaviors where observed (roughly) equally long, the score of 1 (self-locomotion) was given to avoid underestimation of the amount of self-locomotion. The total score was the proportion of the intervals in which self-locomotion was used.

Spatial memory

Spatial memory at age 24 months was measured with the stationary version of the boxes task developed by Diamond and colleagues (Diamond, Prevor, Callender, & Druin, 1997) and an adaptation of the memory for location task developed by Caravale and colleagues (Caravale, Tozzi, Albino, & Vicari, 2005). The boxes task consisted of six items of varying difficulty. Three items involved three boxes and three items involved six boxes. In the test items involving three boxes, three toys were hidden in three identical boxes while the child was watching. In test items involving six toys, the same procedure was followed with six toys being hidden in six boxes. After watching the toys being hidden, children were allowed to search for the toys, one box at a time. Before each search attempt a short delay was inserted during which children were actively distracted by the experimenter. If the box in which the child searched indeed contained a toy, the toy was removed from the box. If the box was already empty, the experimenter showed the empty box to the child. After each search attempt, the experimenter closed the (now) empty box and put it back to its original place in the row of boxes. Once the row was complete again, the experimenter distracted the child and then allowed the child to search for another toy. Thus, children had to remember during each search attempt which boxes they had already emptied and which boxes still contained a toy while holding this information in active memory during the delay. A minimum of three respectively six search attempts was needed in order to successfully find all of the toys. An item was scored as *pass* if the child found all three respectively six toys without searching in an already empty box on more than two consecutive search attempts. An item was scored as *fail* if children searched in an already empty box on three consecutive search attempts. To create an adaptive test, test items not only varied in number of boxes, but also in delay time, with delays of respectively one, five and eight seconds for both the items with the three boxes and the items with the six boxes. Items with three boxes or shorter delay times were considered easier than items with six boxes or longer delays (Diamond et al., 1997). All children started the test with the item with six boxes and five seconds delay. If they successfully passed this item, they were given the most difficult item with six boxes and eight seconds delay. If children failed the starting item, they were given the next easier item with six boxes and one second delay, if they failed this item, the next easier item with three boxes and eight seconds delay was presented and so on, until they either successfully passed an item or reached the easiest item (three boxes with one second delay). The final score was the level of the most difficult item passed with success ranging from 0 (fail all items) to 6 (successfully passed six boxes with eight seconds delay). The Spearman Brown coefficient for test-retest reliability with a four months interval between testing occasions was .55, which was considered acceptable given the relative long interval between test and retest.

In the memory for location task[1] one toy was hidden under a cup in a row of six identical cups while the child was attentively watching. Children then had to find this toy after being distracted by the experimenter during a short delay. The test consisted of three items with delays of respectively one, five and 11 seconds. All children started with an item in which they had to find the toy after being distracted for five seconds. If children failed to find the toy, they were allowed a second attempt with also a five seconds delay, but with a change in the location of the toy (which was again hidden while the child was watching). If the child successfully passed the starter item on the first *or* second attempt, a second, more difficult item with 11 seconds delay was presented. If the child failed the starter item on both attempts, a second, but easier item with one second delay was presented. Also for the second item, if children failed to find the toy they were allowed a second attempt with the same delay, but with the toy hidden under a different cup. The final score was the highest level passed with success: (0) no item passed suc-

1 Note that this is the same task as the task used in chapter 4. In this study we used only data from the first two trials in this task. The trials described here were always the first two trials.

cessfully, (1) one second delay, (2) five seconds delay, and (3) 11 seconds delay. The Spearman Brown test-retest reliability with a four months interval was .49 and considered acceptable.

Children's scores on the boxes task and the memory for location task correlated moderately ($r = .27$, $p = .044$). To determine whether the two measures could be combined into a single spatial memory scale, the Spearman-Brown coefficient of the internal consistency was computed, as is recommended with scales consisting of two items (Eisinga, Grotenhuis, & Pelzer, 2013), yielding a value of .47. This value is acceptable given the small number of items in the scale. Therefore, children's scores on these tasks were combined to create a composite score of spatial memory at age 24 months, by computing the mean of the scores on both tests after *Z*-transformation.

Spatial processing

To test spatial processing, the block design task of the Wechsler Preschool and Primary Scale of Intelligence III (WPPSI III; Wechsler, 2002) was administered following the instruction in the test manual. Children were presented with identical red and white-colored blocks and asked to rebuild a pattern presented either by the experimenter or shown to them on a picture, within a pre-specified amount of time, which varied per item between 30 and 60 seconds. The easier items presented first involved patterns presented by the experimenter and the more difficult items presented later involved patterns presented on a picture. The number of blocks and the patterns used increased in difficulty. Children were administered the items until they made three consecutive errors. The test consisted of 20 items and the maximum score was 40 (indicating that a child completed all items successfully within the specified time). The reliability of this test has been reported to be good (Wechsler, 2002).

Spatial language

Productive spatial language was measured using two tests designed to assess children's productive knowledge of verbs containing a direction and of locative prepositions. Children's productive knowledge of verbs describing movement in a particular direction (such as *push* and *climb*) was tested by showing children a short video-clip of a child performing an action and asking them what the child in the clip is doing. If children did not give an answer, the question was repeated and if children still did not respond, they were given a choice between two options (e.g., is the child pushing or climbing?). Films showing a boy were used for boys and films showing a girl were used for girls. In a pilot study, the items were presented to adult native speakers of Dutch to confirm that the films indeed describe the verbs we wanted to elicit. Children's knowledge of productive locative prepositions was assessed using a task involving pictures presented on a laptop screen. In each picture two objects were presented displaying a spatial relation such as *in*, *on*, *behind* and so forth. After the picture was presented the children were asked to state where the [name of the object] is. The pictures showed highly familiar objects, which all children were able to label correctly. When the children just pointed to the picture, they were encouraged by the experimenter to give a verbal response by posing a close-ended question (e.g., is the apple *in* the basket or *on* the basket?).

The tests included 19 verbs and 12 prepositions that were presented in blocks of five (verbs) or three (prepositions). The last block of verbs contained only four verbs. While the words within the blocks were roughly equally difficult, the difficulty level of the blocks increased. The difficulty levels of the words were determined based on the log-frequency counts in Dutch child language corpora (Bol, 1995; De Houwer, 2003; MacWhinney, 2000; Messer, Leseman, Mayo, & Boom, 2010; Van Kampen, 1994; Wijnen, 1988). Each word was tested with two items and if the child was successful on one of the items, the word was scored as passed. For example, a block of three verbs contained six items as each verb was introduced twice. If a child made errors on two or more words within a block, testing was stopped. The score was the number of words passed with success. The easiest block of verbs contained words such as *jump* and *pull* and the most difficult block contained words such as *slide* and *collide*. The easiest block of prepositions contained words such as *in, on* and *under* and the more difficult blocks contained words such as *behind* and *between*. The test-retest reliabilities of both tasks (with the test-retest moments four months apart) were .82 for the verbs task and .75 for the prepositions task. Further, scores on both measures correlated strongly (r = .81, p < .001) and the Spearman-Brown coefficient was .90, suggesting that the scores can be combined. A total score for productive spatial language was then computed by calculating the mean of the scores on both tests after Z-transformation.

Statistical Analysis

Six separate mediation models were tested. The first three models included exploration of spatial-relational object properties as a mediator of the effect of age of sitting on, respectively, spatial memory, spatial processing and spatial language. The second series of models included exploration through self-locomotion as a mediator of the effect of age of walking on these outcome variables. To test the mediation hypotheses, the four steps described by Baron and Kenny (1986) were followed. First the effect of the main predictor (in the current study age of attainment of sitting respectively walking) on the outcome variable (in the current study spatial memory, spatial processing or spatial language) was evaluated for significance. Second the statistical significance of the effect of the main predictor on the mediator (in the current study spatial-relational object exploration or exploration through self-locomotion) was determined. Third, the effect of the mediator on the outcome variable was tested for statistical significance. The first three steps involved the evaluation of bivariate correlations. For the final step a complete multivariate model was tested using hierarchical regression analysis. In this analysis the main predictor was entered as a predictor of the outcome variable first. Next, the mediator was added to test if the mediator added to the prediction and changed the effect of the main predictor. The Sobel-Goodman test was then used to determine if the mediation effect was significant. Note that analyses with spatial processing and spatial language as the dependent variables were conducted with data from the older cohort only.

Finally, Structural Equation Modelling (SEM), using Mplus (Muthén & Muthén, 1998-2010), was applied to test an explorative model in which the strongest predictors of spatial language (as evident from the previous regression analyses) were all included in a single model. This explorative analysis only involved the older cohort. Therefore, given the small sample size, Bayesian estimation was applied to estimate the model fit because this estimation procedure increases the confidence in parameter estimates obtained with small samples. In this approach the informative fit statistic is the Posterior Predictive Probability (*ppp* value). A *ppp* value around .50 indicates good fit. In addition, for each parameter the 90% credibility interval was computed. A 90% credibility interval means that there is 90% probability that the population value is within this interval (for more details on Bayesian estimation see Van de Schoot et al., 2013). Because Bayesian estimation does not yield clear criteria for comparing different models to determine which model fits the data best, we first applied model trimming using Maximum Likelihood (ML) estimation with bootstrapping to find the best fitting model (Kline, 2005). This model was then estimated using Bayesian estimation to obtain robust model parameters and a robust model fit indicator. We did not define any informative priors for this analysis but used the default priors specified in Mplus. Given the small sample size, the present analysis should be considered as exploratory. In order to reduce the chance of Type II error with the relatively small sample size (especially in analyses including only data from the older cohort) an alpha level of .10 was used as the critical value.

For variables for which data from both cohorts were available (measurements of exploration, spatial memory and age of attainment of motor milestones), a series of *T*-tests revealed that the two cohorts did not significantly differ on any of these variables. In addition, Fisher's *Z*-tests showed that the bivariate correlations between these variables did not differ between the two cohorts either. Therefore, data from both cohorts were combined and used as one set of data in subsequent analyses. Missing data were estimated using the imputation method described by Schafer and Graham (2002). Missing values of each participant were estimated by means of regression analysis, based on the observed values for this participant. In addition, random noise (values drawn from the error distribution of the regression analysis) was added to the predicted values, in order to maintain the variability structure. For the SEM analyses in Mplus missing data were estimated using Full Information Maximum Likelihood (FIML) estimation and for the Bayesian estimation the Markov Chain Monte Carlo algorithm was used to perform Multiple Imputation (Muthén & Muthén, 1998-2010).

Results

Descriptive Analysis

Table 5.2 presents the means and standard deviations for all model variables. Two children in the younger cohort and one child in the older cohort only took part in the first two measurements.

Table 5.2 Descriptive statistics of model variables and indicators

	Younger cohort		Older cohort		Total	
Variable	*n*	*M(SD)*	*n*	*M(SD)*	*n*	*M(SD)*
Age of sitting	28	8.36 (1.49)	31	8.12 (1.57)	59	8.23 (1.52)
Age of walking	29	14.95 (2.57)	30	15.02 (2.1)	59	14.98 (2.28)
Spatial-relational object exploration 20 months	28	.56 (.17)	31	.53 (.22)	59	.54 (.19)
Exploration through self-locomotion 20 months	27	.51 (.20)	29	.47 (.20)	56	.49 (.20)
Mean score spatial memory 24 months[a]	28	-.05 (.81)	30	-.01 (.90)	58	-.03 (.85)
Boxes task 24 months	27	4.24 (.95)	30	4.16 (1.15)	57	4.20 (1.05)
Memory for location task 24 months	28	2.57 (.62)	30	2.67 (.60)	58	2.62 (.61)
Spatial processing 32 months	-	-	28	13.97 (2.83)	28	13.97 (2.83)
Mean score productive spatial language 36 months[a]	-	-	31	.00 (.95)	31	.00 (.95)
Spatial verbs productive 36 months	-	-	31	16.65 (4.55)	31	16.65 (4.55)
Spatial prepositions productive 36 months	-	-	31	9.00 (3.20)	31	9.00 (3.20)

Note. [a] These scores are mean of *Z* transformations.

In addition, some of the data were missing due to technical difficulties with filming, lack of corporation from children and incomplete questionnaires. This resulted in 6% of the data missing. Due to the missing data and attrition of one child in the older cohort that only took part in the measurements at ages 20 and 24 months, analyses using data from later ages were conducted with data from 30 children. The mean scores on spatial language indicate that most children were already rather competent in producing the words belonging to the easier blocks of verbs and prepositions and that most inter-individual variance can be found in children's knowledge of the more difficult verbs and prepositions, presented in the later blocks. Table 5.3 shows the correlations between all variables used in the analyses and reveals that the two forms of exploration correlated moderately. The age of sitting and the age of walking were also positively and moderately inter-correlated as was expected. In addition, age of walking did not correlate with spatial-relational object exploration and age of sitting did not correlate with exploration through self-locomotion.

Table 5.3 Correlations between all model variables

	1	2	3	4	5	6
1. Age of sitting						
2. Age of walking	$.37^{**}$					
3. Spatial-relational object exploration 20 months	.02	.00				
4. Exploration through self-locomotion 20 months	-.12	$-.38^{**}$	$.27^{*}$			
5. Spatial memory 24 months	$-.35^{**}$	-.16	$.38^{**}$	.15		
6. Spatial processing 32 months	-.12	$-.39^{*}$	-.04	$.53^{**}$	.10	
7. Productive spatial language 36 months	$-.31^{\dagger}$	$-.54^{***}$	.10	$.65^{***}$	.15	$.59^{***}$

Note. $^{\dagger}p \leq 10$ $^{*}p \leq 05$ $^{**}p \leq .01$ $^{***}p \leq .001$.

Testing Mediation

To test the mediation hypotheses, first the relations between the main predictors (age of attainment of motor milestones) and the dependent variables (spatial memory, spatial processing and spatial language) were examined. Table 5.3 reveals that age of sitting significantly predicted spatial memory with a medium effect size, suggesting that early attainment of sitting goes together with higher scores on spatial memory at age 24 months. Further, age of walking did not significantly predict spatial memory and age of sitting did not significantly predict spatial processing at age 32 months. Age of walking, however, did significantly predict spatial processing with a large effect size, with the negative sign indicating that attaining independent walking at an earlier age is related to better performance on the spatial processing task. Both age of sitting and age of walking significantly and negatively predicted spatial language with medium-sized effects.

In the next step the relations between the main predictors and the mediating exploration measures were tested. Spatial-relational object exploration was hypothesized to mediate the effects of age of sitting. However Table 5.3 reveals that there was no significant relation between the two variables. Therefore, a mediation effect was not possible. Exploration through self-locomotion was hypothesized to mediate the effects of age of walking. Table 5.3 reveals that age of walking indeed significantly predicted exploration using self-locomotion with a medium effect size, suggesting that early attainment of independent walking at an earlier age is related to higher degree of exploration through self-locomotion at age 20 months.

The third step concerned testing the relation between the mediators and the outcome variables. The results can again be found in Table 5.3. Spatial-relational object exploration

Table 5.4 Results of hierarchical regression analyses for factors predicting spatial cognition and spatial language

Dependent variable	Spatial Memory [a]		Spatial Processing [b]		Spatial Language [c]	
Predictors	***B(SE)***	***β***	***B(SE)***	***β***	***B(SE)***	***β***
			Effects of age of sitting			
Age of sitting	-.20 (.07)	-.36**	-.27 (.35)	-.16	-.19 (.11)	-.32†
Spatial-relational exploration	1.68 (.53)	.38**	-.98 (2.82)	.07	.10 (.85)	.02
R^2	.27		.03		.10	
ΔR^{2d}	.14**		.01		.00	
			Effects of age of walking			
Age of walking	-.05 (.06)	-.14	-.40 (.27)	-.26	-.20 (.07)	-.41**
Exploration using self-locomotion	.33 (.68)	.07	7.06 (2.46)	.51**	2.53 (.77)	.48**
R^2	.03		.40		.55	
ΔR^{2d}	.00		.23**		.21**	

Note. † $p \leq .10$ * $p \leq .05$ ** $p \leq .01$ *** $p \leq .001$ [a] $n = 55$ for sitting and $n = 53$ for walking. [b] $n = 27$ for sitting and $n = 24$ for walking. [c] $n = 30$ for sitting and $n = 27$ for walking. [d] ΔR^2 is computed in relation to the model in which only sitting respectively walking were entered as predictors.

significantly predicted spatial memory with a medium effect size. Exploration using self-locomotion did not significantly predict spatial memory. Furthermore, exploration of spatial-relational object properties did not significantly predict spatial processing nor spatial language. However, exploration through self-locomotion significantly predicted both spatial processing and spatial language, with medium and large effect sizes respectively.

In the final steps hierarchical regression analyses with attainment of motor milestones (sitting and walking) and exploration (spatial relational object exploration and exploration using self-locomotion) as predictors of spatial memory, spatial processing and spatial language were conducted. Results are presented in Table 5.4. Besides confirming what was already reported based on the bivariate correlations, Table 5.4 reveals two relevant additional findings. First, exploration through self-locomotion mediated the effect of age of independent walking on spatial processing. Together these predictors had a large effect on spatial processing. The Sobel-Goodman test confirmed that this mediation effect was marginally significant ($Z = 1.68$, $p = .09$). Second, exploration through self-locomotion partially mediated the effect of walking on spatial language and together the two predictors had a large effect on spatial language. The results of the Sobel-Goodman test revealed that this mediation effect was significant ($Z = 2.20$, $p = .03$). Note that analyses with spatial processing and spatial language were conducted with data from the older cohort only.

Combined Model

Finally, a SEM-model was built in which age of attainment of walking, exploration through self-locomotion, and spatial processing were modelled as predictors of spatial language in a single model. In the previous analyses, these variables were found to be the strongest predictors of spatial language (see Tables 5.3 and 5.4). Note that this analysis was performed with data of the older cohort only ($n = 30$). Spatial processing and exploration using self-locomotion were modelled as mediators of the effect of walking on spatial language. First, ML estimation was applied to find the best fitting model. A model with all direct and indirect paths was a saturated model with perfect fit by definition. In a process of model trimming, insignificant paths were removed to obtain a more parsimonious model with still good model fit. This process resulted in a model in which both the direct effect of spatial processing on spatial language and the direct effect of walking on spatial processing were set to be zero, which did not deteriorate model fit ($\Delta\chi^2(2) = 2.31$, $p = .32$). The resulting model had a satisfactory model fit ($\chi^2(2) = 2.31$, $p = .32$, $CFI = .98$ $TLI = .95$ $RMSEA = .07$). Removing the direct effect of walking on spatial language (which was not significant) resulted in a significantly worse model fit ($\Delta\chi^2(1) = 2.90$, $p = .09$). Therefore, this path was maintained in the model. Next, all the remaining paths were subsequently constrained to zero one at a time, which always resulted in a significantly worse model fit. Therefore, no other paths were removed. Finally, Bayesian estimation of the final model resulted in a good model fit (*ppp* value = .46). The path coefficients of the final model are presented in Figure 5.2. The combined effect of all predictors on spatial language was large and the results show partial

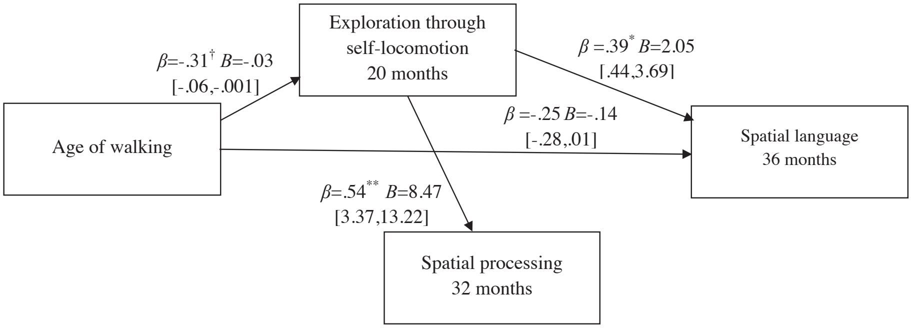


Figure 5.2. Final SEM model for factors predicting productive spatial language at age 36 months ($N = 30$), using Bayesian estimation.
Note. † $p \leq .10$ * $p \leq .05$ ** $p \leq .01$ *** $p \leq .001$. Between square brackets the 90% credibility interval for unstandardized coefficients is given. R^2 for spatial language = .30, R^2 for spatial processing = .30, R^2 for exploration through self-locomotion = .10.

mediation by exploration through self-locomotion of the effect of attainment of walking on spatial processing and spatial language. The Sobel-Goodman test, however, revealed that these mediation effects did not reach statistical significance (mediation of effect on spatial processing: Z = 1.42, $p = .15$; mediation of effect on spatial language: $Z = 1.54$, $p = .12$). This might be due to the low power of the analysis.

Discussion

The current study examined to what extent the ages of attainment of unsupported sitting and independent walking predict young children's development in spatial cognition and productive spatial language. We hypothesized that children's exploration of the spatial-relational properties of objects and children's exploration of objects in space through self-locomotion mediate these relations. These hypotheses were derived from the embodied cognition approach to cognitive and language development, which assumes that cognition, including language, emerges from body-environment interactions (Hockema & Smith, 2009; Smith, 2005) and that, therefore, cognitive-linguistic development should be studied within the context of motor development and movement (Iverson, 2010). The results of the current study, involving two cohorts of children in the age range of 9 to 36 months, provide partial support for these hypotheses.

In line with the hypotheses, the results showed that attainment of sitting predicted spatial memory and productive spatial language, suggesting that reaching this milestone at an earlier age is related to enhanced spatial memory and spatial language later on. Also, in agreement with the hypotheses, spatial-relational object exploration at 20 months was found to predict spatial memory. Contrary to the hypotheses, however, no significant relations were found between age of sitting, spatial-relational object exploration, and spatial processing, nor between spatial-relational object exploration and spatial language. Furthermore, spatial-relational object exploration was not significantly related to the age of attainment of sitting and, therefore, did not mediate the effects of attainment of sitting on spatial cognition and spatial language.

Our findings extend previous analyses conducted with this sample (Oudgenoeg-Paz et al., 2012) and work done by other researchers on the relation between attainment of sitting and the development of for example 3D perception or object individuation (e.g., Soska et al., 2010; Woods & Wilcox, 2013) by showing that the attainment of sitting is also related to, in particular, spatial memory and spatial language. In contrast to previous work, we did not find a relation between the attainment of sitting and object exploration. This might be due to the comparatively long interval between the age at which sitting was attained and the age at which object exploration was assessed (this interval was on average about 12 months). Other studies that did find a significant relation between attainment of sitting and object exploration (such as Soska et al., 2010; Woods & Wilcox, 2013) assessed children's exploration within a relatively short period of time (from a few weeks to a few months) after the attainment of sitting. Possibly, children, who lag behind in sitting and, therefore, initially show less object exploration, can quickly catch up when they ultimately do attain unsupported sitting. Thus, when exploration is measured after a relatively long period of time, the relation between age of siting and spatial-relational object exploration may not be detectable anymore. At this later stage, other factors, such as the materials available in the environment or personal characteristics such as activity level and attention span may become more important in explaining individual differences in spatial-relational object exploration.

Support was found for the hypotheses that attainment of walking predicts spatial processing and productive spatial language, suggesting that an earlier age of walking goes together with increased spatial processing capacity and spatial language knowledge. The results further showed, in agreement with the hypotheses, that these effects are partially mediated by exploration through self-locomotion. Contrary to our hypotheses, we did not find an effect of walking nor of exploration through self-locomotion on spatial memory; we will return to this issue in the general discussion section.

To summarize, the current study adds to previous work done with this sample (Oudgenoeg-Paz et al., 2012) and to other studies (e.g., Campos et al., 2009; Karasik et al., 2011) by showing a relation between walking, exploration and cognitive-linguistic development. The present study more specifically shows that walking is also related to spatial language development, not only general language development. Furthermore, the partial mediation that was found suggests that exploration through self-locomotion might be one of the mechanisms through which the ability of self-locomotion, walking in particular, promotes spatial cognition and spatial language development. This is in line with an embodied cognition view on development.

In the present study, spatial cognition was assessed by tests measuring children's abilities in two subdomains of spatial cognition, namely spatial memory and spatial processing. Instead of pooling the measures to obtain a general composite measure of spatial cognition, spatial memory and spatial processing were included as separate constructs in the main analyses, because previous research had shown that these abilities are differently related to child characteristics and concurrent measures of academic abilities (Alloway, Gathercole, & Pickering, 2006; Levine, Vasilyeva, Lourenco, Newcombe, & Huttenlocher, 2005; Newcombe et al., 2013; St Clair-Thompson & Gathercole, 2006). In the current study, these two subdomains of spatial cognition were indeed differently related to other child characteristics. While spatial memory was related to age of sitting and spatial-relational object exploration, spatial processing was related to age of walking and exploration using self-locomotion. A possible explanation for these differential relations might be found in the different kinds of knowledge and processing skills required for success in the tasks measuring spatial memory and spatial processing respectively, on the one hand, and how the different forms of exploration studied can promote skill development in either domain, on the other hand. Spatial-relational object exploration enables children to learn about spatial relations between objects such as *in*, *out*, and *on*, as they insert objects into a container, taking them out of a container, and stacking objects on other objects. These basic sensorimotor cognitions can be acquired from a single perspective and relatively fixed location of the body in space, and may be sufficient to solve the spatial memory tasks used in this study in which children had to remember *in* which box or *under* which cup the toys were hidden, but children were not required to change perspective or imagine movement. The spatial processing task used in this study, in contrast, required children to look at the blocks from different angles and to imagine block patterns from different points of view. The kind of spatial processing involved in this task is at stake in exploration through self-locomotion. As children move *behind* objects, *between* objects and so forth, they perceive changes in view which are time-locked to the interoception of their own movements, contributing to the development of a sensorimotor processing system that is needed to solve tasks like the spatial processing task in this study and related tasks involving mental rotation. Thus, spatial-relational object exploration is usually stationary and involves a single perspective from which locations and relations in space are encoded, whereas exploration through self-locomotion involves moving around in space and can be seen as emerging spatial processing, which foreruns spatial processing in tasks in which children are required to imagine movement in order to change perspective (i.e., as in mental rotation). Future studies should further test this hypothesis.

Spatial-relational object exploration was not related to spatial language, whereas exploration through self-locomotion was. The fundamental difference in the kind of knowledge and skills at stake in both types of exploration, can again offer an explanation for this pattern of findings. Spatial-relational object exploration is about the sensorimotor understanding of relations like *in* and *on*, likely underlying the acquisition of simple locative prepositions such as *in* or *on*, which are among the most frequent prepositions in early child language and presumably learned clearly before more complex prepositions. Upon closer examination of the data, it appeared that at age 36 months the vast majority of children passed virtually all the items measuring knowledge of these prepositions with success, thus showing hardly any variance in these items which can explain the lack of correlation with spatial-relational object exploration at age 20 months. At age 36 months, however, children still differed considerably in their knowledge of more advanced prepositions such as *behind* and *between*. These more advanced prepositions, in turn, are probably more strongly related to the sensorimotor knowledge emerging from exploration by self-locomotion than to the knowledge emerging from exploration of spatial-relational object properties. For example, through literally moving behind an object and seeing what is hidden behind that object, children may learn the sensorimotor concept *behind.* Similarly, through moving between two objects and perceiving the presence of both objects on both sides, children may learn the concept *between*. In addition, also the verbs used in the spatial language test (such as push or climb) involve mainly gross motor movements. It is plausible that knowledge of these verbs is more strongly related to exploration involving movement in the larger space than to stationary object exploration. Thus, the intrinsic relation with complex spatial language, on the one hand, and the comparatively strong variance in test-items measuring complex spatial language, on the other hand, can explain that clear main and mediator effects were found of exploration through self-locomotion. Future studies should conduct a fine-grained analysis of the relations of the different exploration forms with specific (groups of) prepositions and verbs.

The final exploratory analysis revealed that the significant relation between spatial processing and spatial language disappeared when exploration through self-locomotion as a mediator was taken into account. An explanation for this finding might be that both spatial processing and spatial language are propelled by the spatial sensorimotor knowledge acquired through exploration of the larger space. Thus, the relation between spatial processing and spatial language might be based in the shared variance with exploration through self-locomotion. Given the exploratory nature of this analysis and the small sample involved, these results need to be replicated.

An important point to address is whether the attainment of motor milestones is a necessary condition for the development of spatial language and spatial cognition. Empirical findings indicate that this is likely not to be the case as children who suffer from severe motor impairments can show good performance on tasks measuring spatial cognition and spatial language (Riviére & Lécuyer, 2002; Riviére, Lécuyer, & Hickmann, 2009). Attainment of motor milestones, therefore, seems neither a necessary nor a sufficient condition for cognitive and linguistic development (Campos et al., 2000; Iverson, 2010). While in typically developing children motor development is probably an important factor propelling cognitive and linguistic development, alternative paths are obviously possible. Nevertheless, we suggest that these alternative pathways may all include some form of exploration enabling children to obtain information that is relevant to the development of spatial cognition and language.

The main limitation of the current study is the sample size used for the analyses concerning spatial processing and spatial language. Bayesian estimation and bootstrapping were applied to increase the confidence in the results obtained. Nonetheless, future research with larger samples is needed to replicate the current findings. Furthermore, observations and tests were conducted in the children's home environment. The home setting offered fewer possibilities for standardization and control. However, due to this setting the current study can be considered as ecologically more valid than other work using a lab setting. Finally, future studies could also consider a more detailed coding of exploration behavior. For example, when scoring exploration through self-locomotion no distinction was made between different modes of self-locomotion. As recent work suggests that the visual information received when crawling is very different from the visual information received when walking (Kretch, Franchak, Brothers, & Adolph, 2012), it is valuable to make this distinction also in future studies.

Despite these limitations, the detailed longitudinal data of the current study enabled us to examine the mechanisms mediating the relations between motor milestone attainment and the development of spatial cognition and spatial language. It is important to note that exploration behavior is probably not the only mediating mechanism. Other possible mechanisms might concern factors in the social environment such as the amount and kind of (spatial) language input children receive (for a discussion of such factors see: Gogate & Hollich, 2010; Pruden, Levine, & Huttenlocher, 2011; Walle & Campos, 2014). Multiple factors are likely to play a role in the development of spatial cognition and language. Future work should look more closely at these factors and highlight the dynamic interplay between them resulting in spatial language development.

Chapter 6

Summary and general discussion

The aim of this dissertation was to investigate the relations between young children's attainment of particular motor milestones and the development of spatial cognition and (spatial) language and, in particular, to examine the role of children's exploration behavior as a mechanism mediating these relations. While in the past, motor development was often regarded as a result of mere physical maturation and not considered an important factor in cognitive development (Rosenbaum, 2005), the increasingly influential embodied cognition approach and the related ecological psychology theory on perception-action as the basis of cognition, place movement and motor control in the center of cognitive-linguistic development (e.g., Gogate & Hollich, 2010; Hockema & Smith, 2009; Iverson, 2010). According to the embodied cognition approach, human cognition is grounded in real-time sensorimotor experiences. The attainment of particular motor milestones, such as sitting, crawling and walking, gives rise to new perception and action possibilities and, therefore, fundamentally changes children's sensorimotor experiences (E. J. Gibson, 1988; Soska & Adolph, 2014; Thelen & Smith, 1994). Following this approach, motor development was hypothesized to predict cognitive and linguistic development. Furthermore, children's exploration of their environment was hypothesized to mediate these relations. Exploration can be considered the driving force of development (E. J. Gibson, 1988; Smith & Gasser, 2005). Through exploration of the environment children learn about the affordances (possibilities for action) in their environment and this contributes to their cognitive development. Through spatial exploration, in particular, children gradually acquire spatial concepts, such as knowledge of spatial relations and the skill of mental rotation (Campos et al., 2000; Schwarzer, Freitag, Buckel, & Lofruthe, 2013). Therefore, it was hypothesized that spatial exploration specifically mediates the effect of attainment of motor milestones on *spatial* cognition and *spatial* language.

In this chapter the findings of the studies described in this dissertation are briefly reviewed and discussed. We start with a short summary of the main findings and continue with a general discussion of the findings. At the end of the discussion, directions for future research and practical implications are considered.

Summary of Main Findings

In Chapter 2 of this dissertation we reported the results of the first study. In this study parents reported retrospectively the ages at which their children had reached self-locomotion motor milestones (sitting, crawling, walking) and answered questions about children's spatial exploration behavior during infancy and early toddlerhood, such as their engagement in stacking, sorting and ordering toys, self-locomotion and so forth. This information was used to predict children's spatial memory at ages four and six years. Spatial memory was assessed with a widely used test, which has been developed by Alloway (2007) and is found to be a strong predictor of academic achievement in several subjects (e.g., St Clair-Thompson & Gathercole, 2006). The results revealed that early engagement in spatial exploration predicted spatial memory several years later, while controlling for fluid intelligence, as was hypothesized. The age of attainment of self-locomotion milestones was not directly related to spatial memory, but children who were able to crawl and walk relatively early did, according to parent reports, indeed engage more in spatial exploration during infancy, as was expected, suggesting an indirect effect of attaining motor milestones which is mediated by exploration. Although strictly speaking, only predictive relations were tested, the results offered support to the hypothesis that exploration in infancy is an early precursor of later spatial cognition.

The second study, described in Chapter 3, focused on the relation between attainment of unsupported sitting and independent walking, and the development of productive general vocabulary. First, a growth model of the development of productive vocabulary between ages 16 and 28 months was estimated. Next, the ages of attainment of sitting and walking were included as predictors of the general level (intercept) and the growth (slope) of productive vocabulary. The results showed that children who could sit at an earlier age had a higher overall level of productive vocabulary and that children who could walk at an earlier age had a higher rate of growth of productive vocabulary in this age range. It is important to note that children who could walk at an earlier age did not start with a larger productive vocabulary, but displayed more rapid growth of their vocabulary, which may be reflected in a higher level of vocabulary at a later point in time. Similarly, the larger vocabulary of early sitters (reflected in an effect on the intercept) may be the result of an earlier effect of the attainment of sitting on the growth of vocabulary. Together, the findings support the hypothesis that the attainment of motor milestones propels linguistic development.

The third study, which is reported in Chapter 4, focused on the development of exploration of spatial-relational object properties (e.g., the possibility of containment and stacking) in the second and third year of life. In the study reported in Chapter 2, a global retrospective measure of children's spatial exploration in infancy was used based on parent reports. In the study of Chapter 4, we directly observed young children's free exploratory interaction with a standard set of toys, focusing specifically on how children discover the properties of objects that specify elementary spatial relations. Using a newly developed observation scheme, we scored three forms of children's exploration behavior, namely exploration using single objects, multiple objects, or spatial combinations of objects. Based on the theoretical proposals of Lockman (2000), we expected that the development of spatial-relational object exploration would progress from single object exploration to exploration using multiple objects and finally to exploration using combinations. In Chapter 4 we showed that children's object exploration can be reliably measured with the coding scheme and that inter-individual differences between children in exploration correlated moderately with concurrent test-based measures of spatial cognition, as was expected. Furthermore, while on average development did follow the expected trend, individual developmental trajectories showed both temporary progressions and temporary regressions, that is, intra-individual variation.

To model the overall development of exploration in infancy and early toddlerhood, and to do justice to both the intra- and inter-individual variation, an analytical approach was applied which combined Latent Growth modelling and Item Response Theory. The development of spatial-relational object exploration was modelled as so called 'overlapping waves', that is, as the gradual increase, or flowing, of more complex forms of exploration and the gradual decrease, or ebbing, of less complex forms of exploration over time, in accordance with a theoretical model proposed by Siegler (1996). The results indeed showed that, over time, the exploration of complex affordances using combinations becomes more probable and exploration of less complex affordances becomes less probable. However, in line with the hypothesis based on the model of Lockman (2000), the simple behaviors did not completely disappear, they just occurred less frequently.

In the fourth study, described in Chapter 5, we combined the insights gained in the previous studies and investigated a mediation model, in which exploration was modeled as mediator of the relationships between the age of attaining particular motor milestones, spatial cognition and spatial language. Unlike the study described in Chapter 2 which examined long term effects of retrospectively measured exploration on spatial cognition, in the study of Chapter 5 we used prospective measures and investigated the effects of exploration on spatial cognition and spatial language within a shorter period of time. Moreover, this study extended the study reported in Chapter 3 in two ways. First, exploration was added as a mechanism mediating the relations between motor and linguistic development. Second, rather than using a general outcome measure, we focused on a specific form of vocabulary, namely spatial vocabulary. In addition we investigated the relations between specific milestones, two specific forms of exploration, and specific forms of spatial cognition. This shift of focus enabled us to test hypotheses about the relations between motor development, exploration and spatial skills in a more specific way and to disentangle the pattern of relations found in the previous studies. The results showed that children, who attained the milestone of sitting at an earlier age, had a better spatial memory and a more advanced spatial language in the second and third year of life. Spatial-relational object exploration predicted spatial memory, but it did not mediate the relation between age of sitting and spatial memory. In addition, an earlier age of walking predicted better spatial processing and spatial language in third year of life. These effects were partially mediated by engagement in exploration through self-locomotion. Taken together, the results suggest that the two forms of exploration and the two milestones included in the study provide children with different experiences, which are differentially related to the development of spatial and linguistic skills.

General Discussion

The current dissertation adds to the knowledge of early child development in the domains of spatial cognition and language in several ways. First of all, the studies reported in this dissertation contribute longitudinal empirical evidence to a field, which has been mainly theoretical so far. The results provide partial support for the hypotheses suggesting that attainment of motor milestones predicts, through engagement in spatial exploration, development of spatial cognition and language. The current studies focused explicitly on spatial exploration as the mediating mechanism between motor development and cognitive development, and provided at least partial evidence, retrospectively as well as prospectively, for a core role of engaged spatial exploration in children's cognitive development in the second and third year of life. The relationships between motor development, spatial exploration, spatial cognition and (spatial) language appear to be specific and to depend on various aspects such as the time-scale on which the core variables are measured, the specific motor milestone concerned, the type of exploration considered, and the specific measures of spatial cognition and language used. The present dissertation also contributes to the field by demonstrating the feasibility and advantages of an approach to modelling development that not only takes inter-individual, but also intra-individual variation in development into account (see also Van Geert & Van Dijk, 2002). The intra-individual variation found in the developmental paths of exploration can be seen as indicative of a fundamental characteristic of development, metaphorically addressed by the overlapping waves model of Siegler (1996) and in line with the approaches suggested by Lockman (2000) and Fischer and Bidell (2006), namely that higher level skills (in the present case exploration of complex affordances) build on lower level skills (exploration of simple affordances in the present case) and emerge from the rapid and skilled use of simple skills in real-time. In that sense, the simple skills lay the foundations for picking-up and acting upon more complex affordances present in the situation. While we did not examine the real-time processes directly, the results provide support for these theoretical proposals and demonstrate a way of testing hypotheses based on these models. Below we will elaborate on the main contributions of the current study.

Specificity of the Effects

The leading hypotheses of the current dissertation were formulated in a rather general manner, stating that attainment of motor milestones is presupposed to propel the development of cognition and language by enabling children to explore their environment in new ways, setting the stage for the development of new skills to act upon the environment. As the results only partially supported the hypotheses, it has to be assumed that other factors and issues of timing and measurement are involved as well. In the following sections these factors and issues are discussed.

Time-scales

The time-scale on which the developmental process is examined appears to play an important role in the results that were found. In Chapter 2 we found that on a time-scale of three to five years exploration rather than motor milestone attainment predicts spatial cognition. Based on these findings we suggested that, although initial individual differences in exploration are related to the level of motor development and, therefore, motor development is important on a short-term time-scale, later on, as children develop and variance in level of motor development decreases, individual differences in exploration are dependent on other factors as well, while as such remaining an important factor in the development of future spatial skills. This hypothesis was supported by the findings presented in Chapter 5, where we showed that, on a shorter time-scale, the attainment of walking is indeed related to the development of spatial processing and spatial language, and that the attainment of sitting is indeed related to the development of spatial memory and spatial language.

In Chapter 3 we demonstrated a related point, when we showed that an earlier age of attainment of sitting predicted an overall higher level of productive vocabulary, while an earlier age of walking predicted larger growth of productive vocabulary. As an explanation for this pattern of findings, we pointed to the fact that sitting was attained on average eight months prior to the first language measurement, whereas walking was attained on average one month before the first measurement. Inter-individual differences in the age of sitting were possibly initially reflected in differences in vocabulary growth as a result of the changes in perception-action processes enabled by sitting. However, initial differences in growth gradually lead to differences between children in the average level, or intercept, of vocabulary. After some time, when all children can sit, the immediate effects of being able to sit on vocabulary growth level-off. Inter-individual differences in the ability to walk were also immediately reflected in the growth of vocabulary, due to the changes in perception-interaction processes enabled by walking. However, as the vocabulary assessment took place within the period in which children still differed in the attainment of walking, only effects on growth were found.

Similarly in the study reported in Chapter 5, we suggested that, as in the period of measuring spatial-object exploration (starting at age nine months) almost all children were already able to explore the toy set from a sitting position, we could not relate any variance found in spatial-relational object exploration to the attainment of sitting, due to the lack of variance in sitting ability. Indeed, studies investigating object exploration closely after the attainment of unsupported sitting, that is when children still vary in their sitting ability (Soska, Adolph, & Johnson, 2010; Woods & Wilcox, 2013), did find a relation between sitting attainment and object exploration.

Differential relations

The relations between the motor milestones, types of exploration and spatial skills studied in this dissertation were found to differ and suggest specific relations. In the study reported in

Chapter 5, we found that sitting was related to static spatial memory (being able to encode and remember a spatial array in front of the perceiver), while walking was related to dynamic spatial processing (being able to mentally rotate). In addition, we found that spatial-relational object exploration from a relatively fixed sitting position was related to spatial memory, while exploration of the space through self-locomotion was related to spatial processing. Together, these results suggest that the relations between motor development, exploration and spatial skills are specific and intrinsically related to the specific kind of perception-action processes involved in both forms of exploration. For example, experience with exploring building blocks may facilitate the learning of concepts such as *in, on* and *under*, which are all concepts that can be perceived and known-through-action from a single perspective and relatively fixed location of the body. Exploration involving self-locomotion, in contrast, may be critical for the acquisition of concepts such as *between* and *behind*. Understanding these concepts involves (imagined or simulated) changes in perspective through changing the bodily location and, therefore, is likely to be related to exploration involving self-locomotion through space. This interpretation of the results may also offer an (alternative) explanation for the lack of relation between attainment of self-locomotion milestones and spatial memory reported in Chapter 2.

Although the results of the studies of this dissertation are not fully conclusive, we suggest that also regarding language development the relationships are specific and intrinsically dependent on the kind of perception-action processes involved in exploratory activities. In the study of Chapter 5, a specific relation of motor development with spatial language was found which was mediated by exploration through self-locomotion. Upon closer scrutiny of the spatial language test used, we found that the less complex, single perspective, spatial concepts represented by simple prepositions such as in and on, were already completely mastered by the children at the time of testing (age 36 months), therefore leaving no relevant variance to be explained. This offers an explanation for the lack of effect of observed static spatial-object exploration and for the relatively small and marginally significant effect of attainment of sitting on spatial language as tested in this study.

Complex spatial concepts, however, represented by complex prepositions such as *behind* and *between*, were not yet completely mastered and revealed considerable inter-individual variance, which, as was expected, could be predicted by the attainment of walking and exploration through self-locomotion as mediator.

All findings taken together, the present studies provide evidence suggesting that the developmental relationships between motor development, exploration, spatial cognition and language development are specific and intrinsically grounded in the information structures present in the environment and the actions these information structures afford. Following this reasoning, we suggest that the developmental relationships between these domains cannot be reduced to a general maturation process nor to broad shifts in general developmental stages, as in Piagetian theory (see for example Piaget, 1952). Instead, children develop through multiple concrete experiences in their environment, that is, through exploration. Spatial cognition and spatial language development depend on a manifold of concrete real-life interactions that converge at some point to enable the 'emergence' of these skills (see Thelen & Smith, 1994 for a detailed description of this idea). While, the current study sheds light on only a small fraction of the developmental pathways of human cognition, we contend that the theoretical and methodological approach can be applied to development in a wide range of other domains as well.

Embodied Cognitive-Linguistic Development

A fundamental question on the background of the current dissertation is how the development of (supposedly) abstract concepts can be explained by an embodied view on development. According to the embodied cognition approach general or abstract concepts are also grounded in real-time sensorimotor interactions, but how this grounding should be regarded is not immediately clear. We briefly touched upon this issue in Chapter 4, when we reported on the modelling of spatial-object exploration as an overlapping waves pattern, suggesting that higher level complex behaviors are grounded in lower level simpler behaviors. A critical question to be addressed is whether grounding presupposes memorized knowledge rooting in previous experience or happens in real-time each time a (new) configuration of stimuli is encountered. As a preliminary answer to this question, consider the following example based on the current study. When children combine a block and a cup by inserting the block into the cup, they build on previous separate experiences with the properties of cups and blocks (such as the size of the objects, the possibility of picking them up, and the possibility of containing) that are quickly picked up in the actual situation. This demonstrates children's well-practiced skill in employing the action possibilities specified by these properties, which sets the stage for perceiving the possibility of combining them (which involves, among others, perceiving and matching the size of the particular cup in relation to the size of the particular block). According to an embodied cognition view on development, children's skill to pick up these affordances quickly and act on them accurately does not point to internalized, abstract knowledge of the properties of these particular kinds of objects. Rather, skillful actions are softly assembled in real-time from the actual information structures in the environment and the child's past experiences of interacting with these (or similar) objects: the more experience, the more skilful children's behavior. The term *memories* can be used to describe and explain the skill children show. However, it is important to note that these memories are actually sensorimotor interactions that are triggered anew by and adapted to the information structures specified by the actual objects in the real-time situation. Therefore, they cannot be localized in the person as internal cognitions, but are rather to be regarded as distributed in the body-environment system. Memories in this sense are closely akin to what Piaget (1952) called *sensorimotor schemes.* With experience, behavior becomes relatively stable across situations and this stability is often interpreted as indicating the possession of an abstract concept determining behavior across contexts (Smith, 2009; Thelen & Smith, 1994; Van Geert, 2003). Moreover, with time experiences with actions in multiple contexts do not always have to include direct perception, they also involve planning, simulating or talking about an action (Smith, 2009; Thelen & Smith, 1994). Such mental processes are an extension of direct perception making knowledge more explicit instead of tacit (J. J. Gibson, 1979). Therefore, what seems to be a single stable concept possessed by children, is in fact still a soft assembly of elementary perception-action processes which emerges in real-time and derives its cross-situational stability from the communalities, in terms of context and of actions, between multiple real life experiences (Smith, 2009; Thelen & Smith, 1994). As Esther Thelen and Linda Smith (1994) conclude: "*Because knowing is dynamic and not encapsulated, because it is trajectories and processes rather than structure and computation, higher order understanding can self-organize from the real-time solutions of everyday life. There need not be a ghost in the machine, a knower in the head, or special devices*" (p. 327).

In Chapter 4, children's development of spatial object exploration was modelled by applying Latent Growth Modelling and Item Response Theory, which yielded a latent ability scale. In line with the ideas discussed above, we suggested that the latent ability scale produced by the statistical modelling is not *latent* in the classic sense of the term, that is, referring to a 'true' mental ability 'of' and 'in' the child that can only be indirectly observed. Rather, as we proposed, the scale represents children's increasing *skill* in discovering and employing the spatial-relational affordances of objects, which can be directly observed. In our study, a stable pattern of exploration behavior emerged when the oldest children almost always used combinations in exploring the set of toys provided to them. This suggests that with regard to this set of objects children became increasingly skilful in picking up the spatial-relational affordances specified by the objects and in acting upon them, showing in their behavior mastery of seemingly abstract concepts such as containment (*in*), stackability (*on*) and complementarity (e.g., by using two triangle shaped blocks to create a square or fitting two cups to create a ball).

Directions for Future Research

The findings reported in this dissertation suggest several directions for future research. First and foremost, the results stress the need for rich longitudinal data**.** By using intensive data from frequent measurement points, the dynamics of individual developmental trajectories can be explored. Thus, while several children reach the same level of skill at the same time, close inspection of the developmental processes may reveal that they follow different paths to get there. This information is lost when only long-term correlations are studied (see for example Granic & Hollenstein, 2003; Rakison & Woodward, 2008). Observing children more frequently (every two or three weeks) in the period in which motor milestones are attained, will enable better understanding of the various processes taking place following the attainment of these milestones. Observations should not only address the changes in spatial exploration behavior following the attainment of motor milestones. Recent research suggests that also changes in, for example, social interaction patterns following the attainment of motor milestones contribute to cognitive advances (Karasik, Tamis-Lemonda, & Adolph, 2011; Walle & Campos, 2014).

Another important direction for future research is to identify the specific and intrinsic relations between motor development, exploration, cognitive and language development. Whereas in this dissertation spatial language was considered as a single, one-dimensional skill, future work should investigate prepositions and verbs separately, differentiate between simple and more complex spatial concepts, and focus on the intrinsic relations between specific prepositions and verbs, on the one hand, and the specific motor milestones and forms of exploration, on the other hand. Furthermore, also other forms of spatial language such as words describing shapes, surfaces and textures should be considered (Landau & Jackendoff, 1993). In general, the more specific and intrinsic the relationships found between the different developmental domains, the stronger the support provided for the current theoretical framework.

To develop understanding of the nature of situated embodied cognition as an alternative to representationalist theories, and to gain insight in how complex skills are grounded in less complex skills further, studies should include detailed examination of the perception-action processes that take place on a microgenetic time-scale within a single situation. Based on the theoretical model outlined above, it can be predicted that children initially will engage in single object exploration and that, as time progresses, they will gradually move towards making combinations. The timing of the shift of simple to complex exploration within a single situation and the particular shape of this shift (for example, a smooth or sudden change, with more or less regressions), moreover, can be a valid indicator of the current level and stability of children's exploration skill (Fischer & Bidell, 2006; Van Dijk & Van Geert, 2007). A particularly interesting question is whether even highly skilled individuals show the pattern of first employing lower level exploration (though very quickly) before moving on to the exploration of complex affordances (see Chemero, 2001, for a discussion related to this question). Furthermore, if the task is extended by presenting children with different but similar objects, it can be expected that the gained experience decreases the time they need to spend engaging in simple exploration so that they can make a quicker and more stable shift to making combinations with the new sets of toys. Microgenetic studies can shed more light on the real-time dynamics of the learning process and how this learning process in micro-time feeds into the development of skills on a longer time-scale (Yan & Fischer, 2002).

Practical Implications

The current dissertation demonstrates the importance of motor development and exploration as precursors of later cognitive and linguistic skills. The findings, and more broadly the theoretical approach supported by the findings, can have several implications for parents and professionals working with young children. In the field of early childhood education and care, motor activities and exploration should have a prominent place in the curriculum. Children should have ample opportunities to move around and to explore in a variety of contexts, with a variety of materials in the day care centers and preschool classrooms they attend. Especially with regard to early child rearing in the Dutch context, which is characterized by the frequent use of playpens and special baby chairs that limit changing body posture, locomotion and exploration (see for example Harkness & Super, 2006), parents should be made aware of the importance of striking a balance between the time spent to freely moving around, and the time spent in the playpen or baby chair.

It is also important to increase awareness of possible differences between ethnic-cultural communities and socioeconomic classes. While some cultural communities favor active stimulation of children's motor development, other communities may favor a less stimulating approach, with possible consequences for cultural differences in development (for a review see: Adolph, Karasik, & Tamis-LeMonda, 2010). Differences between families from different socioeconomic classes in the space and materials available for exploration, can lead to class-based differences in child development (Venetsanou & Kambas, 2010). In response to this, local and national governments should ensure the availability of sufficient and appropriate spaces that can be used by all children to move around and explore, whereas parents can be educated how to make optimal use of the materials available to them to stimulate children's exploration.

With regard to clinical populations, research has shown that children with severely impaired motor skills can find alternative pathways to develop spatial skills, including spatial language (Riviére & Lécuyer, 2002; Riviére, Lécuyer, & Hickmann, 2009). However, a high degree of comorbidity between motor impairments and linguistic impairments is the rule rather than the exception (e.g., Cheng, Chen, Tsai, Chen, & Cherng, 2009; Hill, 2001). Thus, it might be that young children who lag behind in motor development can benefit from interventions to stimulate exploration in order to support their cognitive and linguistic development in the long term. This can be especially important for children born pre-term, who are known to lag behind in both motor development and spatial skills compared to children born in term (e.g., De Kieviet, Piek, Aarnoudse-Moens, & Oosterlaan, 2009; Mulder, Pitchford, Hagger, & Marlow, 2009). Moreover, as exploration appears to be important for the development of cognitive, social and linguistic skills, systematic observation of children's exploration with observation tools as the one described in Chapter 4, can be used to detect atypical patterns. Recent research has revealed that children who were diagnosed with Autism Spectrum Disorders in late childhood, already showed deviant patterns of exploration early in life (e.g., Hellendoorn et al., 2012; Koterba, Leezenbaum, & Iverson, 2012; Ozonoff, 2008). Measures of exploration can be used to develop a universal system for screening of early exploration behavior. This will enable the early diagnosis of children at risk for developmental disorders and can contribute to providing them with a well-timed preventative intervention.

General Conclusion

The main conclusion of this dissertation is that the development of spatial cognition and of general and spatial productive vocabulary in young children is related to the attainment of unsupported sitting and independent walking. Attainment of these milestones propels cognitive and linguistic development. Spatial exploration at least partially mediates the relationship between the attainment of motor milestones, spatial cognition and spatial language. Based on these results, we believe that motor development and exploration should be central topics in studies into cognitive and linguistic development.

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Samenvatting (Summary in Dutch)

Introductie

Ouders van jonge kinderen verheugen zich op de momenten waarop hun kinderen achtereenvolgens gaan zitten, kruipen en lopen. Het behalen van deze motorische mijlpalen vergroot evident de handelingsmogelijkheden van kinderen in de wereld, maar in hoeverre zijn deze motorische mijlpalen ook van invloed op de cognitieve ontwikkeling van het kind? Zodra kinderen zelfstandig kunnen zitten of zelfstandig gaan lopen verandert hun 'kijk' op de wereld en leren ze hun aandacht te richten op informatie in hun omgeving die relevant is voor hun nieuwe handelingsmogelijkheden. Bijvoorbeeld, het behalen van de mijlpaal zelfstandig zitten biedt kinderen nieuwe mogelijkheden om objecten in hun nabijheid te pakken en te manipuleren, maar vereist tegelijkertijd dat ze leren om hun aandacht te richten op de informatie die nodig is voor het pakken van objecten, zoals bijvoorbeeld de grootte van de objecten in verhouding tot hun eigen hand of de afstand tussen het kind en het object. Als kinderen zelfstandig gaan lopen, krijgen ze de mogelijkheid om objecten te dragen en te verplaatsen en moeten ze leren om hun aandacht te richten op informatie die nodig is om te kunnen navigeren in de ruimte waarin ze zich bevinden. Doordat kinderen leren hun aandacht op nieuwe aspecten van de omgeving te richten, gaan zij de omgeving en de objecten die zich daarin bevinden ook meer exploreren. Door deze exploratie ontdekken kinderen steeds meer nieuwe handelingsmogelijkheden die de omgeving hen biedt en vergaren ze informatie over de ruimtelijke ordening van hun omgeving. Uit verschillende studies blijkt dat dit ruimtelijke exploratiegedrag mogelijk een belangrijke rol speelt in het leren van ruimtelijke begrippen zoals *in, onder, achter* en *tussen*.

Alhoewel er in het verleden veel onderzoek is gedaan naar vroege voorspellers van de cognitieve- en taalontwikkeling van kinderen is het pas sinds de introductie van de 'embodied cognition' benadering dat de motorische ontwikkeling wordt gezien als een mogelijke voorloper van de ontwikkeling van cognitieve en taalvaardigheden. In deze dissertatie staat derhalve de relatie tussen de motorische ontwikkeling en de cognitieve en taalontwikkeling centraal. Onderzocht wordt of het behalen van de mijlpalen zelfstandig zitten en zelfstandig lopen vroeg in de ontwikkeling voorspellers zijn van de ontwikkeling van ruimtelijke cognitie en van algemene en ruimtelijke taal op latere leeftijd. Daarnaast wordt onderzocht of exploratie van objecten en exploratie van de ruimte waarin kinderen zich bevinden de relatie tussen de motorische ontwikkeling en cognitieve- en taalontwikkeling medieert.

'Embodied Cognition'

Volgens de embodied cognition (belichaamde cognitie) theorie, die gerelateerd is aan de ecologische benadering in de cognitieve psychologie, geïnitieerd door James Gibson, ontstaat cognitie (inclusief taal) uit de real-time interacties tussen kind en omgeving. Enerzijds nemen kinderen informatie uit hun omgeving op die relevant is voor hun handelen, anderzijds genereren kinderen juist nieuwe informatie doordat zij handelend in de omgeving optreden. Door deze zich continu herhalende cycli van waarnemen en handelen, leren kinderen over de wereld om hen heen en verwerven ze nieuwe cognitieve en taalvaardigheden. Verondersteld wordt dat het behalen van motorische mijlpalen een grote rol speelt in dit proces omdat het de bewegingsmogelijkheden van kinderen en dus ook de mogelijkheid om informatie uit de omgeving te kunnen opnemen drastisch vergroot. De eerste hoofdhypothese die daarom in de huidige dissertatie wordt getoetst is dat het behalen van de motorische mijlpalen zelfstandig zitten en zelfstandig lopen de ontwikkeling van ruimtelijke cognitie en (ruimtelijke) taal bevordert.

Een centraal begrip binnen de ecologische psychologie en de embodied cognition benadering is exploratie. Door middel van exploratie ontdekken kinderen zogenaamde 'affordances' (affordanties) in hun omgeving. Affordances zijn mogelijkheden tot handelen en sturen het exploratiegedrag van het kind. Of iets een affordance voor een kind is, hangt zowel af van de beschikbare informatie in de omgeving (bijvoorbeeld welk speelgoed aanwezig is, hoeveel ruimte er is, enzovoort) als van de eigenschappen van het kind zelf (bijvoorbeeld de mate van houdingscontrole, grootte van de handen, mogelijkheid zichzelf te verplaatsen). De informatie die kinderen door exploratie uit de omgeving tot zich nemen en die hun handelen stuurt, is van wezenlijk belang voor de ontwikkeling van cognitieve vaardigheden. Het behalen van motorische mijlpalen biedt meer mogelijkheden tot exploratie en opent de weg voor het ontdekken van nieuwe affordances. De tweede hoofdhypothese die wordt getoetst is dat het verband tussen het behalen van motorische mijlpalen en de cognitieve en taalontwikkeling wordt gemedieerd door exploratie. In deze dissertatie staan twee vormen van exploratie centraal, namelijk exploratie van ruimtelijk-relationele eigenschappen van objecten (bijvoorbeeld objecten die je op elkaar kunt stapelen of objecten die in elkaar passen) en exploratie van de ruimte waarin het kind zich bevindt door middel van zelfstandige voortbeweging. De hypothesen die hierbij worden getoetst zijn dat zowel exploratie van objecten als exploratie van de ruimte het effect van respectievelijk de mijlpaal zitten en de mijlpaal lopen op de ontwikkeling van ruimtelijke cognitie en taal mediëren.

Deze Dissertatie

In deze dissertatie worden vier onderzoeken gerapporteerd die de samenhang tussen motorische mijlpalen, exploratie en de cognitieve-linguïstische ontwikkeling bestuderen. De eerste studie maakt gebruik van een deelsteekproef uit de data van een grotere longitudinale studie. De andere drie studies maken allen gebruik van data verkregen van 62 kinderen die behoren tot twee leeftijdscohorten die gevolgd werden vanaf de leeftijd van 9 maanden tot en met de leeftijd van 36 maanden. De kinderen werden ongeveer iedere vier maanden thuis bezocht door onderzoekers die een reeks tests en observaties bij de kinderen, en vragenlijsten bij de ouders hebben afgenomen. Per cohort waren er vijf meetmomenten (cohort 1: 9-24 mnd; cohort 2: 20-36 mnd), waarvan twee meetmomenten (20 en 24 mnd) overlappend waren.

In de eerste studie, die gerapporteerd wordt in hoofdstuk 2, werd het ruimtelijk geheugen van 51 kinderen getoetst op de leeftijd van vier en zes jaar. Daarnaast werd via een vragenlijst ingevuld door de ouders in retrospectief, informatie verkregen over de leeftijd waarop hun kind belangrijke motorische mijlpalen, zoals kruipen en lopen, behaalde en over het ruimtelijke exploratiegedrag van het kind (bijv. objecten stapelen, voortbewegen in de ruimte) op de peuterleeftijd. De resultaten laten zien dat kinderen die op jonge leeftijd meer exploratiegedrag vertoonden op de leeftijd van vier en zes jaar een beter ruimtelijk geheugen hadden. De leeftijd van het behalen van motorische mijlpalen was geen significante voorspeller van ruimtelijk geheugen op vier- en zesjarige leeftijd, maar kinderen die de mijlpalen eerder hadden behaald, vertoonden volgens hun ouders meer exploratie op jonge leeftijd. De resultaten bevestigen de hypothesen dus slechts gedeeltelijk. Het kan zijn dat op korte termijn het behalen van de mijlpalen belangrijk is omdat het exploratie mogelijk maakt, terwijl kinderen die wat later zijn met het behalen van motorische mijlpalen deze achterstand op langere termijn weer inhalen. Op langere termijn is het dus vooral het niveau van exploratie op vroege leeftijd dat ertoe lijkt te doen.

In de tweede studie, die in hoofdstuk 3 is gerapporteerd, werd gekeken naar het verband tussen het behalen van de mijlpalen zitten en lopen en de ontwikkeling van productieve woordenschat op een leeftijd tussen 16 en 28 maanden. Data van beide cohorten werd gecombineerd in een zogenaamd cohort sequentieel groeimodel. De resultaten laten zien dat kinderen die eerder konden zitten, een gemiddeld grotere productieve woordenschat hadden (gerepresenteerd door de *intercept* van het groeimodel), en dat kinderen die eerder konden lopen een grotere groei in productieve woordenschat lieten zien (gerepresenteerd door de *slope* van het groeimodel). Deze bevindingen zijn in overeenstemming met de hypothese dat het behalen van de mijlpaal lopen, processen in gang zet die op den duur bijdragen aan de ontwikkeling van taal. Het verschil in effect tussen de mijlpaal zitten en de mijlpaal lopen is mogelijk terug te voeren op het feit dat de mijlpaal zitten al veel eerder is behaald (ongeveer 8 maanden voor onze eerste taalmeting), waardoor een mogelijk effect op de groei in woordenschat niet meer zichtbaar is, maar een effect op het algemene niveau als resultaat van een eerdere groeispurt nog wel.

De derde studie, die in hoofdstuk 4 is gerapporteerd, was gericht op de ontwikkeling van exploratie van ruimtelijke-relationele object eigenschappen in het tweede en derde levensjaar. In hoofdstuk 2 werd een grofmazige, retrospectieve maat van exploratie gebruikt, gebaseerd op ouderrapportage. In deze derde studie werd exploratie van ruimtelijk-relationele eigenschappen van objecten door middel van systematische observatie van een spelsituatie gemeten. Met behulp van een codeerschema werd het exploratiegedrag onderverdeeld in drie categorieën: (1) exploratie met één object; (2) exploratie met meerdere objecten (zonder ze te combineren); (3) exploratie door ruimtelijke combinaties van objecten. De resultaten laten zien dat ruimtelijk-relationele object exploratie met dit schema betrouwbaar kan worden gescoord, en dat, zoals verwacht, de interindividuele variabiliteit in exploratie significant correleert met tests van ruimtelijke cognitie. Daarnaast werd, in lijn met de verwachtingen vanuit de theorie, gevonden dat exploratie zich ontwikkelt van exploratie van simpele affordances van één object naar exploratie met meerdere objecten en naar het exploreren van meer complexe affordances door het maken van combinaties. Echter, terwijl gemiddeld genomen het verwachte patroon van ontwikkeling werd gevonden, lieten de individuele ontwikkelingstrajecten veel intra-individuele variatie in exploratie zien, zoals werd weerspiegeld in tijdelijke progressies en regressies in de ontwikkeling. De ontwikkeling van exploratie werd daarom gemodelleerd met een nieuwe methode die recht doet aan zowel de inter-individuele als de intra-individuele variabiliteit. Deze methode combineert latente groeimodellen en met principes van de Item Respons Theorie. De ontwikkeling in exploratie werd gemodelleerd als een proces van zogenaamde '*overlapping waves*'. Dat wil zeggen, naarmate een kind ouder wordt, neemt de frequentie van meer simpele vormen van exploratie tijdens het spel af, terwijl de frequentie van meer complexe vormen van exploratie juist toeneemt. De simpele vormen van exploratie verdwijnen echter niet geheel en worden ook op latere leeftijd nog waargenomen. Dit patroon van ontwikkeling is in overeenstemming met de verwachtingen vanuit een ecologische embodied cognition benadering.

In de laatste studie, die in hoofdstuk 5 beschreven staat, werden de inzichten uit de voorgaande studies gecombineerd en werd een compleet mediatiemodel getoetst. Er werd getoetst of exploratie van ruimtelijk-relationele object eigenschappen op de leeftijd van 20 maanden het effect van de leeftijd van zelfstandig zitten op het ruimtelijk geheugen (op 24 maanden), ruimtelijke verwerking (op 32 maanden) en ruimtelijke taal (op 36 maanden) medieert. Ruimtelijke taal omvat voorzetsels zoals *in, onder* en *tussen* en werkwoorden die een bepaalde richting aanduiden, zoals *duwen* en *klimmen*. Daarnaast werd ook getoetst of exploratie van de grotere ruimte op de leeftijd van 20 maanden het effect van de leeftijd van zelfstandig lopen op deze uitkomstmaten medieert. De resultaten laten zien dat zowel het eerder behalen van de mijlpaal zelfstandig zitten als ook een grotere mate van exploratie van ruimtelijk-relationele object eigenschappen samenhangt met een beter ruimtelijk geheugen, maar dat er geen sprake is van een mediatie-effect van exploratie. Beide factoren dragen kennelijk direct bij aan de ontwikkeling van ruimtelijk cognitie. Daarnaast blijkt dat de mijlpaal zelfstandig zitten een voorspeller is voor ruimtelijke taal op latere leeftijd: hoe eerder de mijlpaal wordt behaald hoe hoger het niveau van ruimtelijke taal. De leeftijd waarop de mijlpaal zelfstandig lopen wordt behaald blijkt eveneens een voorspeller van het niveau van ruimtelijke cognitie en van ruimtelijke taal, en in beide gevallen medieert exploratie van de ruimte dit effect. Kortom, de resultaten suggereren dat de twee mijlpalen en de twee vormen van exploratie de kinderen verschillende ervaringen geven die op hun beurt verschillend samenhangen met de ontwikkeling van ruimtelijke cognitie en ruimtelijke taal.

Conclusies

Samenvattend laten de resultaten van deze dissertatie een complex geheel aan verbanden zien. De verwachte verbanden tussen het behalen van de mijlpalen zitten en lopen enerzijds, en exploratie en ruimtelijke cognitie en (ruimtelijke) taal anderzijds konden slechts deels worden bevestigd. Deze verbanden lijken specifiek te zijn en af te hangen van de leeftijd waarop de verschillende factoren gemeten zijn en het soort gedrag dat is gemeten. Zo blijkt uit hoofdstukken 2 en 3 dat de leeftijd van het behalen van de mijlpalen een effect heeft op de korte termijn, maar op langere termijn is dit effect kleiner of geheel verdwenen. Deze onderzoeken suggereren echter wel dat ook op de langere termijn met name de mate van exploratie op jonge leeftijd nog altijd van belang is. De resultaten beschreven in hoofdstuk 5 laten zien dat de effecten specifiek zijn voor het soort mijlpaal en de vorm van exploratie. Een mogelijke verklaring voor de bevinding dat deze relaties specifiek blijken te zijn, is dat exploratie van de ruimte door zelfstandig voortbewegen inhoudt dat kinderen actief hun perspectief veranderen en dat exploratie van de ruimte daarom bijdraagt aan het verwerven van vaardigheden waarbij perspectief kunnen nemen vereist is. In het huidige onderzoek was deze vorm van exploratie gerelateerd aan prestaties in de ruimtelijke verwerkingstaak en aan ruimtelijke taal, beide zijn vaardigheden waarbij perspectief kunnen nemen vereist is. Zo is bij de ruimtelijke verwerkingstaak mentale rotatie nodig, wat een vorm van innerlijk het perspectief kunnen veranderen is, en impliceert het verwerven van complexe ruimtelijke taal, zoals kennis van woorden als *tussen* en *achter*, eveneens een vermogen om verschillende ruimtelijke perspectieven in te kunnen nemen. In tegenstelling tot de voorgaande bevinding blijkt dat exploratie van ruimtelijk-relationele eigenschappen van objecten sterker gerelateerd is aan prestaties in een ruimtelijke geheugentaak waarbij kinderen moesten onthouden *onder* welke beker of *in* welke doos een speeltje was verstopt. In deze geheugentaak speelt ruimtelijk perspectief kunnen nemen nauwelijks een rol.

De resultaten die in deze dissertatie worden beschreven, ondersteunen (deels indirect) de hypothese uit de embodied cognition theorie dat cognities (zelfs cognities die van een hogere orde zijn) altijd hun oorsprong vinden in meer simpele lagere orde sensomotorische kennis die ontstaat in de interacties van kind en zijn omgeving. Dat houdt in dat een aangeleerd taalconcept zoals *tussen* niet los gezien kan worden van de interacties met de fysieke werkelijkheid die tot het leren van dit concept leiden. Dat laatste is mogelijk de reden waarom we op langere termijn een verband vinden tussen het behalen van motorische mijlpalen, exploratie en de ontwikkeling van cognitieve en taalvaardigheden. Dit betekent dat zowel kind gerelateerde factoren als de (fysieke) context van invloed zijn op de vaardigheden die kinderen verwerven.

Dit onderzoek heeft een aantal praktische implicaties. Zo zou in curricula voor voor- en vroegschoolse educatie meer aandacht moeten komen voor bevordering van de motorische ontwikkeling van het kind en vooral voor mogelijkheden tot exploratie van objecten en ruimten, die passen bij het motorische ontwikkelingsniveau van het kind. Daarnaast zouden overheden ervoor kunnen zorgen dat ook kinderen die door de economische omstandigheden waarin ze opgroeien minder materialen en ruimte in hun directe omgeving beschikbaar hebben, hier alsnog voldoende toegang tot krijgen. Verder kunnen ook ouders voorgelicht worden over de mogelijkheden om thuis de beschikbare ruimte en materialen optimaal te benutten om het exploratiegedrag van hun kind te stimuleren. Tenslotte hebben de bevindingen van deze dissertatie implicaties voor klinische populaties waarbij er sprake is van co-morbiditeit tussen motorische en cognitieve problemen. Mogelijkerwijs kan het bieden van ondersteuning aan de motorische ontwikkeling en bevorderen van exploratiegedrag van jonge kinderen die een achterstand hebben op deze gebieden, bijdragen aan de ontwikkeling van hun cognitieve en linguïstische vaardigheden.

De hoofdconclusie die uit de resultaten van deze dissertatie getrokken kan worden is dat het behalen van de motorische mijlpalen zelfstandig zitten en zelfstandig lopen bijdraagt aan de ontwikkeling van ruimtelijke cognitie en aan de algemene en ruimtelijke taalontwikkeling van jonge kinderen. Ruimtelijke exploratie medieert deze verbanden, althans ten dele. De bevindingen laten zien dat er goede redenen zijn om motorische ontwikkeling en exploratie meer centraal te stellen in toekomstig onderzoek naar de vroege voorlopers van de cognitieve en communicatieve ontwikkeling.

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About the author

Curriculum Vitae

Ora Oudgenoeg-Paz was born on December 5 1975 in Israel. She obtained her high school degree in 1993 from 'Gilboa' high school in Bet Alfa (Israel). She obtained her bachelor degree Magna Cum Lauda in Psychology and Education from the Hebrew University in Jerusalem in 2001. After completing her bachelor degree she worked in various positions in main stream and special education in Israel and in the Netherlands. In 2008 she obtained her master degree Cum lauda in Development and Socialization in Childhood and Adolescence from Utrecht University. During the last year of her master studies she won a Top Talent grant from the Netherlands Organization for Scientific Research (NWO). This grant provided funding for a PhD project, based on her proposal. From 2008 until 2014 she worked as a PhD student in the faculty of social and behavioural sciences at Utrecht University and her PhD project was based on this proposal. During these years, next to conducting research, she has been involved in teaching in bachelor and master degree courses.

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