Young children’s planning in a collaborative problem-solving task

Felix Warneken a, *, Jasmin Steinwender b, Katharina Hamann b, Michael Tomasello b

a Harvard University, Cambridge, MA, United States
b Max Planck Institute for Evolutionary Anthropology, Leipzig, Germany

A R T I C L E   I N F O

Keywords:
Planning
Cooperation
Collaboration
Peers
Problem solving

ABSTRACT

One important component of collaborative problem solving is the ability to plan one’s own action in relation to that of a partner. We presented 3- and 5-year-old peer pairs with two different tool choice situations in which they had to choose complementary tools with which to subsequently work on a collaborative problem-solving apparatus. In the bidirectional condition, exemplars of the two necessary tools appeared in front of each child. In the unidirectional condition, one child had to choose between two different tools first, while the other child had only one tool available. Thus, both conditions required close attention to the actions of the partner, but the unidirectional condition additionally required the anticipation of the partner’s constrained tool choice. Five-year-olds were proficient planners in both conditions, whereas 3-year-olds did not consistently make the correct choice. However, 3-year-olds who had first experienced the unidirectional condition chose the correct tool at an above-chance level. Moreover, communication during the tool choice led to greater success among 3-year-olds, but not among 5-year-olds. These results provide the first experimental evidence that between 3 and 5 years of age children develop the ability to plan the division of labor in a collaborative task. We discuss our findings regarding planning for a collaborative task in relation to prior research on planning abilities for individual problem-solving that appear to undergo developmental change between 3 and 5 years of age.

© 2014 Elsevier Inc. All rights reserved.

* Corresponding author at: Department of Psychology Harvard University, 33 Kirkland St., Cambridge, MA 02138, United States.
E-mail address: warneken@wjh.harvard.edu (F. Warneken).

http://dx.doi.org/10.1016/j.cogdev.2014.02.003
0885-2014/© 2014 Elsevier Inc. All rights reserved.
Collaborative problem solving involves simultaneous coordination of several different behavioral and social-cognitive skills. Theoretical models of collaboration stipulate that partners perform their behaviors based upon a joint action plan, representing not only their own but also their partner's action during the task (Bratman, 1992; Tomasello, Carpenter, Call, Behne, & Moll, 2005). This implies that partners must be able to divide up the labor and coordinate complementary actions derived from the joint goal, including the ability to reverse roles. Developmental studies show that during the second year of life, children begin to successfully solve collaborative problem-solving tasks that require behavioral coordination (Brownell, Ramani, & Zerwas, 2006; Eckerman & Peterman, 2001; Warneken, Chen, & Tomasello, 2006). When children approach age two, they begin to successfully coordinate complementary actions with peers in the absence of any adult scaffolding (Eckerman & Peterman, 2001). Brownell and Carriger (1990) presented 18- to 30-month-old peers with a very simple collaboration task in which one child had to push a lever to align a toy beneath a hole in a Plexiglas table so that the partner could then retrieve it. (The lever was spring-loaded so that the first child had to hold the lever in place until the other retrieved the toy.) In these tasks, since each individual action is quite simple, what is most urgently required of the child is to coordinate with the partner in time to, for example, reach for the toy once the partner is opening the contraption. There is little need to attend to precisely what the other is doing. In fact, using a task in which children had to use two complementary devices to retrieve a reward from an apparatus, Ashley and Tomasello (1998) found that 24-month-olds were almost entirely unsuccessful in a task requiring one child to pull a lever to bring a toy in front of a door that the other child had to open before they could retrieve the toy, but 3.5-year-olds were successful. Other studies have shown that children know when they are not able to solve a task by themselves and actively request a partner's collaboration during interruption periods. At 14–18 months, toddlers try to re-engage a recalcitrant adult partner who stopped working with them on a collaborative problem-solving task (Warneken et al., 2006; Warneken & Tomasello, 2007). By age 3, children assist each other in a collaborative problem-solving task until both peers are successful in retrieving their respective rewards (Hamann, Warneken, & Tomasello, 2012). Thus, evidence suggests that when action outcomes are immediate, children are able to collaborate in the sense of solving a task that cannot be completed by one person acting alone.

Despite the successful behavioral coordination of complementary roles, it is not clear at what level children are able to represent the partner's goal-directed action. Recent research using a visual habituation method shows that at 14 months, infants already grasp the complementarity of collaborative interactions, at least when they observe other agents interact. When infants saw how one agent opened the lid of a box and the other agent took a toy out of the box, they perceived the box opening by the first person not as an end in itself, but as instrumental in enabling the second person to retrieve the toy (Henderson & Woodward, 2011). This indicates that children are in principle able to detect that one action is executed to enable another person's subsequent action. This ability is facilitated if 10-month-olds gain experience performing the subsequent action themselves, i.e. retrieving the toy from the box that an adult opened for them (Henderson, Wang, Matz, & Woodward, 2013).

When engaging in a collaborative interaction themselves, are children able to choose their own action based upon a joint action plan? More specifically, when deciding what possible action to take, do children represent their own and the partner’s actions as interrelated such that their own choice of an appropriate action is in part determined by the choices that the partner has available? Previous tasks cannot provide a satisfactory answer to these questions, because children could change their strategies on the fly, adjusting their own behavior to the ongoing behavior of the peer while both were manipulating an apparatus. That is, although children perform the correct complementary roles, they may succeed not because of an actual choice of complementary action-roles, but because they are forced to choose the action the partner does not perform. Moreover, in some cases, the outcome of the partner’s action was directly visible to them (such as a door opening to reveal a reward) without their having to represent the other’s actions at all.

A more stringent test might be to assess children’s representational capacities by requiring them to choose actions and assign roles before they act on the collaboration apparatus. If children have the ability to make individual decisions based on a joint action plan that encompasses their own and the partner’s action, they should be able to make the correct decisions prior to executing the actions. Therefore, we developed a task that requires peers not only to pay close attention to what the other is
currently doing, but also to plan their actions based on expectations of what the other will do. While there are several studies on older children’s planning with adults and peers (Gauvin & Rogoff, 1989), to our knowledge there are no studies of collaborative problem-solving in young children that require them to anticipate what action the partner will be able to take, and to plan their own actions on that basis.

When do children develop these capacities? Studies of children’s individual planning abilities are informative in this regard, providing us with a specific prediction about the age at which this capacity develops. Planning is challenging for toddlers, even in individual problem-solving situations, although they can engage in some very simple planning of responses (Bauer, Schwade, Wewerka, & Delaney, 1999). Individual planning skills appear to undergo significant changes between 3 and 5 years of age (see McCormack & Atance, 2011, for a review). For example, Atance and Meltzoff (2005) found that 5-year-olds reliably select only those items that would be needed for future hypothetical situations, whereas 3- and 4-year-olds are less targeting, selecting also task-irrelevant, but semantically related, distractor items. Similarly, 3–5-year-olds asked to select two conjunct objects needed for another round of a game, only 5-year-olds succeeded (Russell, Alexis, & Clayton, 2010).

Suddendorf, Nielsen, and von Gehlen (2011) tested appropriate tool selection either immediately or with a delay after the problem formulation (the tool is broken). The 3-year-olds could deal with the situation with no temporal delay, but only 4-year-olds succeeded in the delayed task. The 3-year-olds’ failure was attributed to the difficulty implied by the temporal displacement and attributed to immature planning capabilities. Suddendorf et al. (2011) concluded that by age 4, children can (a) remember a novel problem, (b) recognize the appropriate solution, and (c) act according to that solution by selecting the correct tool “in anticipation of applying it to the problem in the future” (Suddendorf et al., 2011, p. 26).

Taken together, these studies of children’s individual planning skills suggest that planning capacities undergo a major shift between ages 3 and 5, with 3-year-olds mostly failing to plan adequately and 5-year-olds mostly planning successfully. Therefore, the question arises whether these planning capacities extend to situations in which children have to make decisions about how to solve a collaborative problem-solving task. When do children begin to make correct choices about their own actions in anticipation of the complementary actions of a partner?

We presented pairs of 3- and 5-year-olds a collaborative apparatus requiring partners to perform complementary roles to retrieve a reward from a box by using two complementary tools. All children had demonstrated that they could successfully collaborate on the task with an adult when they were equipped with the right tools. Thus, our focus was not on their performance on the collaborative problem-solving apparatus itself, but rather on the children’s prior selection of the tools. Would children choose the correct tools prior to collaboration with the problem-solving apparatus out of sight behind an occluder? Two experimental conditions were administered. In the bidirectional condition, each child had exemplars of the two necessary tools available. In the unidirectional condition, one child was forced to choose between the two tools first, while the other child only had one tool available. Thus, the first child had to anticipate the second child’s constrained choice and select the complementary tool. We asked at what age children could plan their own action (tool choice) so as to coordinate with a partner, with the objective of gaining insight into children’s ability to divide the labor and represent complementary actions involved in a collaborative activity. Based on the suggestion of an age shift in planning skills between 3 and 5, we predicted that 5-year-olds would be more successful than 3-year-olds. In addition, we predicted the unidirectional condition would be more challenging for the younger children because it required them to anticipate the other’s constrained choice.

Method

Participants

We tested 12 dyads of 3-year-olds (mean age = 3–3; range 3–0–3–5; six female) and 12 dyads of 5-year-olds (mean age = 5–4; range 5–0–5–5, six female). Five additional dyads were excluded from analysis due to shyness (3) and technical problems (2). All testing was done in a quiet laboratory room.
Children were paired with an unfamiliar same-sex peer from the same age group. Parents monitored the testing session from an observation room over video. Children came from various socio-economic backgrounds and were recruited from a child database of a medium-sized German city. Children received a small gift for their participation.

Materials

Problem-solving apparatus (Fig. 1)

The problem-solving apparatus required children to perform two complementary roles with two different tools (push tool and turn tool) successively to access a silver ball (6 cm in diameter) containing surprise items.

Tools (Fig. 2)

We used two turn tools and two push tools, differing both in appearance and in function. To emphasize the difference, each tool had an orange or a blue band, which corresponded to the color marking on two sides of the apparatus. The turn tool was reminiscent of a screwdriver, made of a rectangular handle (9 cm × 2.3 cm) with a disk (4.5 cm diameter, 0.8 cm thick) and a small and thin top (2.5 cm × 1.5 cm, 2 mm thick). Thus, children held the tool at the long end and inserted the small end with the disk into the slot, then turned the tool to remove a barrier preventing the application of the push tool. The push tool consisted of a handle shaped like a cube (2.5 cm × 2.5 cm × 2.5 cm) with a disk (2.5 cm diameter, 1 cm thick) and a wooden cylinder (1.5 cm diameter, 7.5 cm long). Thus, children held the tool by the
cube and inserted the cylindrically shaped long end into a whole of the apparatus to push the ball forward.

Selection boxes

Identical selection boxes (32 cm × 25 cm, see Figs. 1 and 2) were placed in front of each child. The box contained toy figures during the demonstration phase and the tools during the actual test phase. The purpose of the box was to provide restricted access to the problem-solving tools as each child could only access one tool. The box had a drawer subdivided into two identical halves, so that objects could be placed on either side. The drawer could be pulled toward either side, but because of a blocking mechanism, once it was pulled to the left or right, it could not be pushed back in (see an opened box in Fig. 1c). This prevented children from changing their initial choice.

Design

All children were tested in two conditions (Fig. 2)

In the bidirectional condition, children had both of the two tools available in their selection box. A signal lamp placed on the floor next to the children indicated by its position which child was supposed to retrieve the tool first. The first child could freely choose one of the two tools. After his or her choice, it was the second child’s turn. In order to choose the correct complementary tool, the second child had to take the partner’s previous choice into account. In the unidirectional condition, one child had both tools available, while the partner only had one tool in the box. In contrast to the bidirectional condition, now the first child had to take into account the partner’s constraints, namely that the second child would have only one tool available to choose. Each dyad was tested in both the unidirectional and the bidirectional condition (order counterbalanced across dyads) and children alternated who had one or two tools in front of them in the unidirectional condition.
Procedure

Since children were unfamiliar with each other, we used an initial collaborative game (see Kirschner & Tomasello, 2010, for details) during a warm-up period of 10–15 min to establish a cooperative context and encourage social interaction among children. Subsequently, children were invited to come to the experimental room. Here they first learned how to operate the selection box. Second, they were introduced to the function of the signal lamp which would signal when to open the drawers. Third, children practiced the use of both tools with the problem-solving apparatus with one experimenter, but not with one another. Children were then tested in eight trials, four trials in each condition. The complete procedure lasted 60–90 min.

Selection box training phase

This training ensured that children understood the drawer mechanism, i.e., that in a given trial they could only pull once, and thus retrieve either the object on the left or the right, and not both. This made clear that the choice could not be changed. During this phase, we used toy cubes that could be thrown into a ‘jingle box,’ which caused a ringing sound and where the toy disappeared (Warneken, Hare, Melis, Hanus, & Tomasello, 2007). The training phase included one demonstration of erroneous box opening, correct box opening, and two trials in which each child had to retrieve one of two objects the first experimenter (E1) was pointing to. After children had reached the criterion of two successive correct retrievals, the signal lamp was introduced. This lamp was placed next to the child who was supposed to start to open the selection box at the time when the lamp lit up, allowing children to discuss their strategy of tool choice for approximately 10 s.

Problem-solving training phase

The purpose of this phase was to familiarize children with the mechanism of the apparatus, the correct tool use, and the necessity of a partner. We presented each side of the problem-solving apparatus separately (counterbalanced across dyads), and stressed the functional aspect of the tools. Before handing a tool to the children, we asked children to which side it belonged and continued providing hints until children selected the correct side. This was done to ensure that children knew where the tools had to be inserted. Each child subsequently collaborated with E1 twice to retrieve the reward. Thus, each child used each tool together with E1 as a partner and, equipped with the correct tools, successfully collaborated on the apparatus before proceeding to the test phase.

After the training, E1 presented a new reward, a silver ball that was filled with two objects (one for each child).

Test phase

In the main test, children had to select the complementary tools to retrieve the silver ball from the apparatus. The ball was filled with different items in each new trial. Each dyad was tested in blocks of four trials in the unidirectional and four trials in of the bidirectional condition. The order of conditions as well as the tool position inside the selection boxes was counterbalanced across dyads. We counterbalanced within participants who had one versus two tools in front of them in the unidirectional condition. At the beginning of each trial, children had to retrieve the tools from the box and use them to get the ball out of the apparatus. The tool box and the apparatus were in different parts of the room, separated by a visual barrier so that children had to make a choice in anticipation of working on the apparatus and could not refer to the apparatus itself while making their choice. Only in the first trial of each condition, E1 verbally indicated how many tools had been placed inside each child’s selection-box. Then both E1 and E2 left the room and the lamp was turned on approximately 10 s later. If neither child started to manipulate a selection box, E1 verbally encouraged them from outside the room. (This was necessary in 16 of 192 trials and only for 3-year-olds.) When children failed to retrieve the ball, either because they chose the same tools or they had chosen the correct tools but had trouble manipulating the apparatus, E1 entered the room when children called or after approximately 30 s without any task-related action taking place. If children had selected the correct tools, but had problems handling them while working on the apparatus, E1 or E2 assisted them to retrieve the ball. If children had selected the wrong tools, they were not able to retrieve the ball. If children had
manipulated the apparatus successfully themselves, the experimenters entered the room and moved on to the next trial.

Coding and reliability

Coding was done from video using the coding software INTERACT. The main dependent measure was children’s success in choosing two complementary tools. Reliability was assessed for a randomly selected 33% (eight dyads) of the data set, yielding perfect inter-rater agreement. In addition, we examined children’s communication during tool selection. Specifically, we coded all verbal communication that was related to organizing the task based upon verbal transcripts from the videotapes. Two raters independently coded all trials of all dyads, resulting in high inter-rater agreement for all categories (Cohen’s Kappa). Specifically, announcements and comments about the speaker’s own action (“I take the blue one.” “I want this one”; Kappa = .74), or the partner’s action (“You take that.” “Can you take the orange one?”; Kappa = .87); explanations or conditionals (“Otherwise it does not work.” “If you take this one, I take that one.”; Kappa = .80). Across all dyads, utterances about the child’s own action occurred in $M = .26$ trials ($SE = .07$), partner’s action in $M = .27$ trials ($SE = .06$), and explanations or conditionals in $M = .11$ trials ($SE = .04$). The main purpose of this measure was to assess if children’s verbal communication was predictive of their success in a given trial. We thus collapsed these three categories and coded for each trial whether children produced at least one of the three types of communicative utterances, yielding a predictor variable that we named task-relevant utterances. This variable thus reflects whether on a given trial, children used a task-relevant utterance at least once.

Results

We used multilevel logistic regressions with Success (Yes/No) on a given trial as binary response term, reflecting whether a dyad correctly chose complementary tools on a given trial. These regressions were conducted with R statistical software version R 3.0.1 (R Core Team, 2013) using the package ‘lme4’ (Bates, Maechler, & Bolker, 2013). In all models dyad identity was included as a random effect to control for repeated measures. In all analyses, we added gender as a predictor, but since it never increased model fit, we collapsed data across genders.

We first assessed effects of age or condition on choice of correct tools. Mean rates of correct choices are displayed in Fig. 3. We first compared a null model that included dyad ID as the only explanatory variable and compared this model to a full model, which included the predictor variables Trial (1-8), as well as the main effects and interactions of Age (3 years; 5 years), Condition (unidirectional [U]; bidirectional [B]) and Order of condition (BU; UB). A likelihood ratio test showed that the inclusion
Table 1
Model parameters and test statistics with Success (Yes/No) as dependent variable. Cells display β-values (log odds) with standard errors in parentheses. Coefficients indicate the estimated effects of predictors on the response term Success (Yes = 1, No = 0) relative to the following baseline levels: Age group = 3 years; Condition = Bidirectional, Order of condition = BU, Task-relevant utterance (Yes = 1, No = 0).

<table>
<thead>
<tr>
<th></th>
<th>Model 1</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>−.02 (−.36)</td>
<td>−.39 (.40)</td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 years</td>
<td>2.00 *** (.42)</td>
<td>1.91 *** (.45)</td>
</tr>
<tr>
<td>Order of condition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uni-Bi</td>
<td>1.80 ** (.64)</td>
<td>1.88 ** (.65)</td>
</tr>
<tr>
<td>Condition</td>
<td>.24 (.49)</td>
<td>.26 (.52)</td>
</tr>
<tr>
<td>Condition × Order of condition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uni × Uni-Bi</td>
<td>−2.15 *** (.81)</td>
<td>−2.07 *** (.84)</td>
</tr>
<tr>
<td>Task-relevant utterance</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>96 (.43)</td>
<td></td>
</tr>
</tbody>
</table>

*p < .05.
**p < .01.
***p < .001.

of these predictors provided a better fit to the data than dyad ID alone, $\chi^2 = 35.65, df = 8, p < .001$. Next, we sequentially dropped single terms from the model to assess whether a given term significantly contributed to model fit and to arrive at the most parsimonious model to adequately predict children’s responses. Removing the covariate Trial did not reduce fit significantly, indicating that success did not increase or decrease across the whole session. Trial was thus removed from further model comparisons. Age did not statistically interact with Condition or Order of condition, but was predictive as a main effect, as removing Age from the model reduced the fit significantly, $\chi^2 = 19.52, df = 1, p < .001$. Age was thus included in further analyses. Removing the interaction of Condition and Order of condition significantly reduced fit, $\chi^2 = 7.79, df = 1, p < .01$. The results are displayed in Table 1 as Model 1, including Age as main effect and the main effects and interaction of Condition and Order of condition. Thus, results show that 5-year-olds were significantly better at choosing the complementary tools than 3-year-olds and both age groups performed better in the bidirectional condition if it was administered after the unidirectional condition.

We used one-sample t-tests to assess if children chose the correct tools at a level significantly above chance. The probability of each dyad selecting the two correct tools solely by chance was $$.5$ Reflective of the age effect, 5-year-olds chose the correct tools at an above chance level in both conditions – bidirectional: $M = .94, SEM = .03, t(11) = 13.40, p < .001$; unidirectional: $M = .88, SEM = .05, t(11) = 7.71, p < .001$; whereas 3-year-olds reliably chose the correct tools in the bidirectional condition, $M = .67, SEM = .07, t(11) = 2.25, p < .05$, but not the unidirectional condition, $M = .52, SEM = .09, t(11) = 2.39, ns$. However, this result should be assessed in light of the significant interaction of Condition and Order of condition in the regression analysis: 3-year-olds chose above chance in the bidirectional condition only if it followed the unidirectional condition – Uni-Bi: bidirectional $t(5) = 4.00, p < .05$. These analyses confirmed and extended the multilevel logistic regressions, showing that 5-year-olds were not only more proficient than 3-year-olds, but also chose correctly at a rate significantly above chance. Moreover, 3-year-olds did not consistently choose correctly, with the potential exception that when the unidirectional condition was administered first, several dyads reached above-chance performance in the subsequent bidirectional condition.

As a next step, we assessed whether children’s communication contributed to their success. Data of one dyad and one trial of another dyad had to be excluded from analysis due to problems with the sound recording (leaving 183 observations from 23 dyads instead of the 192 observations from the full sample of 24 dyads). Children used task-relevant utterances in a mean of $A5$ of trials ($SE = .07$). An analysis of variance with Age (3 years; 5 years) and Condition (unidirectional; bidirectional) as independent variables and rate of task-relevant utterances as dependent variable showed no difference between condition, but a trend for age, $F(1, 21) = 3.45, p = .077$. Five-year-olds tended to produce more task-relevant utterances, $M = .57$ trials, $SE = .08$, than 3-year-olds, $M = .33, SE = .10$. For analyses of how communication contributed to success, we thus chose Model 1 and added Task-relevant utterance as binary predictor variable to ascertain if inclusion of this factor explained additional variance. A model including Task-relevant utterance as main effect yielded a significantly better fit, $\chi^2 = 5.29, df = 1, p < .05$, resulting in Model 2 displayed in Table 1. As is shown in the model, when children produced task-relevant utterances, the log odds increased by $.96$, which corresponds to an odds ratio of $2.61$ and thus indicates that children more than doubled their chances of success when they communicated than when they did not.

1 What was the probability to end up with two complementary tools by chance? In the bidirectional condition both children can choose between two tools. If each child chooses randomly between her two available tools, there are four possible outcomes: AA, BB, both being failures; and AB, BA, both being successes. Thus randomly choosing children would result in correct choices in half of the trials. In the unidirectional condition only one child can choose. If the choosing child selects randomly between the two tools, the dyadic result would be two complementary tools in half of the trials. Thus, in both conditions children selecting randomly would be correct in half of the trials.
Discussion

This study examined young children’s ability to coordinate complementary roles in anticipation of a collaborative task with a peer partner. Based on the developmental course of individual planning, we hypothesized that 5-year-olds would be able to plan for a collaborative task in a skillful manner, whereas the 3-year-olds would experience difficulties.

The results for the 5-year-olds were very clear. They averaged about 90% correct in both the unidirectional and bidirectional conditions. Five-year-olds were proficient regardless of condition order and across trials, although they tended to be better in the bidirectional condition if they had first collaborated in the unidirectional condition. The results for 3-year-olds were more mixed, but in a systematic way. When children started with the bidirectional condition, in which they could each freely choose a tool, their performance was at chance in both conditions. But when they started with the unidirectional condition, in which the child had to notice that the partner’s choice was constrained to one of the tools, they became over 80% successful in the subsequent bidirectional condition. Apparently, just gaining more experience did not in itself improve their performance, but attending to the choice in front of the partner in order to be successful in the unidirectional condition helped 3-year-olds in the subsequent bidirectional condition. One conclusion is thus that 3-year-olds, if left to their own devices, do not attend to their collaborative partner sufficiently to plan their actions effectively; but they can learn from personal experience in the right kind of situations (without verbal instruction or scaffolding from adults) to do so.

Analyses of communication during tool choice revealed that children were more likely to make the correct choice if they announced their own action or suggested what choice the partner should make. This strategy increased slightly with age and explained additional variance beyond the effect of age. This outcome provides further evidence for the notion that children become better at relating their own action to that of a partner when making decisions about how to proceed with tool choice and making more deliberate choices when the ensuing action is made verbally explicit.

Our task was more difficult than those in most other studies of collaborative problem solving in young children because it required children to attend to precisely what their partner would do. In the bidirectional condition, children needed to attend to what the partner was doing in terms of tool choice before the actual problem solving began. In the unidirectional condition, they had to, in a sense, imagine the partner’s choice of tool before he or she made it, since the partner had only one tool to choose. Children in the bidirectional condition could thus see what the partner did and react to it, whereas in the unidirectional condition they had to anticipate what the partner would do. This explains, presumably, the different level of difficulty of the two tasks for 3-year-olds, as well as the overall difficulty of the tasks relative to those in previous studies that did not require such detailed attention or anticipation of the partner’s behavior.

The age trend in our study matches quite well with that found in the individual planning literature. In the studies that employ individual tasks generally similar to ours – individuals selecting objects or tools for future use (Atance & Meltzoff, 2005; Russell et al., 2010; Suddendorf et al., 2011) – the age trend is remarkably similar: 5-year-olds are highly skilled and 3-year-olds are either not skilled at all or show limited skills. This consistency provides at least indirect evidence that our study did require children to plan their own behavioral choice by taking the other’s either actual or anticipated behavioral choice into account.

Another possible explanation for the age trend concerns the cognitive representational requirements involved. Suddendorf et al. (2011) found that 3-year-olds could hold in mind and manipulate a single representation in individual planning, whereas, according to Case’s (1985, 1996) theory, the ability to hold in mind and execute one action while monitoring multiple representations develops between 3 and 5 years of age (dimensional control structures in Case’s model). Our task required children to hold two representations in mind - their own and the partner's tool choice as it relates to the overall goal – which should have been challenging for 3-year-olds. In addition, our task required children to integrate their own as well as their partner’s actions into one coherent action plan (Bratman, 1992). Coordinating roles in action as the collaboration unfolds, as in most previous studies of children’s collaboration, arguably does not require the same differentiation and simultaneous integration
of multiple cognitive representations. Only the requirement to allocate the roles prior to action, as in our study, demands this ability.

Our task was thus especially challenging for both of these reasons. It required anticipation and planning before any actual action, and it required a mental comparison between the two tool choices and how they would work in the problem before any action. The finding that experience in the unidirectional condition facilitated planning in the bidirectional condition for 3-year-olds supports this conclusion. Because the unidirectional condition forced the second child to anticipate what the other would do before choosing a tool, the experience in this condition might have “trained” 3-year-olds to inhibit their own initial impulse regarding tool choice and rather to focus on the partner’s choice first, which then transferred to the subsequent bidirectional condition. Future research should investigate in more detail which contexts facilitate the establishment of joint action plans in young children’s problem solving.

Our study thus raises questions about the relation between individual and collaborative problem solving. Although not designed to directly address this question, our results suggest that young children do not have additional difficulties employing their planning abilities in problem-solving tasks requiring collaboration. In fact, it raises the possibility that children employ similar cognitive representations when they reason about two complementary actions (in terms of means-end relationships) as when they reason about two complementary roles (in terms of social partners executing these actions). To test this claim directly, future researchers could present the same group of children with both individual and collaborative versions of the task used here. Such a within-subject comparison could determine whether individual problem-solving abilities develop prior to or in parallel with children’s social-cognitive collaborative skills.

Another possibility is to look at individual variation in children’s social cognition (such as attributing goals and perspective taking) as well as problem-solving and planning skills that have no social component at all, to see if social cognition tasks explain additional variance beyond non-social planning. Much of the variance is likely to be explained by individual problem-solving and planning skills as prerequisites for collaborative problem-solving, but social cognitive skills should explain additional variance. Specifically, tool selection was embedded in a collaborative context in that tools were needed to subsequently perform a task that required collaboration. We would thus predict that the ability to form joint intentions and skillfulness in collaboration is an important prerequisite as well, as the need to select tools is meaningful only if agents comprehend the use of the tools for collaboration. Individuals without understanding of collaborative activity would not have engaged in the tool-selection task at all, but the relative contributions of general problem-solving skills and social cognition for success in these types of task remain to be determined.

In sum, although there have been a number of studies with children in the age-range of 4 to 9 years of age performing joint planning tasks with adults and sometimes peers (Duran & Gauvain, 1993; Gauvain, 1992; Gauvain & Rogoff, 1989), ours is the first experimental study of young children’s planning prior to action in a collaborative problem-solving context. The finding suggests that by age 3 children are able to learn, under certain circumstances, to take account of what a partner is doing in a collaborative problem-solving context. By age 5 they are already quite skillful at attending to and even anticipating a partner’s actions. Future research should focus on comparing children’s individual problem solving and planning skills with those they show in collaborative problem-solving contexts.

Acknowledgments

We thank Eva Siegert, Christian Biermann, Christiane Markmann, Julia Löpelt, Julia Ulber, Svea Taubert for help with testing the children and video coding, Henrik Roethel and Manfred Ulrich for help building the apparatuses, Roger Mundry for statistical advice and Kerrie Pieloch and Natalie Benjamin for editing. This work received funding from the EC Seventh Framework Program (FP7/2007–2013) under grant agreement no. 215805.

References


