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Experimental data on children's engagement in cooperative tasks

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OVERVIEW

This document provides a summary of three experimental studies with young children conducted at the MPI EVA since the beginning of the CHRIS project in March 2008 until May 2009. The goal of these experiments has been to investigate the core capacities that enable children to collaborate in problem-solving tasks that require the joint engagement of two people. Correspondingly, the primary purpose of this document is to describe the rationale, methods, and results of these experiments, embedded in a discussion of how developmental psychology and robotics can inform each other about the critical (cognitive) skills for collaborative activity.

Therefore, in the introduction we start out with a discussion of the relationship between developmental psychology and robotics, followed by a summary of the cognitive skills that young children possess early in life before they begin to collaborate successfully with others. The last part of the discussion is concerned with the conceptualization and the empirical evidence of collaboration in young children. This sets the stage for the main part: A detailed description of the methods and findings of our studies with young children, investigating children's skills in behaviorally coordinating their actions with others (Study 1) as well as their representation of and commitment to joint goals (Studies 2 & 3). We conclude the document with reflections on how these findings inform the implementation in and assessment of collaborative skills in robots.

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Portions of this research have been presented at the Meeting of the Society for Research in Child Development, Denver, CO, 2009.

Hamann, K., Warneken, F., Tomasello, M. (April 2009). Children's commitment to a shared goal in peer collaboration. Poster.

Steinwender, J., Warneken, F., Tomasello, M. (April 2009). Cooperative Problem-Solving and Spontaneous Role Reversal in Peers. Poster.

Warneken, F. & Tomasello, M. (April 2009). Collaboration in Young Children and Chimpanzees - Coordinating Behaviors and Sharing Intentions. Paper.

INTRODUCTION

1. Developmental psychology and robotics as a collaborative enterprise

The purpose of the current project and possibly other collaborations among roboticists and developmental psychologists more generally is twofold: First, to use the insights from developmental psychology to build robots and secondly to use the methods from robotics to build developmental theories.

What developmental psychology can do for robotics. Specifically, the first goal is based upon the idea that in order to construct an artificial system that is able to flexibly interact with other agents in changing and complex environments, it might be helpful to look at organisms which acquire these skills quite readily – human children. Therefore, **one major goal is to identify the core capacities for cooperation that (a) enable the most basic forms of cooperation that we find early in human ontogeny and (b) constitute at the same time the building blocks for later-emerging and more complex forms of cooperation.** A promising approach is to look at social activities like joint problem-solving and social games. Obviously, there are major differences between e.g. building a Lego-tower and building the Eiffel Tower. However, these activities share key characteristics and are potentially based on the same psychological capacities that builders minimally have to possess in order to collaborate with each other successfully. For example, joint problem-solving in children often involves some kind of division of labor in which two participants adopt specific roles in the service of an overarching goal (the tower; or subgoals such as building the base, putting the last stone on top). Therefore, these collective activities involve patterns of social interaction that have similarities to its adult counterparts, supposedly underlain by similar cognitive capacities. Identifying these core capacities and implementing them in robotic systems entails the prospect that these serve as a generic template which enable robots to collaborate successfully not within one restricted situation alone, but apply the skills to other situation with minimal learning and minimal instruction as do young children.

Therefore, this document summarizes the key insights from developmental psychology concerning the cognitive capacities for collaboration that children possess early in ontogeny. Note that research specifically addressing the cognitive prerequisites for collaboration is in its early ontogeny itself. The first publications in this domain were born in the year of 2006.

Another, but related way in which developmental psychology can inform robotic research pertain to the **scenarios in which robots and humans interact in a collaborative task, including relevant coding categories and statistical tools to assess their performance.** This entails a task analysis to define commonalities and differences of various interaction-situations along important dimensions in order to assess the breadth of situations in which robots can potentially interact. Examples for this are the dimension of the goal structure of an activity (individual versus shared goals) or along the dimension of the type of acts performed (e.g. the distinction between parallel and complementary roles) or the issue of perspective problems as defined in the Vocabulary on the WIKI. Moreover, based upon the robotics literature that circulated within the CHRIS-project, the tools for behavioral assessment used in robotics appear to still be in an embryonic stage. Therefore, we attempt to describe the extensive coding and the statistical analyses used in empirical studies in enough detail to inspire the development of improved behavioral assessment in the field of robotics.

What robotics can do for developmental psychology. Another major goal of the project is to use robotics to test psychological theories. In psychology (and the behavioral sciences more generally), the underlying cognitive structures must be inferred from their behavioral outcomes as they manifest themselves under different experimentally controlled situations. However, rather than inferring a cognitive architecture from behavior, a more direct approach is to implement the architecture and record the resulting behavior. In other words, psychology has it backwards, but robotics can directly test whether the purported cognitive architecture is in principle able to perform a certain behavior. More specifically, **based upon theoretical considerations and the empirical data with children, we can infer certain cognitive representations that are supposedly necessary for children's efforts to collaborate with others. Once these are implemented in robots, we can assess whether they are actually doing the job that they should do according to the theoretical model.** To be more precise, we assume that there are different cognitive representations that enable children to perform certain types of social behaviors and engage in collaborative interactions of varying levels. Collaboration is not viewed as an all-or-none phenomenon, but as a dynamically developing capacity that has precursors and moves through stages of different complexity. Therefore, what we hope to achieve is to implement not merely the most sophisticated cognitive representation that enables the most flexible and mature form of collaboration, but to gain insight into what developmentally earlier cognitive representations can and *cannot* achieve, and what improvement results from developmentally later emerging cognitive representations.

The implementation of these capacities in robotic systems requires that the cognitive architecture is described in enough detail and formalized appropriately. We derive our concepts mainly from analytic philosophy and developmental science, and this means that they cannot necessarily be straightforwardly translated into concepts that are relevant for programming robots. Therefore, **one objective is that models of cognitive architecture are described more concretely concerning the operating mechanisms** (e.g. what it means to represent an individual goals versus a shared goal) than typically done in psychology. This cross-talk will hopefully not only result in the construction of skillful robots, but also a common conceptual framework and vocabulary that is applicable for cognitive science as a whole, including the sub-disciplines of developmental science and robotics.

We will be rather brief in describing what the underlying cognitive representations are that are hypothesized to underlie the human capacity to collaborate with others. This is because they are described in detail in Tomasello et al. (2005). For shorter descriptions see Tomasello & Carpenter (2007) or Warneken & Tomasello (2007). Last but not least, the WIKI-document containing the CHRIS-Vocabulary provides brief definitions of the most important concepts surrounding the topic of collaboration.

2. The development of children: Background skills

Let's first talk about what we are not going to talk about. These are some of the capacities that we assume children are already equipped with or have acquired before they start to engage in collaborative activities in the second year of life. This ranges from basic locomotor skills over physical cognition to early forms of social cognition. For the sake of readability, we avoid citations in this part, but are happy to provide them upon request.

Locomotion

Children typically begin to crawl at around 5 months of age and prefer to locomote in this way from around 5 to 11 months. Almost immediately when they start to crawl, they avoid crossing "cliffs", i.e. sharp drops that they are able to detect based upon cues from depth-perception.

Infants start to walk with the help of adults or by holding onto furniture between 7 to 12 months and transition to walking independently by 14 months at the latest. In our cooperation-studies, children sometimes had difficulty to coordinate walking and standing while manipulating an apparatus at 14 months, but at 18 months this does not pose a challenge to them anymore.

Reaching and grasping

Infants from around 5 months of age realize which objects are within or out of reach and no longer attempt to reach out-of-reach objects. This problem re-appears during puberty when humans try to reach for the stars. Infants grasp objects from early on, first with the whole hand, but at around 12 months they produce the so-called pincer grip in which the thumb and the opposing forefinger pick up small objects.

By around 10-12 months at the very latest they not only grasp objects, but also manipulate them (like banging a spoon on the table). At around their first birthdays, they are able to manipulate one object to manipulate another object. For example, they can use a cane to retrieve an object that is out of reach for them or pull a piece of cloth towards them to access an object that is placed on top of it. This is taken as a first manifestation of problem-solving (see below).

Physical cognition

Young infants have a rich understanding about the physical worlds. They are able to identify objects as separate entities, and from 3 months of age on they possess an understanding of object permanence, i.e. they expect that objects continue to exist even if they are not directly visible to them (e.g. because they are hidden behind a screen). Moreover, they expect objects to move as connected bounded units (and are thus surprised if one object turns into two or two objects into one without any external force); they expect objects to move along continues connected paths (rather than “jumping” from one position to the next like as if they were “beamed” from one location to the next); they expect that objects do not just start to move by themselves without an external force, but only if something else caused them to move like a billiard-ball hitting another. Importantly, infants can differentiate between inanimate objects and animate agents, and do not act surprised if an animate agent (e.g. something that has eyes) moves without any external cause being detectable.

Quantities

Infants have basic math-skills: Infants of 4 month of age can add and subtract small quantities: In one test, they first see an object, which is subsequently occluded by a screen and then another identical object is placed behind the screen. When the screen then drops, they act surprised when only one object appears (although this was what they had seen before), but are not surprised if now two objects are visible (a novel visual display, but one that corresponds to 1+1=2). The same works when an object is removed rather than added. However, infants can perform these operations successfully only with small numbers – up to about 3.

In addition, infants can also discriminate larger quantities – although in a more global manner that does not require counting. Infants of around half a year can discriminate between larger quantities in ratios between 2:1, e.g. 10 vs. 20 items or 20 vs. 40 items. However, these abilities are limited as infants fail to discriminate quantities in ratios of 3:2.

Understanding goal-directed action

From early on, infants represent the behavior of other agents as goal-directed action. For example, somewhere between 5 to 9 months they begin to interpret other people’s hand-grasps as being directed at certain objects: In a first display, children see a hand repeatedly reaching to the left for a ball (and not to the right to a bear). After a short break, the positions of ball and bear are switched. Now the hand reappears and either reaches for the same object (the ball) which is in a new location or reaches along the same spatial trajectory for the same location with the different object (the bear). At this age, infants appear to expect the hand to continue to reach for the same object, not the same location, thus encoding the goal-object rather than the movement as the critical variable.

Infants also seem to understand that agents adjust their movements in light of the goal that they are pursuing. After 12-month-old infants are habituated to an agent (an animate dot) jumping over a wall and approaching another dot on the other side, when the wall is then removed in later trials, infants expect the dot to approach the other dot directly. Thus, rather than expecting the dot to continue the previous jumping-motion, they expect the dot to follow a (previously unobserved) horizontal trajectory. This is taken as evidence that infants assess the agent's action with regard to the goal, with the jump as a behavior that is only necessary when the goal is obstructed.

At around the same age, infants can differentiate accidental from purposeful actions. As described in the CHRIS-Vocabulary, accidents are especially informative about goals because the defining feature of an accident is not the physical or behavioral outcome itself, but whether the outcome does or does not match the agent's goal. Namely, similar environmental outcomes can be either the result of a purposeful action (when the outcome matches the goal) or an accident (when goal and outcome do not match). Here is an example of how this was tested: In Behne, Carpenter, Call, and Tomasello (2005) an experimenter was handing over objects to the subjects in various ways. The critical test cases were those in which the object was not passed on to the infants, either because the experimenter was unwilling to do so (e.g. teasing the child) or unable to do so (e.g. because she accidentally dropped it). Infants from 9 month of age onwards became more impatient (reaching, turning away, banging on a table) when the experimenter was unwilling than when he was unable to do so. Therefore, children responded not to the outcome alone (which was the same in both situations), but the intention leading to it.

This is also important for observational learning. A set of studies using imitation measures have shown that at about 14 months of age children make such distinctions when learning the use of novel objects from others. When infants observe a person manipulating a novel apparatus in a way that results in an interesting effect, they reproduce the actions a model has produced on purpose (e.g. vocally marked by "There!"), while at the same time ignoring the actions that were produced by accident ("Whoops!"; Carpenter, Akhtar, & Tomasello, 1998). At around the same age, infants can even infer the goals the other is trying to achieve without actually seeing the intended outcome. In Meltzoff (1995), 18-month-old infants observed an actor try but fail to, for example, place a ring on a hook. When it was their turn, they brought about the intended but unobserved goal (ring on hook) rather than the unintended but observed outcome (ring falling down). Taken together, there is concordant experimental evidence that infants understand other people's individual actions in terms of the goals they are trying to achieve and are even able to infer goals in novel situations.

Gaze-following and joint attention

Almost from birth, infants have an automatic response to the gaze-direction of other people (e.g. when they are looking at a human face, they tend to look more to the left when the face moves the pupils towards the left) and during the first year of life they begin to also turn their heads in the same direction to near targets and by around one year of age also to more distant targets. Starting at 12 months of age, infants even follow gaze around barriers. That is, they seem to respond to the fact that another person is looking at something that are outside of their own field of view. Namely, when in Moll & Tomasello (2004), the experimenter looked behind a barrier and acted excited, infants locomoted towards the hidden location, indicating that they understood that the experimenter saw something that they could not see themselves.

Pointing: comprehension and production

From around their first birthdays, infants begin to both understand pointing as a referential gesture and use it themselves. For example, when an experimenter hides a toy in one of two possible locations, they are more likely to choose the location that the person is pointing at than the location the person ignores. Importantly, they are able to tell apart whether the person is pointing intentionally (using the pointing gesture as a communicative means) or the hand is just “pointing” at the location accidentally, without being a communicative gesture (e.g. because the experimenter is looking at her watch and only as a side-effect holding her hand in a way that looks like a point).

On the production-side, infants at again around one year of age use pointing gestures in flexible ways: *imperatively*, in order to have another person e.g. give them a desired object, *informative*ly, e.g. in order to indicate to another person where the object is that the person is looking for (and not because the child wants it for herself), and in order to *share attention* to an object or event (e.g. by pointing to a zeppelin in the sky and continuing to point until the other person joins in and gives feedback (faithfully or nonfaithfully) that this is the coolest thing in the world).

Therefore, for the current studies in children from 18 months onwards, we can assume that they have no problems to understand pointing as a referential gesture and that they are able to use pointing gestures readily and flexibly when collaborating with others.

Let’s now turn to the major theme of this document.

3. Collaboration

As summarized in the CHRIS vocabulary and Tomasello et al. (2005), we refer to collaboration if two or more agents perform actions jointly in order to achieve a shared goal. More specifically, the following criteria should be met: **(1) Agents are *mutually responsive* to one another, that is, their actions are to some degree interdependent. They pay attention to one another and mutually adjust their behavior in coordinated ways. (2) Agents represent the *shared intentions* of the joint enterprise, i.e. the plan of action comprising both the overarching shared goal (the mental representation of the desired state of the environment) and each partner's individual intentions (their individual actions towards their subgoals) that are performed in pursuit of the shared goal. (3) Moreover, collaboration entails a *mutual commitment* to the shared goal: This is expressed, for instance, in making sure that both partners are engaged in their individual roles (and re-engaging a recalcitrant partner), and providing help when the partner encounters problems in executing her action.**

Studies dealing with (1) are concerned with children's developing ability to *coordinate* their behaviors toward a shared goal. This is what we investigated in Steinwender, Warneken, & Tomasello (in preparation) by means of potentially less demanding tasks than previously used in prior research (see study 1 below). From previous research, it is known that at around 14 months of age, children begin to coordinate their actions in simple versions of collaborative problem-solving tasks and social games with an *adult* partner (Warneken & Tomasello, 2007). In the following months, this early and still rudimentary form of coordinative skill is refined continually. Children from 18 to 24 months of age become increasingly more sophisticated in playing social games like making a toy block bounce on a trampoline that due to its size requires that two individuals perform *parallel* hand and arm movements. Moreover, they demonstrate their understanding of *complementary roles* in managing games and problem-solving tasks where, for example, one has to send a toy block through one of two tubes for the other to catch, coordinating who performs which role and which of the two tubes is chosen at a given time (Warneken, Chen, & Tomasello, 2006). Thus, in the second year of life, toddlers begin to coordinate their behavior with adult partners spatially and temporally in order to achieve a goal.

When collaborating with peers, children’s skills become particularly apparent because peers – unlike adults – cannot scaffold their activities. In other words, we can better assess to what extent the behavioral coordination achieved is actually due to the skills of the child rather than to an external coordinator such as an adult. Existing research suggests that in these peer-contexts, children start to collaborate skillfully from around 24 months of age (Brownell, Ramani, & Zerwas, 2006; Brownell & Carriger, 1990, 1991). For instance, they pull in handles jointly (in parallel) to make a musical toy sing (Brownell et al., 2006). Studies dealing with peers' deployment of complementary roles, though, found such an understanding to emerge either quite late (with 3.5 years of age, Ashley & Tomasello, 1998) or to be rather instable (with 24 months, Brownell & Carriger, 1990, 1991).

Therefore, this research indicates that from about 14-18 months of age, children are able to coordinate their actions (at least with adults) reliably. However, from these studies it remains unclear how these young children represent the social activity cognitively. Specifically, do they understand the *shared goal-structure* (2) of collaborative endeavors? As mentioned above, one aspect of a shared goal is that one has both partners' roles in mind, which has also been referred to as a “bird's eye view” on the social situation at hand (Tomasello et al., 2005). One measure of this “bird's eye view” are role-reversals, i.e. the ability of partners to switch roles in tasks with complementary roles, indicating that they have not only an understanding of the own individual action (e.g. holding a frame to the wall), but also the role of the partner (driving a nail into the wall). Studies with young children using rather simple bidirectional activities (such as holding out a plate and the other person placing an object on top), indicate that 12-month-olds seem to take the other's role into account (Carpenter, Tomasello, & Striano, 2005). We utilize this measure in Steinwender et al. (in prep.), with the critical new feature that this is used in peer-collaboration rather than adult-child interaction.

Another measure used to test whether children take into account the other’s role are interruption periods. Namely, in situations in which the (adult) partner suddenly stops playing his part in a joint activity like the trampoline task reported above, 18-months-olds (and even some 14-months-olds) try to re-engage the partner (Warneken et al., 2006). This suggests that they represent the other's action and understand it as crucial within the joint activity. By 21 months of age at the latest, they take into account the intentions leading to the interruption. Specifically, they clearly treat the other as an intentional agent whom they help if he is unable to play his part, but not if he is unwilling to do so (Warneken, Gräfenhain, & Tomasello, in preparation).

Taken together, these studies show that from early on, children are able to (1) socially coordinate their actions toward a goal that they (2) represent as a “shared goal”.
But do they also understand something of the *commitments* (3) involved? Children’s attempts to prompt a recalcitrant partner back into the joint activity provide some evidence that they do. They seem to want the other to perform his role, that is, to be committed to the task. There is little direct evidence so far for children’s *own* commitment though - for example, in that they help the other to achieve his or her subgoal. The issue of (3) joint commitments is the major focus of the studies by Hamann, Warneken, and Tomasello (in preparation, see studies 2 & 3 below).

EMPIRICAL STUDIES

Study 1: Collaborative Problem-Solving in Peers

Steinwender, Warneken, & Tomasello

The act of collaborating together is a very common activity in humans. When interacting with others we show goal oriented behavior and also rely on others to achieve our goals, like in assembling an armoire together, getting the salt from across the table or completing a research publication in time. As this manifold abilities to coordinate spatially and temporally with one another is used without any effort by adults, it is interesting to investigate the earliest signs of collaboration in children. When do children start to collaborate with others and to what extent are they able to coordinate their behavior with others? Recent research on adult-child interactions shows rudimentary coordination in 14-month old children while retrieving objects hidden inside of problem-solving apparatuses (Warneken & Tomasello, 2007). Of course, in such an interaction the adult is much more skillful and experienced in solving spatial-temporal problems, which means to be placed at the right positions and to act at the right moment. The child's activity is potentially structured by the activity of the adult which will - unlike a child - stay at her position, remember the task at hand and also conceptualize the steps necessary to achieve the goal together.

One way to get a better picture of the "pure" ability of children to engage in the earliest forms of collaborative abilities is investigating peer-interaction: the collaboration of children of the same age and same skills – in the absence of an adult structuring the activity for the children. Research on peer collaboration demonstrates that children interact with other children successfully at the age of 2-3 years (Ashley & Tomasello, 1998; Brownell & Carriger, 1990; Brownell et al., 2006, Eckerman et al., 1989). Importantly, successful collaboration depends to a large extent on the complexity of the tasks. In Ashley and Tomasello's (1998) problem solving task with predefined complementary roles, children did not succeed reliably until 3.5 years of age. This is in contrast to the results obtained by Brownell and colleagues using complementary roles (Brownell 1990, 1991) as well as parallel roles (Brownell, 2006), where rudimentary problem-solving skills are already present in 27-30 month-old children. One major difference between these two studies was that in Ashley & Tomasello (1998), a fairly complicated pulling-mechanism was used, putting high demands on children's understanding of the physical properties, whereas in the studies by Brownell and colleagues, the workings of the apparatuses were more direct and potentially grasped more easily by the children. Hence, for the current study we used complementary problem-solving tasks with more physically intuitive mechanisms.

Problem solving apparatuses with complementary actions require that people perform two structurally different, but interdependent roles. First, each role is located at a different side of the apparatus and second, these roles have to be executed in temporal coordination with each other. Furthermore, the successful execution of one role does not automatically include the successful execution of the other role. Thus, there must be some agreement on who takes over which role. Children know that they need the co-participation of a partner to solve the apparatus successfully and hence they have to assign the roles at least during the actual problem solving if not already done beforehand. Previous research used complementary roles which children could freely choose (Brownell et al., 1990, 1991, 2006), but this research did not investigate in how far children can switch flexibly between the two roles (role-reversal). This ability to reverse roles indicates that children represent the spatial-temporal action sequence of the partner as well as their own sequence. Further the interrelation of both roles must be known to coordinate ones own movements with the movements of the partner. This "bird's eye view" (Tomasello et al., 2005) on the complete collaboration scene includes the action sequence of both partners including all subgoals necessary to achieve the shared goal. We thus investigate children's ability to switch roles in the present study and take the occurrence of spontaneous role reversals as measure of a bird's eye perspective.

The bird's eye view indicates a cognitive representation of the current, observable situation. But is this acquired knowledge also applicable on new situations with either new partners or new problems? Do children learn from one situation and then are able to transfer this knowledge to a similar situation? If a transfer between similar problems occurs already in young children, then this indicates that they have some sort of generic cognitive representation which enables them to analyze the current aspects of the problem solving activity and generalize to the underlying principles. We were interested at what age this ability to transfer knowledge across similar problems contexts occurs and thus include two structurally similar problem solving apparatuses in the present experiment.

In summary, in the current study we investigated the development of early collaborative problem-solving with tasks that require the joint engagement of two people. We used two problem-solving apparatuses that were based on the same principle: A mechanical part has to be moved and held constant by one child such that the other child can retrieve the now available target object. In other words, partners have to perform complementary actions, i.e. actions that are different, but interrelated. Because the two actions were not pre-assigned to the children beforehand, children had to negotiate themselves who would take over which role. Moreover, as each task was tested over repeated trials, we could assess whether children would engage in spontaneous role-reversal – a measure taken as indicator that children represent the collaborative nature of a task. We tested three age-groups to investigate the developmental course of their problem-solving abilities from the supposedly earliest manifestations of this behavior to an age at which children are quite proficient at collaborating. Therefore, this study contributes to two critical aspects of collaboration: (1) coordination and (2) the representation of shared intentions, as defined above.

Methods

Participants

We tested three age groups with roughly equal numbers of boys and girls. Each age group consisted of 8 dyads: the youngest group was 18 months old (M=18 months 15 days; range = 17 -19 months; 3 girls dyads), the middle aged group was 24 month old (M=24 months; range = 22 - 26 months; 5 girls dyads), and the oldest 36 months (M=36 months, range = 34 -38 months; 4 girl dyads). Ten more dyads were tested but excluded from analysis due to technical problems (2), no motivation to participate (7), and fussiness (1). Participants were acquired through birth lists of a medium-sized city in Germany with signed consent from their parents. All children were tested in their daycares and paired with familiar partner of the same sex.

Tasks and Materials

We tested children in two structurally similar problem-solving apparatuses: Two children have to perform two complementary actions to retrieve a reward. The two apparatuses are called the elevator (a wooden box 30 x 60 cm and 60 cm high; transparent barrier 25.5 cm high; see Figure 10 (a)) and the slide (a transparent box 18 x 100 cm and 8.7 cm high with a retrieval hole 4.5 x 5 cm; transparent barrier of 100 x 150 cm with a 17.5 x 26 hole in the center about 43 cm above the floor; see Fig. 1(b)). The *elevator-task* requires one child to push up a cylinder (Role B) which is immersed in a table and hold it in position until the other child can grab to object (Role A). The second apparatus, the *slide-task* requires one child to pull a rope (Role B) so that a container holding the reward object moves up an incline and stops below of a hole. Role B requires the child to hold the rope in place because otherwise the reward object slides back to its resting position. When the child in Role B placed the object below the hole, then the other child can retrieve the target object (Role A). At both apparatuses, transparent screens prevented retrieving the object while pushing up the cylinder or pulling the rope respectively, thus making it impossible for one child to solve the problem on her own.

Figure 1. Cooperation Tasks *Figure (a)*. Elevator *Figure (b)*. Slide

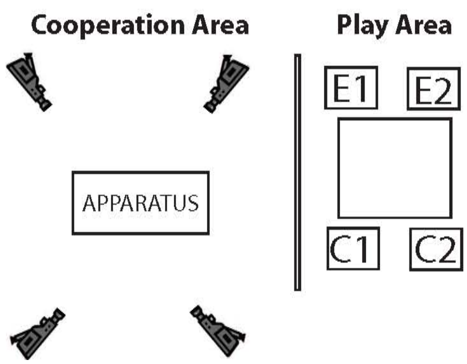

Figure 2. Room Setup. The experimental room was divided by a curtain into a play area (right part with table, E1 and E2 denotes the position of the two experimenter, C1 and C1 the position of the children) and a cooperation area (left part with cameras and experimental apparatus).

Procedure

The general procedure included always a warm-up game, followed by an introduction to the target game, a demonstration of the problem-solving apparatus and the final test phase. The target game was introduced in order to motivate the children to retrieve the target object: After the children played the game once (e.g. completing a puzzle), on the next round the target object was missing (e.g. the last puzzle piece), but could be retrieved from the collaboration apparatus.

More specifically, the detailed procedure was as follows: Two female experimenters (E1 and E2) played with the children in the communal daycare room for a few minutes and then invited them to come to a separate experimental room. This room was divided by a nontransparent curtain into two areas, the play area and the cooperation area (see Fig. 2). In the play area children played one more warm-up game which required them to take turns and thus ensured them to have at least a playful experience together before testing. After 2-4 rounds of the warm up trials the target game was introduced. This game provided the target object later to be retrieved from the apparatuses. There were two types of target games. In the *penguin game a* little penguin figure was placed on a stairwell, on which it moved upwards and then slid down a spiral slide to its starting location. The *teddy bear game* was a puzzle in which children assembled a teddy bear figure out of pieces such as the teddy's shoes and shirt. Each child was first assigned to either the shoes or the shirts and then children took turns in dressing the teddy.

After the children and the experimenters played the game once, on a second round suddenly a critical object was missing: in the penguin game the penguin figure, and in the teddy bear game the teddy bears head. The first experimenter (E1) now told the children that she knows where another object is hidden and guided the children to the collaboration apparatus. There the experimenters clearly indicated the location of the target object inside the apparatus verbally and by pointing at it, making sure that both children noticed the hidden object.

We had to adapt this procedure slightly for the 18-months-old children as they were not capable of the complex movements to handle the penguin or to puzzle the teddy pieces. Instead, for 18-month-olds we introduced the *jingle machine*, which is a highly rewarding game as known from other developmental studies (Warneken et al., 2007; Herrmann et al., 2007). When children throw a cube through a tilted pipe, it slides down into and disappears in a box with a xylophone, creating a jingle sound. The target object was two of these cubes stuck together by a hook-and-loop tape which we pulled apart in front of the children so that each child got one cube to throw into the jingle machine. This procedure was repeated about three times until the children were excited about the game. These cube objects were placed as target objects inside the respective apparatus and the procedure continued as described for the older children ..

Demonstration Phase and Instructions

The general idea was to introduce the collaborative task in gradually more explicit demonstrations as in Warneken, Chen, and Tomasello (2006): If children were able to solve the task after minimal demonstration, they proceeded to the test phase and if they initially failed, demonstrations were repeated and made more explicit in a standardized 3-stage sequence. After the demonstration phase, the actual test phase began with 4 consecutive trials per task. Trials ended after children successfully retrieved the object or a maximum of 2 minutes.

Specifically, the three demonstration stages were as follows (see Fig. 3): In *demonstration stage 1* (exposure to mechanism) the experimenter (E1) demonstrated the barriers and openings of the apparatuses accompanied by naming the target object (e.g. “teddy”, “penguin”) and manual reaching gestures. The experimenter showed that barriers prevented her from reaching for the target object directly, but also showed that there was an opening through which the respective target object could be accessed. As a next step, the experimenter demonstrated three times how to manipulate the mechanism (lift the cylinder in the elevator task or pull the string in the slide task), accompanied by pointing gestures towards the object and verbal markers such as “There, the teddy!” Thereafter, the experimenters instructed the children again to get the object out and then went behind the curtain, leaving the children room to retrieve the object by themselves. The allotted trial length was a maximum of two minutes. If children retrieved the object after the demonstration, they proceeded to the test phase (see Fig. 3 for the whole structure). If the object was not retrieved at this demonstration stage, the experimenters came back to the cooperation area and *demonstration stage 2* (full demonstration) was applied: E1 and E2 demonstrated the coordination and positioning needed to retrieve the object, i.e. one experimenter operating the mechanism while the other experimenter was located on the side of the apparatus from which the target object could be retrieved. Specifically, E2 operated the mechanism three times and E1 always touched the object and said: "Teddy! There!" when it was in front of the opening and thus accessible to her. After the demonstration was completed, we told the children to retrieve the target object: “Now its your turn. We will wait behind the curtain.” Again children had two minutes time to solve the problem (in which case they proceeded to the test phase), or, if they still failed, watched a third demonstration. In this *demonstration stage 3* (individual instruction), children were instructed individually by each solving the task together with E1. To do so, the experimenter demonstrated the pushing/ pulling movement again and then encouraged the individual child to do this movement herself. If she did so, the experimenter switched position and was ready to retrieve the object on the side opposite to the child. Then the object was retrieved cooperatively and the experimenter handed the object shortly to the child. Because the object was needed for the next demonstration for the second child, the experimenter took the object again. Afterwards, the other child participated in this individual demonstration session. As a last step, children were again told to retrieve the target object together. If they passed, they proceeded to the test phase, and if they still failed, the test with the respective apparatus ended.

Sometimes children left the apparatus and came around the curtain to the experimenters, who tried to motivate them to engage in the problem-solving process with the general statement: "Try it again!"

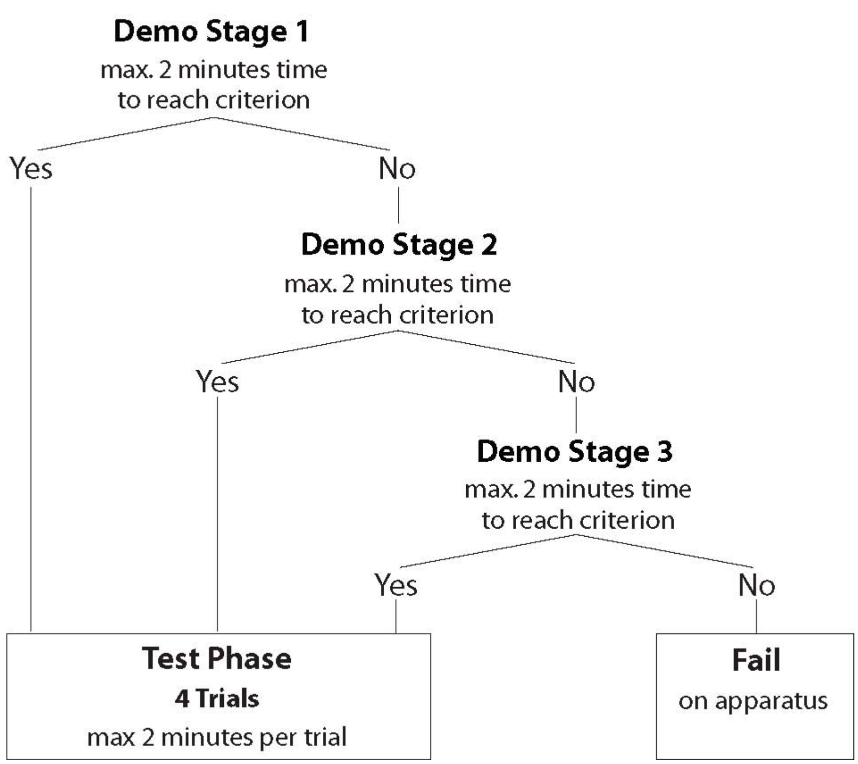

Figure 3. Instructional stages.

Coding

All sessions were videotaped with four cameras. All coding was done from digital video with the use of the coding software INTERACT. We measured the following variables:

- *success*, i.e., the number of correct solutions,
- how many *demonstration stages* were necessary until the success or failure,
- *latency to success* as the time needed from approaching the apparatus until the retrieval of the object,
- *failed attempts* are unsuccessful manipulations on the apparatus,
- the number of spontaneous *role-reversals*,
- knowledge *transfer* from the first to the second apparatus.

The starting point for *latency to success* was when at least one child entered a radius of 50 cm around the apparatus. We then noted the number of *failed attempts* to solve the apparatus until the correct retrieval of the target object (i.e. pulling the string, but dropping it before the partner was able to retrieve the object). The *object retrieval* was defined as time point where the object had been clearly taken out of the machine and had been at least 10 cm away from hole (rather than the child just touching, but not retrieving it or putting it back in). A *role-reversal* was defined as a spontaneous switch of positions at the final retrieval configuration across trials. This means that a role-reversal happened when child A in trial 1 retrieved the object (Role A) and the same child in the next trial handled the mechanism (Role B). Thus, switching roles within one trial was not counted as role-reversal as this was no successful configuration. To investigate for potential *transfer* effects from the first apparatus to the second, we looked at the time needed to retrieve the object at each trial for both machines.

Results

First, we analyzed children's ability to successfully retrieve the target object. Success in the problem-solving task (see Fig. 4) was significantly affected by age (Kruskal-Wallis test: $H(2) = 14.249$, $p < 0.001$). The younger children mostly failed completely or showed accidental success, whereas at two years of age, almost all dyads solved all 4 trials (see Table 1 for details).

Table 1 Number of trials solved across all age groups at the two apparatuses. N = 16 consists of 8 dyads tested at two machines.

	Number of Trials with Success						
Age	0	only demo	1	2	3	4	*Total*
1.5 years	6	2	0	2	1	5	16
2 years	1	0	1	0	1	13	16
3 years	0	0	0	0	0	16	16

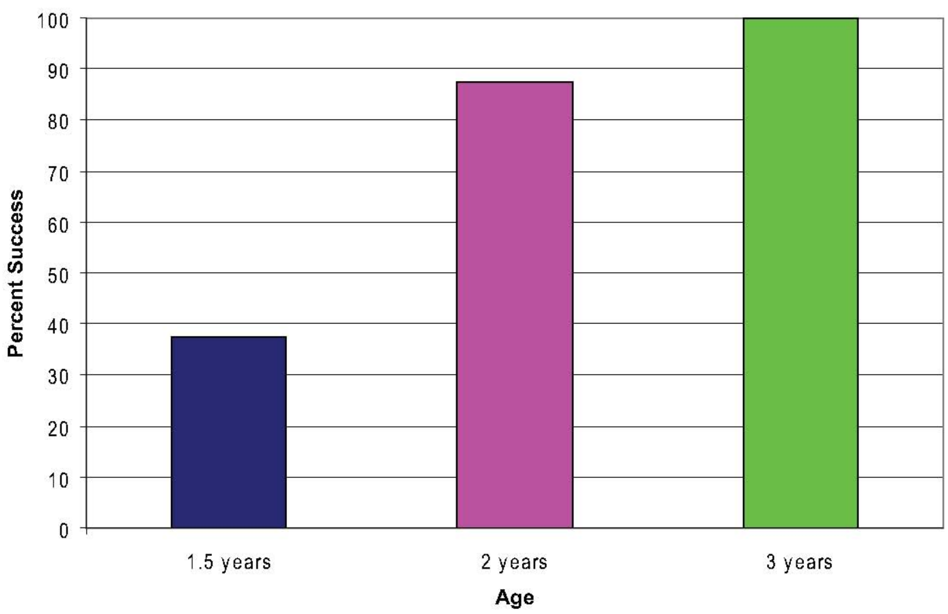

Figure 4. Success. Percent of solved trials for the three age groups. Each age group consists of 8 dyads who did 4 trials on two machines.

But how much instructional guidance did children need to solve the task? Again, there was a clear age-effect for the demonstration level needed to collaborate successfully (Kruskal-Wallis test: $H(2) = 14.581$, $p < 0.001$). Specifically, for three-year-olds, the information provided in demonstration stage 1 (in which children only saw the mechanism), was sufficient for them to collaborate successfully most of the time (see Fig. 5). Children of the two younger age-groups needed more information about the solution procedure. Whereas 80% of the two-year-old children could solve the problems after demonstration stage 1 and 2 (full solution), only 50% of the youngest children succeed after this instructional input. With additional more explicit instructions (stage 3 with individual instruction), only 69% of the youngest dyads succeed compared to 94% of the 2-year-olds. Still, after all demonstrational stages, one third of the 1.5. year olds cannot retrieve the objects.

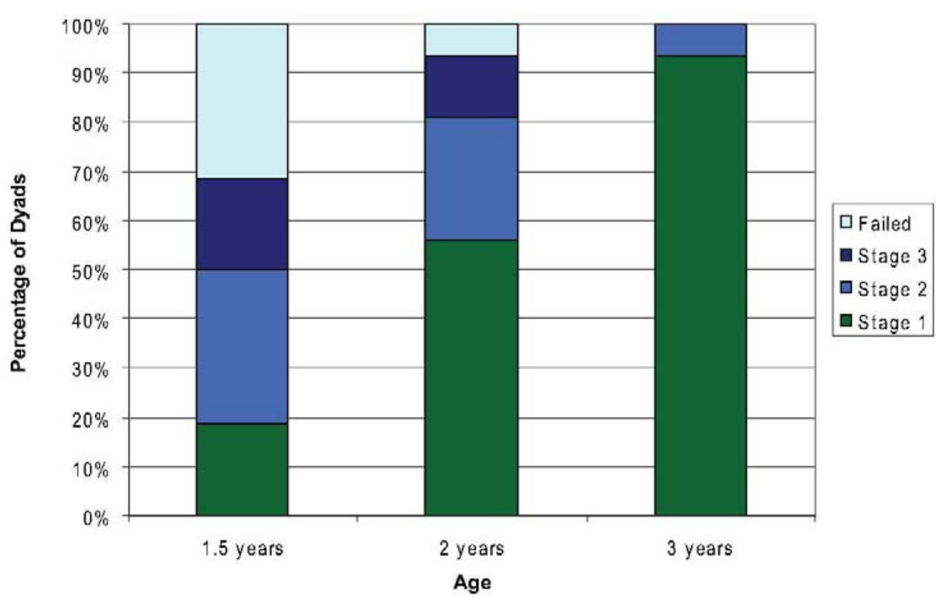

Figure 5. Instructional stages. Percentage of dyads according to the instructional stages needed to solve the problems.

In addition to the success rate, we were interested in how quickly children solved the problems. Obviously, latencies are only relevant for those subjects who eventually solved the task, which meant that because only two dyads among the 1.5 years-olds succeeded in both tasks, only latencies from the two-and three-old children were included in the analysis. We conducted a 2(age) × 2(apparatuses) repeated measures ANOVA on the mean latency across the 4 trials. There was a significant main effect of apparatus ($F(1,13) = 9.289$, $p = 0.009$) and of age ($F\ (2,13) = 8.134$, $p = 0.014$). Fig. 6 depicting latency to success shows that children needed more time to solve the slide than to solve the elevator task. Furthermore, three-year-old children were faster problem-solvers (mean = 10.30) as compared to two-year-old children (mean = 18.38 seconds).

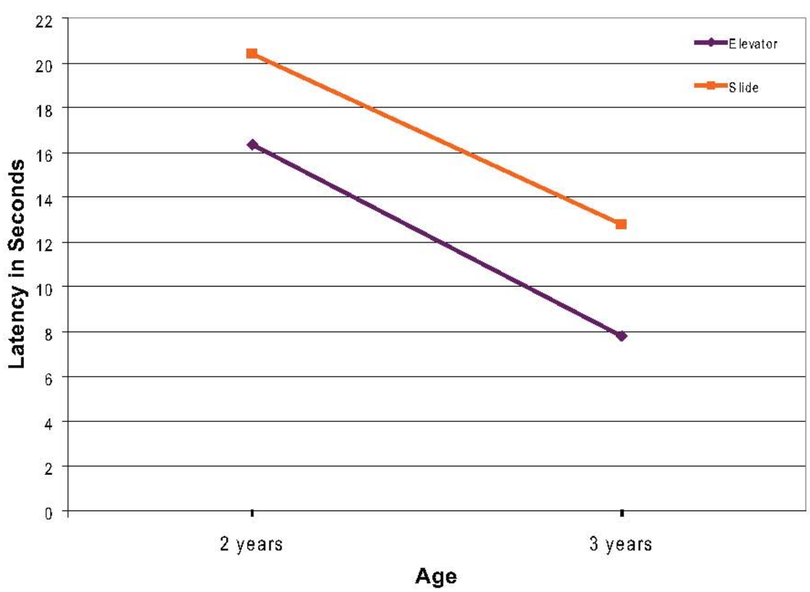

Figure 6. Latency to success. Time needed to retrieve the object from the apparatus. Please note that the data of the 1.5-year-old children is based on only 5 dyads who solved the apparatuses (partially).

To clarify why the youngest age-group needed more time to solve the task, we further analyzed the behavior during the solution process. Three-year-old children acted more efficiently, performing only those acts that were necessary to solve the problems: approaching the apparatus, determining the position of the role, taking the required position needed for the role and then performing the required action. Also the two year old children performed only a few unsuccessful solution attempts compared to the 1.5-year-old children (see Fig. 7). These youngest children did not provide many data points, thus their behavior could not be analyzed further. As there was no interaction-effect between the age group and the apparatus (Mann-Whitney U test: N = 13 (2 y: 5, 3 y: 8), U = 13, $p = 0.333$), we collapsed the data of the two apparatuses. There is no significant difference between the two apparatuses concerning the number of attempts (Wilcoxon test: T+ = 24.0, N = 13, $p = .773$). But 3-year-old children needed less attempts to solve the apparatuses (Mann-Whitney U test: N = 16, U = 1, $p < 0.001$).

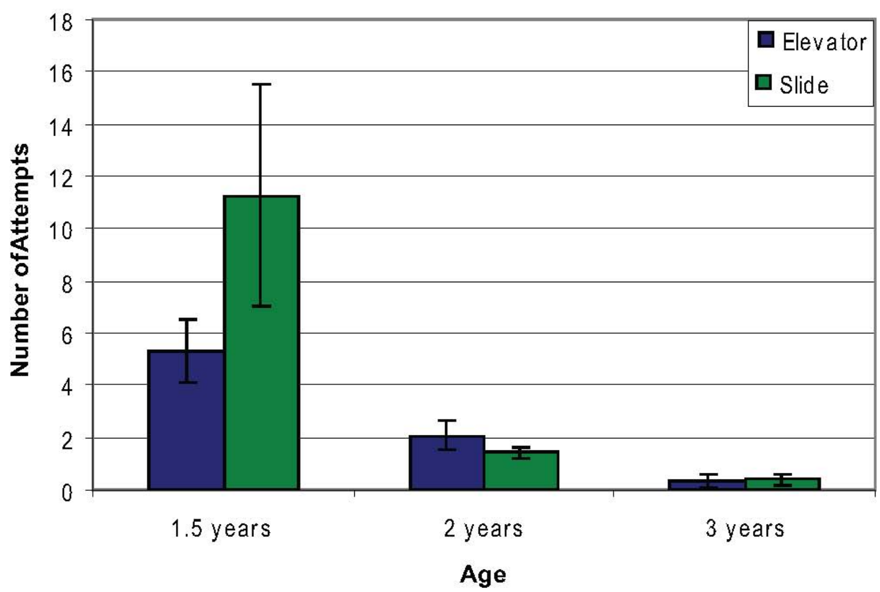

Figure 7. Failed attempts. Unsuccessful pushing or pulling of the mechanism as well as unsuccessful grabbing for the target object.

Furthermore, we were interested in how flexibly children switched between the two complementary roles. All but 4 dyads (all from the youngest age group) showed at least one spontaneous role-reversal. As each dyad was tested with two apparatuses with 4 trials each, maximally three role-reversals could be performed. Figure 8 shows the increase of spontaneous role-reversals with age. As there was no interaction-effect between the number of role-reversals and the apparatuses, we calculated the mean percent of role-reversals collapsed across apparatuses. Two-year-old children did not differ in the number of role-reversals from three-year-old children (U = 14.5, p = 0.069). Thus, both age-groups were equally likely to switch flexibly between complementary roles.

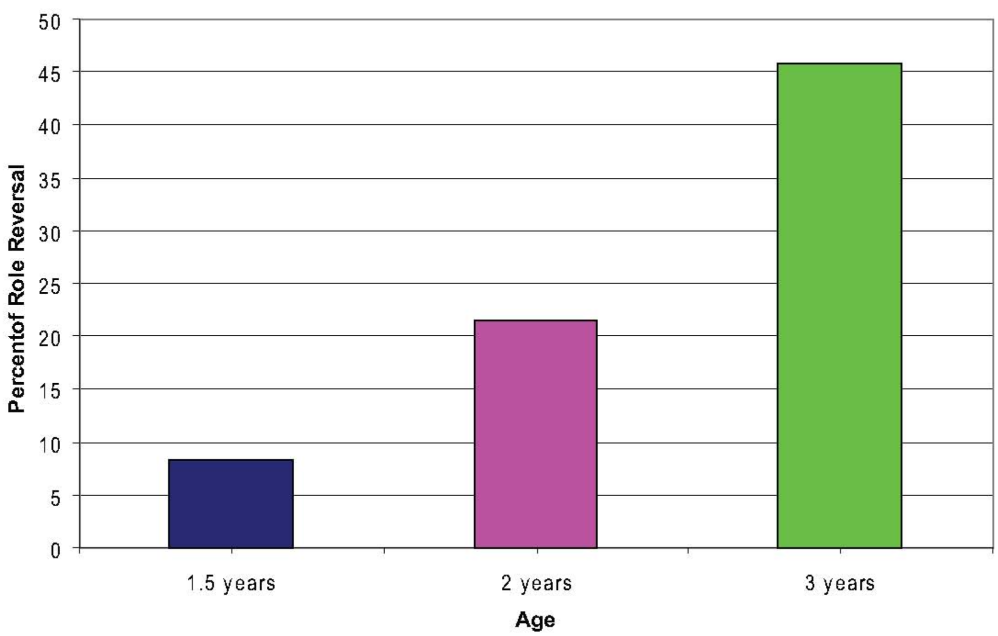

Figure 8. Role-reversal. Spontaneous role-reversals per age group. During four trials maximally three role-reversals can be performed.

To investigate potential transfer-effects across the two apparatuses, we measured the latency to solve the problem across all 4 trials from one machine to the other (see Fig.

9). The transfer across apparatuses occurs between trial A4 and B1. In a regression analysis we first compared the slope of the first four trials with the slope of the second four trials (i.e. A1-4 with B1-4). This data of the first and second slope was then analyzed in a 2 (age) × 2 (slope of first and second apparatus) repeated measures ANOVA. There was no significant effect of age and apparatuses. Two-and three-year old children solved the first apparatus with the same latency as the second apparatus.

Second, we compared the time needed to solve the apparatus in the first trial with the time needed to solve the first trial of the second apparatus. If children learned something about the mechanical properties and the peer coordination necessary to solve the problems, then we would expect a difference in these very first trials. A 2 (age) × 2 (latency of first trials of both apparatuses) repeated measures ANOVA yielded no main effect for the first trials (i.e. A1 and B1), but a main effect of age (F (1,14) = 7.133, p = 0.018). Thus, children needed the same amount of time in the first trial on both apparatuses to retrieve the object. Comparing across both age groups, 3-year-old children in the first trials of both machines are faster (mean = 12.27 seconds) than two-year-old children (mean = 29.47 seconds). We then repeated the same analysis for the immediate transfer from the last trial on the first apparatus (A4) to the first trial on the second apparatus (B1). Here, again the three year-old children were faster problem-solver than the tqo-year-old children (2 (age) × 2 (latency trial A4 and trial B1) repeated measures ANOVA: F(1,14) = 11.291, p = 0.005).

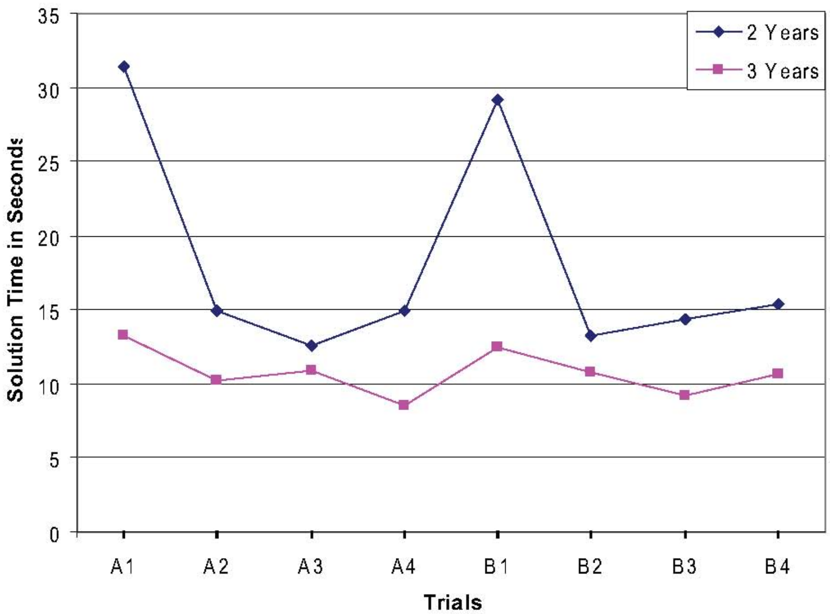

Figure 9. Transfer. Transfer from one apparatus to the second. Plotted here is the time needed to the object retrieval in each trial against the 8 trials at both apparatuses.

Discussion

This study investigates problem-solving abilities in 1.5-, 2-, and 3-year old peers. Confirming previous research (Brownell & Carriger, 1990, 1991; Brownell et al., 2006), we find that 1.5 year-old children are not yet ready to solve complex problems reliably together with a peer. However, from two years of age on, peer dyads can quickly retrieve an object from a problem-solving apparatus with complementary roles. To achieve a correct solution, they need little instruction, fail only at few solution attempts and show also spontaneous role reversals. These abilities are further developed at the age of three where children are even more efficient and flexible problem-solvers. Our results demonstrate that young children at two years of age can participate in social collaborative activities with peers. We extend previous research on peer collaboration in three ways: First with the application of gradual, systematic instructions and second with the usage of two structurally similar test apparatuses to test knowledge transfer across problems and third with the investigation of spontaneous role reversals.

Peer collaboration

In previous studies by Brownell and colleagues (1990, 1991, 2006) children did not seem to take into account and anticipate the actions of the partner before around 27 months of age. However, we found that children collaborating reliably at the age of 24 months. This is potentially due to our more intuitive problem-solving apparatuses which depend on gravity rather than on spring loaded handles. In addition, it is possible that children were successful at an earlier age because of the use of gradually more specific demonstration stages, possibly providing the required information for the children to understand the underlying principle and the structure of the two interrelated roles. Namely, across all three age groups the full, social demonstration stage seemed to enable children to combine the two separated actions (pushing/ pulling and retrieving) into one coherent action sequence executed by two agents. Thus, it is of further interest to investigate the constraints of the optimal social teaching and collaboration situation. Are children better problem-solvers together with a partner compared to an individual problem-solving attempt? What is the best way to instruct children to solve complementary problems? Do two-year-old children profit the most from a social demonstration as their main problem is that they cannot easily integrate two separate actions into one action sequence?

Role Reversal

Another aspect of the study was the question whether children represent the role of the partner, expressed in their tendency to perform spontaneous role reversals. The present study indicated that from the few dyads as young as 1.5 years that could solve the problems more than once (5 dyads), already 2 dyads showed one spontaneous role reversal. We interpreted spontaneous role reversal as an indirect measure of children's ability not only to represent their own role but also the other's role, indicating that they possess the the ability to form a bird's eye perspective on the problem at hand.

Studies 2 & 3

Peers' Mutual Support when Pursuing Shared Goals

Katharina Hamann, Felix Warneken, and Michael Tomasello

The present set of studies is directed at investigating children's commitment to shared goals in dyadic collaborative activities. The shared goal comprises both partners' intentions, that is, their individual actions as well as their individual subgoals (Tomasello et al., 2005; Tuomela, 2007). Correspondingly, commitments can be expressed by making sure that both partners perform their individual roles, and that each of them achieves his or her individual subgoal. Because the interaction is dyadic, this expression is also twofold in another way: On the one hand, (1) I want my partner to be committed, that is, to be engaged in his role, and to do his part in achieving the joint goal (what could be called "you-to-me commitment"). On the other hand, (2) my own engagement requires me to perform my role until the joint goal is fulfilled as well ("me-to-you commitment").

Previous research was mainly directed at children's understanding of the partner's commitment (1). The rationale of these studies was to establish a joint action together with the child and to interrupt it unexpectedly (Ross & Lollis, 1987). More specifically, the experimenter and the child played a game together, for example, the trampoline game, which is to jointly make a block bounce on a trampoline. After having played for a while, the experimenter suddenly stopped participating. From 18 months onwards, children reliably tried to re-engage the adult. This suggests that they want the partner to be engaged in performing his role in the joint activity at hand, and thus expect him to be committed to the joint play (Warneken et al., 2006). Moreover, when he is unable (but not when he is unwilling) to perform his role, 21- and 27-months-olds try to help him (Warneken et al., in preparation). Importantly, the joint activity is interrupted in both cases, and thus the behavioral effect is the same. Still, children respond differently in these cases which indicates that they perceive the other as an intentional agent who chooses to collaborate with them or not, either breaking the commitment (when he is unwilling) or failing to collaborate without breaking the commitment (when he is unable). The commitment to perform one's own role until the joint goal (2) is achieved has not been directly investigated yet. The present studies aim to fill this gap in (a) establishing a collaborative activity with the joint goal consisting of individual subgoals for both partners, and (b) having the child achieving her subgoal first (study 2), or being advantaged in receiving one of the partner's rewards accidentally (study 3). In both scenarios, the partner needs the child's support to be successful as well. In study 2, we asked if children show their commitment by continue to collaborate for the other to obtain a reward, even if they themselves have already gotten theirs. In study 3, we asked if children would share with the other if they unexpectedly had received one of his or her rewards. The studies were conducted with peers to avoid effects of scaffolding. The children under investigation were 2;6- and 3;6-year-olds, thereby making sure that they are able to coordinate in an activity with interdependent roles (cf. Steinwender et al., in preparation.)

Study 2

The first task assessed if children are committed to the joint goal by confronting them with the following situation: after having worked jointly on a task, only one child (A) was rewarded. The other child's (B) reward was inaccessible unless A collaborated with B. If A had formed a joint goal, that is, if she had B's goal (reward) in mind as well as her own, she should readily follow through until the joint goal is fulfilled: that both children have their rewards. This collaborative task was compared to a noncollaborative baseline based on the rationale that without a joint goal, children should find it less urgent to provide support, although they nevertheless might be helpful as well.

Method

Participants

Participants were N = 24 two-year-olds (12 dyads, 7 male, mean age = 2;8, *range* = 2;6 to 2;10) and 24 three-year-olds (12 dyads, 6 male, mean age = 2;8, *range* = 3;6 to 3;10). Six additional dyads had to be excluded due to shyness (n = 1), loss of motivation (n = 2), and technical or experimenter error (n = 3). All children were native German speakers, recruited in urban day care centers, and came from mixed socioeconomic backgrounds.

Materials and Design

The rewards were colorful, wooden toy blocks. Once gathered, children could use them to play a rewarding game, the "jingle machine game", which was a colorful box with a xylophone inside. The toy blocks were thrown into it, produced a ringing sound and disappeared. Children had to manipulate the test apparatus (see Figure 10) in order to retrieve two blocks, one for each of them, by moving them jointly from their initial out-of-reach placement to a position where they could grasp them. The blocks rested in bowls on a long rod stretching across the apparatus - visible through a transparent screen, but out of reach. Children had to move the rod towards holes in the screen by holding its handles and lift it up the stairway steps together. Moving the rod on one's own was technically impossible. By opening and closing the holes, we could vary children's access to the toy blocks depending on procedural phase and condition.

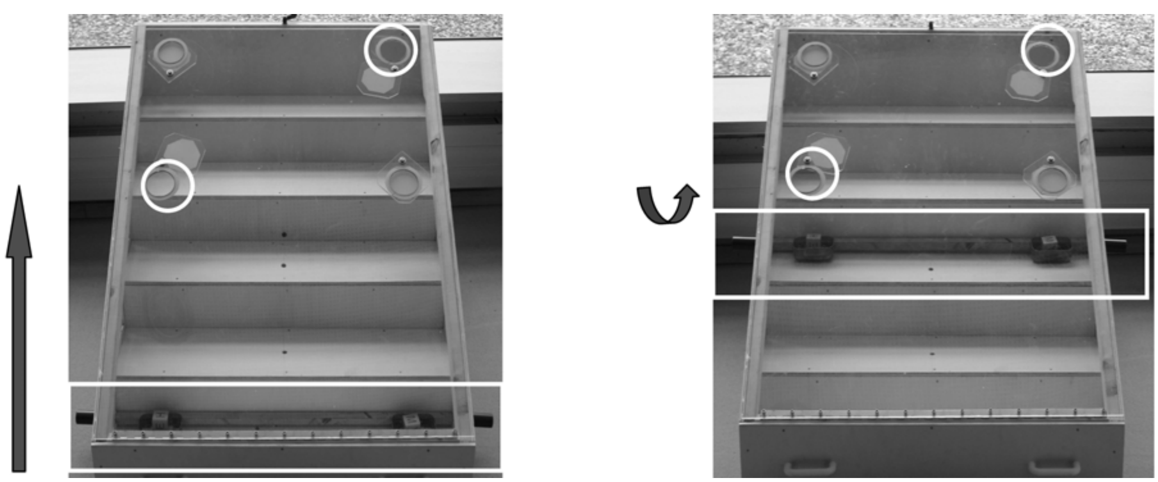

Figure 10. Pictures of the test apparatus (front view) in both conditions. On the left: Collaborative condition with board to be moved several steps jointly; on the right:

Baseline condition with the child on the left (A) having access instantly. Size of apparatus: ca. 77 x 90 x 80 cm.

After a demonstration phase (see below), we conducted two conditions in a within-subjects design, administered in blocks of four trials each. Between the blocks, a motivational trial was inserted with the two toy blocks being accessible immediately. The dependent measure was identical in both conditions (see again Figure 10): One child (A) was advantaged by having access to her block halfway through, whereas the other (B) needed her (collaborative) help. In the *Collaborative condition*, the blocks had to be moved up jointly all the way from the bottom of the apparatus before A had access (see Figure 10-a). In the *Baseline condition*, instead, no joint action preceded A's retrieving the block. We hypothesized that A would provide help more readily when both children had collaborated beforehand (Collaborative condition) due to the joint goal involved here, than when they had not (Baseline condition). Since children were assigned to one side of the apparatus in the very beginning and role "A" was alternated over trials, both children were supposed to have advantaged access twice per condition. The order of conditions was counterbalanced across dyads.

Procedure

We tested pairs of familiar children in a quiet room in their daycare centers. All testing was done by two female experimenters. Each session was videotaped and lasted approximately 25 minutes. After a short familiarization period in their playgroup, children were brought to the testing room.

Demonstration Phase. The goal of the demonstration phase was to teach children the mechanism of jointly moving the board to obtain the blocks. Additionally, they had to be familiarized with some features of the test phase, namely, that (1) they would have access either immediately or only after having collaborated, and (2) sometimes at the first and sometimes at the second level of holes. However, the specific experimental event that one child might have advantaged access to her reward, and the other needed her collaborative help to obtain hers as well was never demonstrated. The following demonstration trials were administered. First, the blocks and the “jingle machine game” were introduced, together with the test apparatus containing the blocks (demo trial 1). Second, the two experimenters demonstrated how to move the board successfully and that lifting on one side only was useless. Additionally, they assisted the children in their first attempt to solve the problem together (demo trial 2). Next, children were invited to retrieve the blocks, with experimenters providing verbal cues only if necessary (demo trial 3). The last trial was a pretest trial: children were left alone while operating the apparatus. If they retrieved the blocks successfully, they entered the test phase. If not, trials 2 to 4 were repeated maximally twice until they succeeded. Between trials, E1 set up the apparatus while E2 and the children waited outside the room.

Experimental Phase. Like in the pretest trial, children were invited to retrieve the blocks. Since in piloting the study we found that some children did not even notice that their second hole was open, they were also told to pay attention to where they might have access (and so to realize that one child was disadvantaged but nevertheless had a chance to get her block). They were reminded again during the trials if it appeared that they needed this kind of hint (by E1 saying, “And where on your side the hole is open? Well, get out the blocks, we’ll wait outside.”) During trials, the experimenters monitored children from outside the room via a video-screen that was connected to a camera inside. After both children had thrown their blocks into the jingle machines, or a predefined time had elapsed (30 s without clear attempts to move the board by A), E1 came in, asked them to leave the room and set things up for the next trial.

Coding and Reliability

All sessions were videotaped and coded by one observer. 20% of sessions were coded independently by a second observer for interrater reliability. For categorial ratings, Cohen’s kappa was calculated, for ordinal ratings, Cohen’s weighted kappa (Fleiss & Cohen, 1973).

Of main interest was whether and when children provided *collaborative help* for their partners: Did they lift the rod all the way until B was able to access her reward? Thus, we scored A's support for B after having retrieved her block: A could either provide support immediately (1), playing with the jingle machine first and help thereafter (2), or not provide support at all (3) (Interrater reliability: $\kappa = 1$). Dyads received one code per trial, that is, a maximum of 4 codes per condition (8 per session.) Because we observed that some children tried to help but used an unsuccessful strategy, we also scored children's *other helping attempts,* that is, if children with role A tried to manipulate B's part of the apparatus in order to retrieve the block (e.g., trying to open the closed hole, or trying to move the handle on their own; $\kappa = .84$). In order to assess to what extent A's helping was elicited by B, we coded B's *communicative acts* toward A. The critical time period was between A retrieving the reward and starting to help collaboratively (or else the end of the trial after 30 seconds with A doing nothing relevant). Communication was assessed with the following coding categories: 0 - no verbalizations, 1 - unrelated verbalizations ("We can go outside"), 2 - signs of discontent with the current state of affairs (moaning), 3 - referential utterances ("There!"), 4 - state descriptions ("This hole is closed!"), 5 - Requests, demands, questions ("Can you help me?"). Interrater reliability was $\kappa = .77$.

Results

Analyses addressed two major questions: (1) does the collaborative context make a difference in children's collaborative helping, and (2), are there any age differences in these responses to the other's needs? The main measure was thus the support provided by one child for the other. Children's collaborative help even *before* pursuing their private goal is most relevant here. In addition, because some children were unsuccessful but still seemed motivated to provide help, we turned to other helping-related attempts in a secondary analysis. We also wanted to know to what extend children's support was elicited by the partner and therefore analyzed their communicative behavior. Lastly, we checked if the length of sessions had an effect on children's success.

Primary Analysis

Collaborative helping. We hypothesized that collaborative contexts with joint goals should result in children providing collaborative help readily, especially compared to noncollaborative contexts. The measure for children's support was threefold, with the behavior most convincingly indicating a joint goal being A's instant helping ("immediate"). Other behaviors were providing support only after having played with the reward first ("delayed"), or not at all. For computations, the proportion of trials children demonstrated either immediate or delayed support was used. An ANOVA with the between-subjects factor age (2.5 vs. 3.5 years) and the two within-subjects factors condition (Baseline vs. Collaboration) and type of support (immediate vs. delayed) yielded a main effect of age ($F(1, 22) = 140.82$, $p < .001$) and a significant age x condition x type of support interaction effect ($F(1, 22) = 5.75$, $p < .05$). A look at the data (see Figure 3 and Table 1) suggests a complex pattern responsible for this significant three-way interaction. Apart from the fact that the 2-year-olds provided support much less often than the 3-year-olds, the most important finding is that they did not discriminate between conditions. The 3-year-olds, instead, did discriminate: in the Collaborative condition, they chose providing immediate support over playing first ($t(11) = 3.76$, $p < .01$), whereas in the Baseline condition, no such difference occurred. Overall, the older children provided immediate support more often in the Collaborative condition than in the Baseline ($t(11) = -2.58$, $p < 0.05$). Nonparametric tests yielded similar results.

Secondary Analyses

Other helping attempts. Besides the mutual collaborative help above, children showed other forms of supportive attempts as well. Most convincingly, some of the children with role A came over to their partner's side and tried to open her hole or to move the handle. This might be an additional reflection of children's motivation to help. A 2(age) x 2(condition) ANOVA yielded a main effect for age ($F(1,22) = 23.104$, $p < .001$) and a main effect for condition ($F(1,22) = 5.84$, $p < .05$). This was due mainly to the 2-year-olds, for hardly any older children were engaged in this kind of behavior (only 2 3-year-old dyads compared to 10 2-year-old ones). This was not surprising given that 3-year-olds usually helped efficiently. In the Collaborative condition, the helping attempts occurred more often than in the Baseline (Mean proportion of trials = .26 vs. .17)

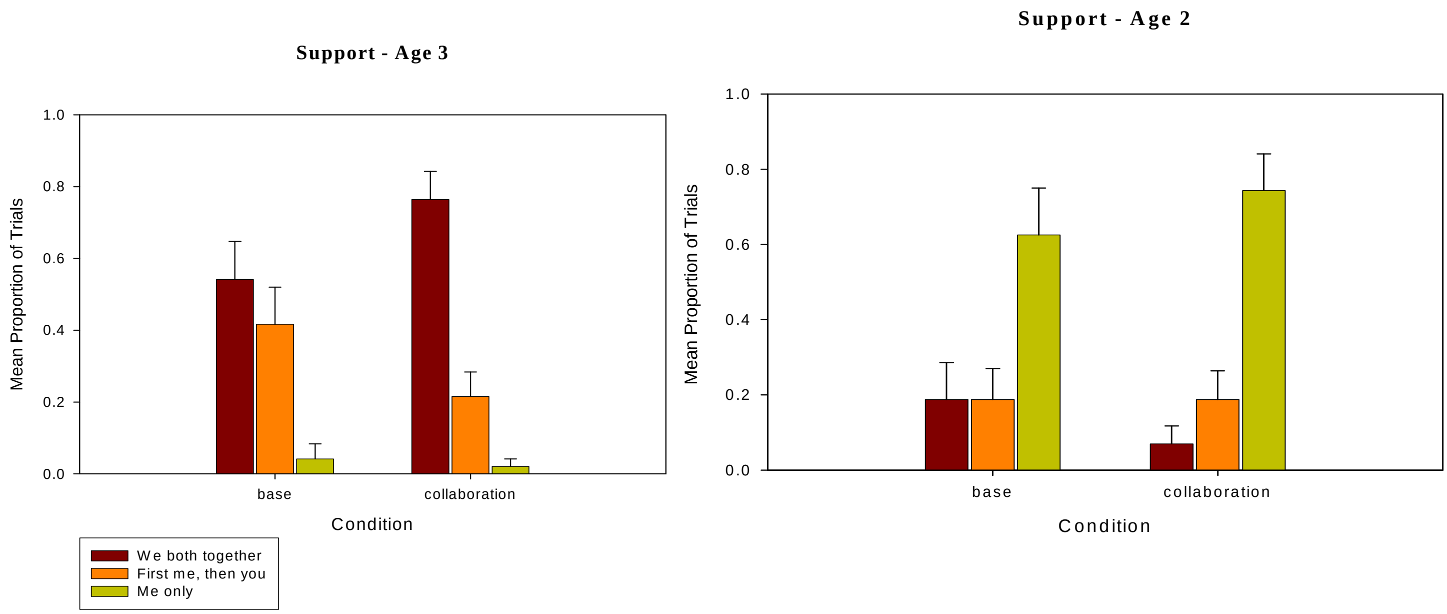

Figure 11. Type of support, split for age groups and conditions.. “We both together” refers to immediate helping, “First me, then you” to delayed helping. Error bars represent standard errors of mean.

Communication. We wanted to know to what extend children’s support was elicited by their partner. In trials with subsequent collaboration, 38.2% of children directly requested the other child to help (e.g., “Can you help me?”), and in additional 11.7% of trials they stated that something was wrong (e.g., “This hole is closed!”). However, in 44.7 % of trials children collaborated without requests or comments from the disadvantaged child.

Effects of session length. The 2-year-olds proved to provide support rather infrequently. We wondered if the length of the session with 9 consecutive test trials did influence their overall performance, for it might have been too long regarding this relatively demanding task. Indeed, we found a significant decrease of performing successfully (providing collaborative help) over the 8 trials (GLMM: point estimate (SE): -0.52 (0.195), $z = -2.65$, $p < 0.01$, with no effect of order of conditions). The three-year-olds, instead, showed no decrease.

Discussion of Study 2

The aim of the present study was to investigate children's commitment to the joint goal of a collaborative activity. If one agent happens to be unable to achieve his individual subgoal, would the other provide support? And would he or she do this more readily than in a situation without a joint goal?

With regard to the 3-year-olds, our findings are clearly affirmative. If their partner was in need of support, they provided the necessary assistance, although they themselves had received a reward already. Moreover, they helped the other more readily in a collaborative condition as compared to a non-collaborative baseline. We think that the joint goal involved in collaborative activities but not in neutral contexts is responsible for this difference between conditions, and that our findings thus demonstrate children's commitment to the joint goal that *both* of them should achieve their specific subgoals. It is important to highlight that the 3-year-olds in our study proved to understand the contribution of *their own role* in pursuing a shared end: they continued to collaborate although this added nothing to their own benefit at hand. This behavior did not even have to be elicited by their partner in the majority of trials. These findings supplement recent research showing that children also understand the *partner's role* in shared activities, for instance, by re-engaging him when he stopped participating (e.g., Warneken et al., 2006).

The findings for the 2-year-olds are very different: the younger children hardly provided the necessary assistance, nor did they discriminate between conditions either. The reasons for these results are unclear. We think it is rather unlikely that they were not committed to the joint goal at all since they demonstrated their motivation to help: regarding the liberal measure of "other helping attempts", all children discriminated between conditions with the 2-year-olds being engaged in these attempts much more often than the older children. The latter finding is not surprising given that the 3-year-olds were very successful in providing support in the “right” (experimentally intended) way. But why would the 2-year-olds not help collaboratively? In the pretest trial and during the Collaborative condition, they demonstrated their skills to manipulate the test apparatus in the correct way. Still, they did not apply this knowledge to help their partner. One possibility is that although they have an idea of the shared goal, they are not yet ready to fully understand *both* roles involved. They probably understand that they need their partner for joint success (as indicated by studies by Warneken et al., 2006), but they might have trouble to see that their partner also needs them. The vitality of this interpretation arises from the fact that the dependent measure used here was collaborative itself. This suggests a relation to the developing understanding of perspective-taking abilities. Another explanation is the complicated goal structure involved here: the overarching (joint) goal consists of two slightly different (individual) subgoals, and the same means needs to be applied twice to achieve each subgoal. This might have been cognitively too demanding due to limited working memory capacities. Together with the finding that the younger children’s performance decreased over time, these considerations suggest that the task used here was too difficult to reveal a potential influence of the shared goal on the 2-year-olds’ helping behavior.

Thus, we conducted a second study with a task that was less demanding in terms of task complexity and the main dependent measure. In using the same procedural methods, we tested again both 2- and 3-year-olds’ commitment to the joint goal in collaborative as compared to neutral contexts.

Study 3

The incentive for study 3 was to create a task that was simpler to process for the younger children than the task used in study 2. Therefore, we decided to use sharing, and not collaborative help, as the dependent measure. For producing an equal split for both partners, it was sufficient to hand over or let the other take the reward. Thus, this measure was not collaborative itself. Similar to study 2, this second task assessed if children were committed to the joint goal in asking if they make sure that both of them get an equal share out of a collaborative activity. After having pulled in ropes jointly, an initially similar amount of rewards for both of them ended up in an unequal split "accidentally". This was compared to a Baseline condition in which rewards were distributed unequally as well, but without any previous collaboration.

Method

Participants

Participants were 24 two-year-olds (7 male and 5 female dyads, mean age = 2;8, *range* = 2;6 to 2;10) and 24 three-year-olds (5 male and 7 female dyads, mean age = 3;8, *range* = 3;6 to 3;10). Four additional dyads had to be excluded because of experimenter or technical errors. All children were native German speakers, recruited in urban day care centers, and came from mixed socioeconomic backgrounds.

Materials and Design

Rewards were colored glass marbles. Once obtained, children could use them to play a rewarding game, the "jingle machine game" (the same as in study 2). The task was to manipulate a test apparatus (see Figure 12) to retrieve the marbles. Two were placed in each of two bowls on a board inside the apparatus, visible through a transparent screen. One long rope was attached to the board in a way that its two ends were outside the apparatus, and only pulling in both of them simultaneously would result in the board moving forward (cf. Hirata, 2007). Once the board reached the front, the marbles could be retrieved through small holes. Additionally, we built in a mechanism to simulate an accident in order to create an unequal split right before the marbles were accessible. This mechanism consisted of o the board being slightly tilted and an arrangement of two transparent mini-panels within the bowls. One panel was identical with the inner barrier of the heightened bowl. During the movement it slipped out so that one of the marbles rolled over to the other side. The other marble was detained from going by the second (fixed) panel.

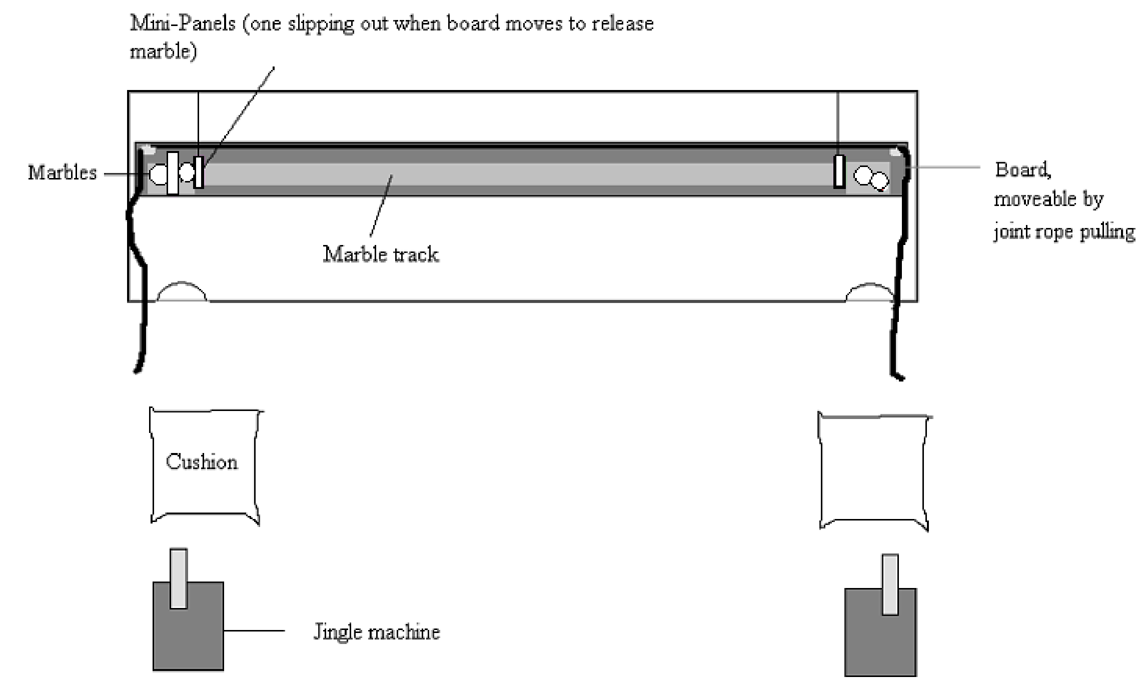

Figure 12. Sketch of the test situation (Collaborative condition) in study 2. Size of apparatus: ca. 180 x 60 x 15 cm.

The design was identical to that of study 2. After a demonstration phase, we conducted two conditions in a within-subjects design. Again, conditions were presented as blocks of four trials each, with a motivational trial in between where each child received two marbles immediately. The dependent measure was identical in both conditions: For one child (A) received 3 marbles and the other (B) only 1, to bring about an equal split A had to share her rewards with B. In the *Collaborative condition*, the marbles had to be pulled in jointly, and the "accident" created an unequal outcome. In the *Baseline condition,* however, no joint action preceded the uneven split: the rewards were set up unequally (3 vs. 1) on the board that was already in the front so that they could be retrieved instantly. We hypothesized that A would share more often when both children had collaborated beforehand (Collaborative condition), than when they had not (Baseline condition). Children were assigned to one side of the apparatus in the very beginning. Like in study 2, role "A" was alternated over trials, that is, both children received 3 marbles twice per condition. The order of conditions was counterbalanced across dyads.

Procedure

The procedure was almost identical to that of study 2. Pairs of familiar children were tested in a quiet room in their daycare centers. All testing was done by two female experimenters. Each session was videotaped and lasted approximately 20 to 30 minutes. After a short familiarization period in their playgroup, children were brought to the testing room.

Demonstration Phase. Throughout the demonstration phase, rewards were distributed evenly, and the apparatus operated properly without any accident. Like in study 2, we started with an introduction of the marbles, the jingle machine game, and the test apparatus containing the marbles (demo trial 1). Second, experimenters demonstrated that pulling one end of the rope proved to be unsuccessful, and pulled in the board *jointly* afterwards (demo trial 2). Next, children were invited to pull the ropes to retrieve the marbles themselves, with the experimenters providing assistance if necessary (demo trial 3). In the next trial, nothing but verbal cues were provided (demo trial 4). The last trial was the pretest trial: children were asked to retrieve the objects by pulling in the ropes while experimenters waited outside. If successful, they entered the experimental phase. If not, trials 3 to 5 were repeated maximally twice until they succeeded. Between trials, E1 set up the apparatus while E2 and the children waited outside the room.

Experimental Phase. Trials were preceded by the experimenters escorting the children to the apparatus. They made sure that they both sat in front of the apparatus and held the ropes. Then children were asked to retrieve the blocks, and the experimenters left the room. Children were monitored via a video-screen that was connected to a camera inside. Trials ended when children had played with the jingle machines, or after 30 seconds of problem-related behaviors. Again, they were not present when the apparatus was set up for the next trial.

Coding and Reliability

All sessions were videotaped and coded by a single observer. 20% of sessions were coded for reliability by a second observer who was unaware of the hypotheses of the study.

The major question was whether children who gained more rewards would *share* them with their partner, that is, whether A (who got three) gave one marble to B, thereby producing an even split of 2:2. Additionally, we were interested in the *type of sharing*: did they hand over the rewards actively, or did they rather leave them for the other to take? Coding categories represented different stages from passive to active sharing (1 - passive inattentive: A leaves marble in her/his bowl; B takes without A paying attention, 2 - passive attentive: B takes marble with A paying attention; 3 - active indicating: A points to marble or invites B to take it; 4 - clearly active: A handles B the marble or tries to roll it back inside the apparatus.) Whenever there were several attempts (e.g., A tries to roll the marble back actively but then leaves it and B takes it out) the higher code was assigned. To find out to what degree A's sharing was elicited by B's requests, we looked at B's *communicative attempts*. Codes represented the following categories: 0 - no eliciting, 1- unrelated verbalizations, 2 - signs of discontent with the current state of affairs, 3 - referential utterances ("There!"), 4 - state descriptions ("I have only one marble!", "Mine rolled over!"), 5 - possession-related utterances ("Mine!"), 6 - Requests, demands, questions ("Can I have one of yours?").

Results

The major questions were identical to the questions in study 2: (1) does the collaborative context make a difference in children's tendency to share, and (2), are there any age differences? Additional analyses were directed at the types of sharing, and how sharing was mediated by communicative attempts of the disadvantaged child. Preliminary analyses revealed an effect of order of conditions. Thus, this variable was included in further analyses.

Primary Analysis

Equal sharing. We wanted to know to what extent children share in response to an unequal split of 3:1 in a collaborative context, compared to a neutral context without joint action. The dependent measure was if children shared to create an equal split. A 2(age: 2.5 vs. 3.5 years) x 2(condition: Baseline vs. Collaboration) x 2(order of conditions: Baseline first vs. Collaboration first) ANOVA yielded a main effect of condition: children in the Collaborative condition shared more often than in the Baseline ($F(1, 22) = 21.85$, $p < .001$; see Figure 11). There was also a main effect of order of condition ($F(1, 22) = 4.72$, $p < .05$), but no effect of age. The interaction between order of condition and condition became marginally significant ($F(1, 22) = 4.23$, $p = .053$). Post-hoc t-tests showed that the effect of condition was stronger when the Baseline was administered first ($t(11) = -3.76$, $p = .003$) than when the Collaborative condition was first ($t(11) = -3.02$, $p = .01$). This suggests a transfer effect from the Collaborative to the Baseline condition: initial sharing in the Collaborative condition led to more sharing in the subsequent Baseline condition, but an initially neutral context did not influence the sharing in the collaborative condition afterwards. There were no other significant interactions. Nonparametric tests yielded similar results.

Secondary Analyses

Type of sharing. To analyze children's sharing behavior more closely, we distinguished different types ranging from "clearly active" (e.g., handing over one marble) to "passive inattentive" (e.g., child leaves one marble, but does not pay attention to the other child's doings.) See Table 1 for a summary of the data. Altogether, children shared actively twice as often as passively, with passive sharing almost always involving attending to the other taking the marble. In the Baseline condition, the rate of active sharing was higher than in the Collaborative condition, where the children more often just attended to the partner taking it.

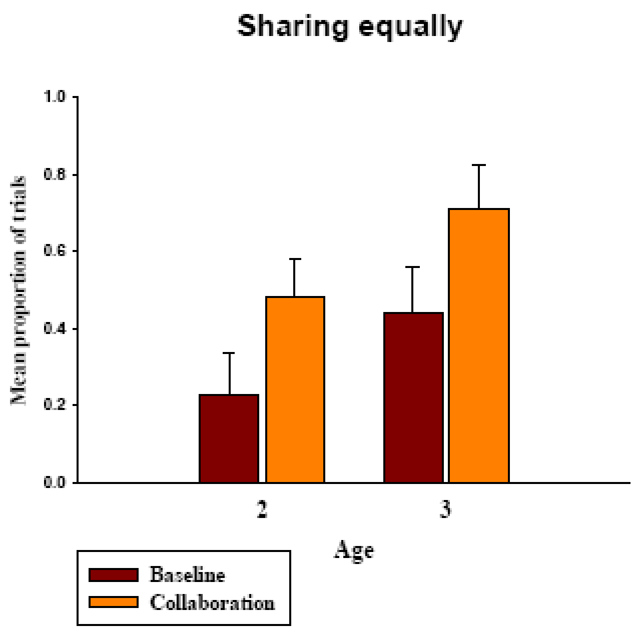

Figure 13. Mean proportion of trials children shared equally, presented for conditions and age groups. Error bars represent standard errors of mean.

Table 1 Percentages of types of sharing for the age groups and conditions.

	Age 2.5		Age 3.5		
Type of sharing	Baseline	Collaboration	Baseline	Collaboration	Sum
Passive unattentive	1.02	1.02	1.02	1.02	4.08
Passive attentive	2.04	14.29	2.04	9.18	27.55
Active indicating	0.00	0.00	0.00	3.06	3.06
Clearly active	12.24	8.16	22.45	22.45	65.31
Sum	15.31	23.47	25.51	35.71	100.00

Communicative attempts. Additionally, we wanted to find out whether sharing was spontaneous or elicited by the disadvantaged child. Overall, it was elicited by direct requests in 22.68% of the time. In 34% of trials, they either stated that something was wrong or pointed out that *their* (B's) marble was in A's tray now. Equally often (in 37% of sharing trials) they produced no or only unrelated utterances. In general, children tended to request the rewards more often in the Baseline than in the Collaborative condition (34.5% vs. 17.5% of sharing trials). Conversely, they did so without any problem-related utterances almost three times as often in the Collaborative than in the Baseline condition (13.4% vs. 5.2%).

Discussion of Study 3

In study 3, we wanted to create a task that was simpler to process for the 2-year-olds than the task used in study 2. We were interested in the question whether having a joint goal would lead children to correct an unequal split. Therefore, we again compared a collaborative with a neutral context, assuming that collaboration involves a joint goal whereas a neutral context does not. Our hypothesis was that if children collaborated prior to being confronted with unequal amounts of rewards for each of them, they would be more likely to share than in a situation without prior collaboration. The present findings confirm this hypothesis. Both 2- and 3-year-old children shared their rewards more frequently in a collaborative context as compared to a non-collaborative baseline. The lack of differences between age groups suggests that we were successful in creating a task less demanding than the one used in study 2, and that even 2-year-olds are responsive to the implications of joint goals, namely, that both partners should achieve their individual subgoals (here: receiving two marbles).

What might have helped children in the collaborative condition was that the marble rolling over to the other side of the apparatus was a clear attention-getter, making the unequal outcome very salient. Another problem with the apparatus is that it can entail assumptions about possession: it is *my* marble that rolled over to your side, and you have to give it back. Thus, enhanced attention, possession and collaboration are confounded in study 3. Only further experiments, for instance with one marble rolling over to the other side without collaboration, can help disambiguating these different readings.

Discussion of Studies 2 and 3

Summary of the present findings

Previous research had shown that children from about 18 months of age appear to have some understanding of shared goals in collaborative activities, including the different roles involved. Yet another part of cooperative endeavors is that they entail mutual commitments: we expect our partner to be just as engaged to achieve our joint goal as we ourselves are. Research so far provides evidence that even 18-month-olds show that they want the other to be committed. This is indicated by their attempts to prompt a reluctant partner back into the joint activity (Warneken et al., 2006), thereby appreciating him being an intentional agent: they try to help him when he is unable, but not when he is unwilling to perform his role (with 21 months at the latest; Warneken et al., in preparation). But to what extend do children commit themselves to the joint goal? Are they willing to take the other's subgoals (as part of the overarching joint goal) into account just as their own? The present studies indicate that they do. Young children (2;6- and 3;6-year-olds) appear to make sure that both agents' subgoals are achieved, given that they can manage the task cognitively. In study 2, 3;6-year-olds continued to collaborate until the other could obtain a reward, although they themselves had been rewarded already. In study 3, both 2;6- and 3;6-year-olds showed that they want the other's subgoal to be fulfilled in correcting the unequal (and accidental) outcome of a joint activity. The importance of the *joint goal* is highlighted by the fact that children's performances differed in collaborative and noncollaborative contexts. Without collaboration (and hence without a joint goal), children provided support occasionally but less often than in collaborative contexts (with a joint goal).

Age-differences

The 3-year-olds proved their commitment to the shared goal in both studies. The 2-year-olds, however, hardly helped the other collaboratively so that he or she could achieve his/her subgoal (study 2). That they were nevertheless motivated to help was indicated by their unsuccessful helping attempts. Also, they proved their commitment in the cognitively less demanding task of study 3. What is responsible for these differences in performance? We think that the complicated means-end structure of the task in study 2 could be a reason: its working memory capacities might have overstrained the young children. Another possible explanation is that this task affords perspective-taking abilities they have not yet at their disposal: whereas they probably know that they need the other for achieving their goal in the collaborative activity, they still might have trouble understanding that the other also needs them. Further studies are needed to distinguish between these alternatives.

Yet another possibility is that the younger children are still instable in their ability to differentiate between joint and nonjoint activities. In simpler scenarios as the one we conducted, they often even seem to overestimate the joint or social character of a situation, for instance in re-engaging someone who stops playing *next* to them (just as if he would play *with* them; Gräfenhain, Behne, Carpenter, & Tomasello, in press). One year later (with three years of age), then, they are able to draw this kind of fine-grained distinction. This might be related to children's understanding of the rights and obligations involved in joint as compared to non-joint activities: in a joint activity, partners refraining from the joint action without obvious reasons should be reminded to fulfill their role as they committed themselves to the activity, whereas this prompting is not appropriate for partners engaged in an individual (parallel) activity. Furthermore, children acknowledge to the partner their own refraining from the activity (by e.g. leaving the task) more often in joint than in non-joint contexts - for example, when they rather want to play a more attractive game with someone else (Gräfenhain et al., in press). Thus, the understanding of rights and obligations in collaborative activities appears to develop during this age period as well, and could contribute to our different findings for the 2-year-olds.

Problems with the present studies

One could object that the results of study 2 could also be explained by reciprocal helping (citation) and thus rely simply on understanding individual, and not shared, goals: I help you because you helped me. We think that this is rather unlikely given the results of study 3, where reciprocal helping is not an option due to the dependent measure (sharing) being very different from the collaborative activity itself (pulling ropes). Conversely, the major limitation of our second task (study 3), namely, that children's behavior might be explained in terms of possession without referring to joint goals at all (I give you back what's yours), is not an issue in study 2 because each child's (sub-)goal to "possess" one reward is identical in both conditions and thus cannot explain the differences we found here. Thus, the two present studies might, to some extent, mutually compensate their weaknesses. Still another issue is attention. Our collaborative tasks require coordination and thus paying attention to the other's doings, whereas this is not the case in the neutral (baseline) contexts. This might be especially the case for the task used in study 3 where the "accident" draws the attention to the unequal outcome. But this is the case in all kinds of face-to-face interactions, for virtually all concrete collaborative activities build on the understanding and deployment of shared attention.

4. Conclusions for the implementation in robotic systems

How can the current experiments inform research in robotics? In the following section, we want to highlight which aspects appear to be most important in this regard. Specifically, the current experiments provide different collaborative scenarios, observational and statistical tools to assess performance in these tasks and provide insights into the capacities that agents need to possess in order to collaborate successfully.

Scenarios

We developed 4 different collaboration scenarios in which two agents have to interact in order to solve problem-solving tasks successfully. Two involve parallel roles (Stairs, Board-pulling) and two involve complementary roles (Elevator, Slide), the latter therefore allowing for the possibility of role-reversal.

Observational and statistical tools

We offer several behavioral criteria according to which children's (and ultimately more generally agents') performance can be assessed:

- Success rate
- Latency to success
- Efficiency (success/number of attempts)
- Trial-to-trial learning (assessed by changes in latency over problem trials on the same task)
- Transfer (assessed by changes in latency between tasks)

Task demands and core capacities for collaboration

Action-monitoring. The experiments by Hamann et al. show that agents have to be able to not only monitor the status of their own action (especially whether their own goal has been achieved), but also the status of the partner's action.

Namely, in the Stairs task they have to pay attention also to the other side of the apparatus and assess whether their partner is able to retrieve the reward on the other side. In children, this is done through visual perception. If easier to implement, a robot could use a different modality to check the status of the other's goal-directed action.

Importantly, the setup of the Stairs apparatus in principle allows us to predict when which agent will be able to achieve his or her respective goal because the arrangement of the holes is set up beforehand. In the Board-pulling apparatus, however, an unpredictable accident occurs, in which outcome and goal do not match, as one ball rolls over from one side to the other. Therefore, agents have to be able to either visually track the accident or update that the current status (3 balls on one side, 1 on the other) does not match with the intended goal. Therefore, the different tasks require different levels of cognitive flexibility to update representations after the occurrence of unpredictable outcomes.

We are currently in the process of assessing whether the discrepancy in the children's performance in the two tasks is due to the salience of the accident and/or their ability to track the status both on their own and the partner's side (e.g. how the reward on their side is moving up the stairs and how the reward on the other side moves up the stairs). This is done by testing children working on a highly similar version of the task individually, requiring them to first retrieve the reward half-way through on their own side, then move the rod up all the way in order to also retrieve the other reward from the other side. This will enable us to assess whether this is a general attention problem or a social-attention problem.

Representation of shared intentions and role-reversal. The current experiments provide different measures for the assessment of young children's capacity to represent their own and the other's actions as interrelated actions towards a shared goal. As described in the introduction, one is role-reversal, which children master in the second year of life, indicating they have a bird's-eye view perspective on the situation. Tests with robots should confirm that this bird's-eye view perspective is actually a necessary prerequisite for these kinds of behaviors, especially role-reversal.

Hamann et al. introduce measures of another aspect of shared intentions, i.e. the mutual commitment to act towards the goal until it is actually achieved, including subgoals of the agents. As described in detail above, to give evidence for mutual commitment as a critical aspect of collaboration (something that children appear to develop between 2 and 3 years of age), the agent must not only be able to prompt the other and re-direct her towards the goal if the other agent ceases to participate, the agent must also be able to provide help and adjust her own actions to the partner if the partner is for some reason unable to continue her action. In other words, even if agent A has done her job and has proceeded to a stage in the action-plan in which usually she would terminate the activity, she needs to monitor agent B and make adjustment to the plan if necessary.

Spatial and temporal coordination. The tasks by Steinwender et al. show that children are able to coordinate their actions both spatially and temporally. Spatially, because the positions are not pre-assigned and children have to negotiate who operates in which side of the apparatus. If this is too demanding for the robot (or impossible for a robot-torso), roles could be pre-assigned and then switched between trials. In both cases, a representation of the two interrelated actions would be necessary, but the demands on planning skills and locomotion are reduced. Concerning the temporal coordination of actions, all tasks used are highly demanding, as one agent has to adjust her actions to the actions of the other: For example, in the slide-task one child has to pull and hold the string in place until the other person has taken the object out, i.e. monitor that the other person and determine her action only after the other person has completed her action as well. A simpler version might be to have agent A perform the act before agent B, with no further temporal fine-tuning necessary.

One difference between the slide, elevator and the stairs on the one hand and the board-pulling apparatus on the other hand is that in the former three, errors can be corrected. Namely, if children fail to wait for the other (pulling the string of the slide, but letting go before the other was able to retrieve the object), they can repeat the action until being ultimately successful. This is reflected in the measure of attempts necessary for completion, which shows clear developmental differences between 1- , 2- and 3-year olds. In the board-pulling apparatus, however, one agent is not supposed to start acting until the other agent is ready to act on her side, as otherwise the rope is pulled out of the apparatus and the reward is lost. Therefore, this task requires high levels of inhibition, which is very challenging for children before 2.5 to 3 years of life. This problem can be compensated by external regulation (such as an adult telling the child when to pull) or communication among the peer collaborators. The important point to keep in mind is that for the construction of robots designed to collaborate on this last apparatus, special attention must be paid to how the robot initiates the activity, whereas for the first three apparatuses, it is particularly important that the robot is able to monitor when the task is actually accomplished and to know when to stop.

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