Playing for Us: The Influence of Joint Action on Planning in Three-year-olds

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Abstract

Learning to plan sequences of actions and appropriately adapt our actions during interactions with others are both critical skills upon which much of human society is built. We know that children's joint action and planning skills are both undergoing development during the preschool years, but not much is known about how the joint action context influences young children's planning. In this study, we examined the effect of playing alone or with a joint partner on sequence planning during a problem-solving game in three-year-old children. We found that children were better at planning ahead in the individual than the joint condition of the game despite the joint condition requiring fewer actions on the part of the child. In contrast, children were equally good at problem-solving (i.e., correcting an error) in both conditions. The possible reasons for this difference and directions of future research are discussed.

Keywords: joint action; planning; cognitive development

Working together with others is important across a variety of everyday tasks, ranging from simple, mundane actions to considerably complex plans and action sequences. When we interact with a partner in a work or athletic setting, the complexity of coordinating our actions with another's is quite clear. In contrast, when we perform simple everyday actions such as passing a cup of milk to another person, we likely do this with ease and do not dwell on the coordination with the other or the expectations about the others' action. When acting with another person, planning our own actions requires coordinating our actions with another individual, whether this coordination is conscious and complex or seemingly automatic. Planning our actions when interacting with another is a task that spans many domains and is critical for much of cognitive and social development. Examining the developmental emergence of this skill can shed light on how and when the factors necessary to working with others are integrated.

When performing a task by ourselves, we can create a plan internally and carry out the task without interruption. When jointly acting with another, however, we need to take the other person's actions into account. According to Sebanz and Knoblich (2009), intentional coordination of actions with another requires representing both one's own and one's partner's roles in the task. They suggest that adults engaged in joint actions predict a partner's actions in a joint action task by representing the action of a partner and one's own actions in a functionally equivalent way. In fact, incorporating a partner's task "affects one's own action planning and performance even when there is no need to take the other's part into account at all" (p. 357). One mechanism thought to underlie the representation and prediction of another's actions is simulation (Gallese & Goldman, 1998). That is, when one perceives someone else acting in a goal-directed manner, one's own motor system is activated as if one was performing the action oneself (Rizzolatti & Craighero, 2004). Simulating a partner's action from a first-person perspective can then be used to make predictions about upcoming events (Wilson & Knoblich, 2005). Additionally, the motor system is preferentially activated for predictions of others' actions within a joint action context (Kourtis, Sebanz, & Knoblich, 2010). What is simulated and how perceptual information available can be transferred into a motor simulation is still a topic of vivid discussion (see for example Uithol et al., 2011).

The necessity of incorporating another agent's actions in a similar way to one's own actions when interacting with a joint partner suggests that the ability to represent other agents' actions in a similar way to one's own would be a developmental prerequisite for appropriately planning one's actions within a joint context. One piece of behavioral evidence that young children seem to represent others' actions in a similar way to their own actions is that infants' ability to produce particular actions is directly related to their perception, prediction, and motor activation when viewing others perform the same actions (e.g., Cannon et al., 2012; Gerson & Woodward, in press, van Elk et al., 2008). Meyer and colleagues (2011) found neural evidence that this is especially so in joint action contexts. Greater activation in the motor system was found in three-year-old children watching a joint action partner than when these same children watched someone with whom they were not collaborating. Further, variation in performance on the joint game and in the amount of motor activation observed when the child watched the partner act were related, suggesting that the child's motor system activation was likely related to the integration of their partner's and their own actions.

In addition to a representation of others' actions, the incorporation of others' actions into one's own planning is critical to acting appropriately in joint contexts. In order to address how the presence of others affects planning, research must examine differences in planning one's own actions during individual and joint tasks. A recent study with adults (Meyer, van der Wel, & Hunnius, 2013) measured planning of actions that could be performed alone or with another person. It was found that participants learned to initiate actions based on predictions about the subsequent steps in a task after they gained experience acting in the task. This was true in both the individual and joint contexts, suggesting that participants were able to use their experience to predict their own or a partner's actions and plan their actions accordingly.

The research reviewed above indicates that motor activation during the observation and prediction of others' actions is heightened within joint action contexts and that the simulation of others' actions facilitates motor planning in joint contexts. Although motor planning is one important aspect of planning sequences of actions, sequence planning also requires higher-order processes such as future thinking and cognitive control. That is, when performing an initial action that propagates a series of embedded actions, one must plan not only the motor aspects (such as movement, timing, and spatial location) but also consider the consequence of these actions on the future steps in the sequence. Adults are proficient sequence planners, but planning skills are still undergoing development throughout early childhood (Carlson, Moses, & Claxton, 2004; McCormack & Atance, 2011). Difficulties in planning and other higher-order cognitive skills have been linked to the relatively prolonged development of the prefrontal cortex (see, for example, Welsh, Pennington, & Groisser, 1991).

Previous research examining the development of sequence planning within joint action contexts has largely measured children's planning when engaged in a game with a parent or another adult. These studies have found that the development of planning with others is a prolonged process, in that older children (e.g., between 6 and 11 years) often outperformed younger children (e.g., between 3 and 5 years) on planning tasks (e.g., de la Ossa & Gauvain, 2001; Gauvain, 1992; Gauvain & Rogoff, 1989). This research, however, focused largely on the role parents played in guiding the joint actions through bids for joint attention, scaffolding of the child's actions, and teaching of strategies or rules. Because parents were involved and influencing children's actions during the joint planning games, measures of the child's planning skills were often measured after the joint task. The lack of planning measurements during joint actions does not take into account whether planning in a joint context adds more cognitive demands to a planning task. In the current study, we explore the planning skills of three-year-old children *during* a problem-solving task when playing alone or with a partner who acts in a predictable, uniform manner.

We created a game in which the child was required to plan ahead in order to accurately solve a matching game. If he or she did not plan ahead, the child had the chance to correct the error during a subsequent step of the game. All children played this game both alone and in alternating turns with a joint partner, "Kip." The joint partner was a hand puppet introduced during the joint action condition and kip always acted predictably so that we could assess the influence of a social partner's presence without the social partner's actions directly influencing any of the child's actions. Kip was introduced as separate from the experimenter and the experimenter used a different voice when acting as Kip so that the child did not expect Kip to scaffold his or her actions. We then examined differences between children's accuracy in planning and problem-solving during the individual versus joint conditions. If simulating a person's actions in order to motorically plan one's own actions is the key difference between individual and joint planning, then children's performance during the joint condition should not be hindered. In fact, because children took turns playing with Kip, the joint condition required less motor planning than the individual condition; children only had to place two balls in the correct buckets during each trial instead of four. Therefore, if all planning was carried out through the motor system, children's planning should be better in the joint condition than the individual condition. If, however, other cognitive processes are necessary in order to integrate one's own plans with another person's actions, plans, and goals, then children should perform worse in the joint condition than in the individual condition. That is, if the presence of another actor increases the cognitive demands of higher-order functioning, such as cognitive control, future thinking, and sequence planning, children should perform better in the individual condition than the joint condition.

Method

Participants

Thirty-two 37-month-olds (mean age = 3 years, 38 days) were included in the final data set for this study (15 females, 17 males). All children were recruited from a database of families who volunteered to participate in child studies. An additional 10 children participated but were not included due to equipment malfunction (n = 2), experimenter error (n = 2), not completing all trials (n = 3), or lack of learning of the rules of the game or refusal to play with Kip (n = 3).

Stimuli and Procedure

Each trial consisted of a set of four balls, four buckets, and a clear, plastic tube that held the balls. There were always two buckets of one color (e.g., green) and two buckets of another color (e.g., yellow). In all but the first training trial, there were two balls of one color (e.g., green), one ball of a second color (e.g., yellow), and one ball that was multicolored (e.g., half green and half yellow). The tube was created to dispense the balls one at a time in a particular order while still allowing participants to see the colors of the upcoming balls (see Figure 1). The multi-colored ball always came out of the tube in the second position, and the three solid-colored balls were pseudorandomly distributed in the first, third, and fourth positions. Except in the demonstration trial, different color combinations (consisting of red, light blue, dark blue, green, and yellow) were used across trials so as to minimize learning specific rules about colors and to keep the children's attention. In joint play trials, the experimenter wore a hand puppet of a chicken (called "Kip"). The experimenter used a different voice so as to differentiate herself from the puppet.

Figure 1: Example of the game setup. Each trial involved three-solid colored balls, a multicolored ball, and two buckets in each of two colors.

Training Children were taught how the game worked via a set of training trials. First, the experimenter placed a set of four solid-colored balls (brown and black) into matching buckets. This short phase was to teach children that balls had to go into matching buckets. Next, one of the solid balls (the one in the second position) was replaced with a multi-colored ball. When the experimenter extracted the multi-colored ball, she showed the child that it could go in either the brown or the black bucket. After showing them this, she always left the ball in the inappropriate bucket in terms of meeting the end goal. That is, if there were two brown balls in the tube, the multi-colored ball would be placed in a brown bucket (and vice-versa if there were two black balls). This "mistake" was made in order to show participants the importance of considering the upcoming balls in the tube and to indicate how errors could be corrected. The experimenter then placed a black and brown arrow in front of the bucket to indicate which bucket held the multi-colored ball. After the incorrect placement of the multi-colored ball, the experimenter would show the child that one of the remaining solid-colored balls no longer had an appropriate bucket in which to be placed. She would talk to the child about how this could possibly be fixed and remind them about the meaning of the arrow and hint about a possible solution: "Do you remember what this arrow means? This means that the multi-colored ball is in this bucket. And where can the multi-colored ball go?" She would then extract the multi-colored ball and place it in the opposite colored bucket. She moved the arrow to the new bucket and then placed the solid-colored ball in the appropriate bucket. After having done this, she would remind the child of how the problem had been solved.

Two training trials followed this demonstration in which the experimenter scaffolded the child throughout the game. These two trials consisted of two different sets of colored balls, randomly assigned. During these trials, the experimenter handed the participant each of the balls and asked him or her to place them in the matching bucket. She frequently reminded the child that all the balls had to "fit" in the buckets (and pointed to the balls in the tube). If the child struggled, the experiment gave a series of hints. If the child encountered a solid-colored ball that had no matching bucket, the experimenter first gave him or her time to try to solve the problem themselves. Then she gave the participant a series of hints, allowing time for the child to recognize the solution between each hint. As in the demonstration trial, hints increased in detail, ranging from asking what the arrow meant to reminding the child that the multi-colored ball could go in either bucket. If the child still did not respond to the hints, the experimenter moved the mixed ball and demonstrated the solution to the problem. In this way, at the end of the training trials, the experimenter always ensured that the balls were matched with an appropriate bucket at the end of the trial. After these two trials, the experimenter told the child he or she was ready to play without help. Individual or joint play trials then began (counterbalanced between participants).

Individual Play The individual condition consisted of six trials. In each of these trials, the child retrieved each ball from the tube, one at a time, and placed it into a bucket. The experimenter did not participate except to ensure that the child did not retrieve the following ball before placing the one in his or her hand into a bucket. If the child encountered a problem (i.e., a solid-colored ball without a matching bucket), the experimenter did not interfere unless the child looked to the experimenter for help. When the child expressed uncertainty and enquired for help, the experimenter would give the same hints as during the training trial, again giving the child time to solve the problem at each step. After all of the balls were placed in buckets, the experimenter asked the child if they were all correct (regardless of whether or not they were). If the child realized then that there was a problem, the experimenter again only helped (as above) if the child enquired.

Joint Play First, a small hand puppet was introduced to the child. The child was told the name of the puppet (*Kip)* and that Kip wanted to play with him or her and they could take turns (see Figure 2). The joint play session consisted of nine trials. In the first, fourth, and seventh trial, Kip let the child place the first (and third) ball and Kip placed the second/multi-colored (and fourth) ball. Kip always placed the multi-colored ball in the bucket that allowed all forthcoming balls to be placed correctly. In the other six trials, Kip placed the first and third balls and the child placed the second and fourth balls. This ensured that the number of trials for which the child had to plan (by placing the multi-colored ball correctly) was matched across the individual and joint conditions. If the child incorrectly placed the multi-colored ball and realized this error when later attempting to place a solid-colored ball, the experimenter followed the same procedure as in the individual play trials as far as waiting for the child to enquire in order to give any hints. If Kip had to place the solid-colored ball that had no matching bucket, she would knock on the full buckets and say "uh oh—this ball can't go in this one" while looking at the empty bucket and would ask for the child's help. If the child did not immediately solve the problem, the experimenter followed the same pattern for giving hints as in other trials.

Figure 2: During the joint action condition, children alternated taking turns with Kip, the hand puppet.

Coding The focal question in this study concerned children's ability to plan where to place the multi-colored ball so that all following balls could fit in matching buckets. For each trial in which the child placed the multi-colored ball (six individual play and six joint play trials), a trained coder judged whether the child placed the multi-colored ball in the correct bucket (for the end goal achievement) before the following ball was retrieved from the tube. This factor will be referred to as *planning*. The proportion of trials within the individual and joint condition for which the child's planning was correct was calculated and used as a dependent variable. A second question was whether children would correct errors if their initial ball placement was incorrect. For this factor (called *problem solving*), coders judged whether the child removed the mixed ball and placed it in a correct bucket. If so, the coder noted whether the child carried out this action with or without needing the assistance of hints from the experimenter. The proportion of trials correct after problem solving without hints from the experimenter were calculated for each condition (note: this gave children credit both for initially correct and correctly solved trials without assistance). A second trained coder coded 25% of the videos and agreed on 99% of trials.

Results

As described above, the variable of interest for *planning* was the proportion of trials for which children were initially correct in their placement of the multi-colored ball and the variable of interest for *problem solving* was the proportion of trials in which the child had correctly placed all balls (without hints) by the end of the trial. Initially, we conducted a repeated-measures analysis of variance (ANOVA) with Condition (i.e., individual or joint play) and Solution Stage (planning vs. problem-solving) as within subjects factors. The between-subjects counterbalancing factor of Order (i.e., whether the child participated in the individual or joint condition first) was also included to account for possible learning effects across time. This analysis revealed a main effect of Solution Stage ($F(1,30) = 93.33$, $p < .001$, $\eta_p^2 = .76$), a Solution Stage X Condition interaction ($F(1,30) = 5.15$, $p = .031$, $\eta_p^2 = .15$). No other main effects or interactions were found (*p*s > .13, η_p^2s < .08). The main effect of Solution Stage indicated that the proportion of trials that children successfully planned was significantly lower than their problem solving performance. The interaction suggests that the extent of this difference was affected by condition (individual vs. joint). The lack of main effect or interactions with Order suggests that children who engaged in the joint versus individual task first did not differ from one another in their performance.

In order to follow up on this interaction, we examined pairwise comparisons of estimated marginal means. The difference between individual and joint conditions was significant for planning ($md = .11$, $SE = .048$, $p = .031$; see Figure 3) in that children were significantly better at planning during the individual than the joint condition. This difference between conditions was not present for problem-solving ($md = .001$, $SE = .035$, $p = .98$). That is, children were equally able to solve the problem in both conditions. Additionally, children performed significantly better during problem-solving than planning within both individual and joint conditions (*p*s < .001).

In order to examine planning and problem-solving performance relative to chance levels (50% of trials correct), we conducted one-sample t-tests. In the individual condition, children were better at planning than would be expected by chance ($M = .61$, $SE = .028$, $t(31) = 3.95$, $p < .001$, Cohen's $d = 1.42$). Children were not above chance levels of planning in the joint condition ($M = .50$, $SE = .037$, $t(31) = .034$, $p = .97$, Cohen's $d = .012$). When children had the opportunity to correct their errors (i.e., problem solve), they performed at above chance levels in both conditions (*t*s > 12.3, *p*s < .001).

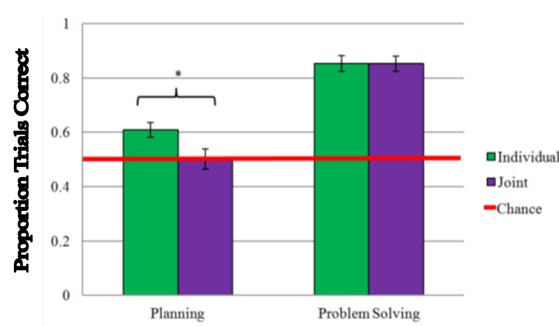

Figure 3: Children were significantly better at planning in the individual than joint condition (*$p = .031$), but were above chance in problem solving in both conditions.

Discussion

Children were significantly better at planning their actions appropriately when they played alone than when they took turns playing with a social partner. That is, when playing alone, they were more likely to take into account the colors of the remaining balls when choosing where to place the mixed ball. When playing with a partner, children's initial placement of the mixed ball was seemingly random (i.e., the placement was correct about half the time [at chance level]). Importantly, this was true despite the fact that children had fewer actions to carry out during the joint condition. In the individual condition, children were responsible for placing all four balls correctly. In the joint condition, however, children only needed to place two of the four balls. The joint partner always played correctly on her trials, so the task of placing half the balls should have, in principle, been easier. The fact that children did not perform as well in this case suggests that something about sharing the task with a partner made it more difficult for the children to plan. That is, motor planning alone was not sufficient for carrying out the task; the demands of sequence planning were made more difficult by the presence of another actor.

In contrast to the difference found in planning, when children encountered a proceeding ball for which there was no matching bucket, they were equally competent at solving this problem regardless of whether they were playing alone or with a partner. The fact that children could and did solve the problem without hints from the experimenter (or Kip) in both conditions suggests that children understood the goal of the task and what actions were necessary in order to achieve this goal. Thus, it was not a lack of understanding of the task that prevented children from planning appropriately during the joint condition. This is impressive given the complexity of the task carried out by the children.

Further, children's planning and problem solving did not change as a function of the order in which they played the individual and joint conditions. This indicates that children did not learn the task over time, regardless of which condition they played first. Additionally, the fact that children who played the joint condition first did not plan more effectively during the individual condition than children who played the individual condition first suggesting that children were not learning how to plan from Kip's turns placing the mixed ball. Given that Kip always placed the mixed ball correctly (on the three trials in which she placed this ball), it was possible that children could have used their partner's correct actions to improve their own planning, but the lack of order effect suggests this was not the case in this study.

An important question to address in future studies is why children were better able to plan during the individual than the joint condition. Several possibilities remain to be examined, including aspects of attention, inhibition, and the social nature of the task.

One possibility is that attention to the future balls to be placed differed when children were playing alone or with Kip. If attention does differ, it suggests that the presence of a partner made it more difficult for children to concentrate on the task at hand and control their attention according to the task goal. Baron (1986) has suggested that the presence of others causes shifts in cognitive processing. This might be particularly true during early development when attentional control is still developing.

Similarly, children may have struggled to maintain attentional control because of the timing differences between the two task conditions. That is, children could play continuously during the individual condition of the task but were required to pause their own play while their partner acted during the joint condition. It is possible that, it was not simply the presence of the other, but the fact that the child's play was interrupted that made planning more difficult. Whether the break in play led to disrupted attention control or directly to difficulty with planning is unclear, and may be driven by other mechanisms such as inhibitory control or working memory. Ongoing studies in our laboratory aim to address this possibility.

Finally, the mere presence of a social partner, rather than the pauses in play or attention, may have undermined children's planning. Sebanz, Knoblich, and Prinz (2003) suggest that the presence of others influences task performance, regardless of whether one is acting with the other person. They argue, "social facilitation effects are not moderated by the specific actions carried out by others" (p. 12). Instead, they suggest that the presence of another improves performance on simple tasks but impairs performance on more complex tasks. This possibility would be interesting to explore developmentally because of shifts in complexity of particular tasks as children gain both domain-general and domain-specific skills.

The current findings shed light on the difficulties encountered when first attempting to incorporate predictions of a partner's actions with one's own planning. It suggests that planning for two individuals, even when they share a common goal, is more difficult than planning for oneself. The relative complexity of the planning task in this study may have provided the ideal setting in which to examine planning differences across contexts at this age. It is possible that, given a less demanding task (or this task at an older age), children would have performed similarly in both conditions. On the other hand, a more difficult task may have created floor effects in which children would not have performed at above chance levels in either condition. The variability in planning in this study was likely due to an interplay between task difficulty and developmental period. Whether and how individual versus joint planning differs in different developmental periods and at different levels of task complexity should be explored further.

The joint action condition in this study was minimally "joint" in that it involved a turn-taking task in which the social partner always performed correctly. Turn-taking reduced timing and coordination demands common in other joint action tasks. Further, if children learned that the joint partner always acted correctly, he or she could have simply ignored the partner and continued to play without taking him or her into account. The fact that children did perform differently in individual and joint conditions suggests that they likely viewed these conditions differently (but see possibility of timing differences above). Future research should consider the differential influences of more or less involved interactions with the social partner.

Findings from the current study suggest differences in three-year-old children's planning, but not problem-solving, when they play alone or jointly play with a partner. The mechanisms underlying this difference should be addressed in future research. Given that children of this age have the ability to view a partner as an intentional agent, predict another's actions, and plan their own actions, it seems that the integration of these skills is still undergoing development. How this differs when playing with parents, who may scaffold their actions, or with peers, who are less predictable in their actions, is an interesting avenue of future work. A better understanding of how planning within joint actions develops is important in order to further explore educational consequences, underlying neural mechanisms, and individuals who show a prolonged or atypical developmental pattern.

Acknowledgments

We would like to extend our gratitude to Angela Khadar, Dirkje van der Aa, Marlene Meyer, Denise Janssen, Celeste Peereboom, Barbarien Bruens, and other members of the Nijmegen Baby Research Center for their help with data collection and thought-provoking discussions. We are especially grateful to the parents and children who participated in this study. This work was funded by a Brain-and-Cognition-Excellence-Grant from NWO (433-09-253).

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