



Joint action coordination in 2½- and 3-year-old children

Marlene Meyer*, Harold Bekkering, Markus Paulus and Sabine Hunnius

Donders Institute for Brain, Cognition and Behaviour, Radboud University, Nijmegen, Netherlands

Edited by:

Ivan Toni, Radboud University,
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Germany

Maria Gräfenhain, Georg-August-
Universität Göttingen, Germany

*Correspondence:

Marlene Meyer, Donders Institute for
Brain, Cognition and Behaviour,
Radboud University, P.O. Box 9104,
6500 HE Nijmegen, Netherlands.
e-mail: m.meyer@donders.ru.nl

When acting jointly with others, adults can be as proficient as when acting individually. However, how young children coordinate their actions with another person and how their action coordination develops during early childhood is not well understood. By means of a sequential button-pressing game, which could be played jointly or individually, the action coordination of 2½- and 3-year-old children was examined. Performance accuracy and variability of response timing were taken as indicators of coordination ability. Results showed substantial improvement in joint action coordination between the age of 2½ and 3, but both age groups performed equally well when acting individually. Interestingly, 3-year-olds performed equally well in the joint and the individual condition, whereas 2½-year-olds did not yet show this adult-like pattern as indicated by less accurate performance in the joint action. The findings suggest that in contrast to 3-year-olds, 2½-year-olds still have difficulties in establishing well-coordinated joint action with an adult partner. Possible underlying cognitive abilities such as action planning and action control are discussed.

Keywords: joint action, action coordination, development, early childhood

INTRODUCTION

Joint actions are a part of everyday life. The success of a joint action is highly dependent on the ability to coordinate our own actions with those of our action partner (Sebanz et al., 2006). To establish a smooth joint action coordination with another person we need to monitor our action partner's contribution to the common action and flexibly incorporate the other's actions into our own action plan (Sebanz et al., 2003; Tsai et al., 2006, 2008). Thus, coordinating actions with another person introduces additional demands compared to individual actions. Nevertheless, adults can achieve similar performance levels whether they are coordinating their actions with an action partner or acting on their own (Knoblich and Jordan, 2003). The ability to effectively coordinate one's own actions with those of others, however, is not present from birth. In the current study we examined the development of joint action coordination in early childhood. Coordination of actions was investigated when children were acting either individually or together with a joint action partner.

Action coordination entails the coordination between two people as well as intrapersonal action coordination. Though a large body of research is concerned with action and action coordination development, to date, investigations have often focused on intrapersonal coordination of actions (e.g., Clark et al., 1988; Getchell, 2006; Brakke et al., 2007; von Hofsten, 2007). Our knowledge about the development of action coordination between two people is mainly based on studies which investigated children's helping behavior and their performance in collaborative problem-solving tasks or during social games (e.g., Brownell et al., 2006; Warneken et al., 2006; Warneken and Tomasello, 2007). As outlined by Brownell et al. (2006), coordinated behavior with an action partner improves drastically within the first 3 years of life. While 1-year-olds' coordination with others is still limited and largely relies on scaffolding by adults (Smith, 1978; Warneken and Tomasello, 2007), 2-year-old children are able to solve simple cooperation tasks together

with peers and adults (Brownell and Carriger, 1990; Brownell et al., 2006; Warneken et al., 2006; Hunnius et al., 2009). Around this age, children succeed for instance in pulling a handle simultaneously with a peer (Brownell et al., 2006) or in reaching for an object when an adult makes it available (Warneken et al., 2006). Three-year-olds, but not younger children, successfully master more complex cooperation tasks which for example involve complementary roles for the two action partners (Ashley and Tomasello, 1998). Around the same age, developmental changes in related social-cognitive skills can be observed. Emerging social-cognitive skills in domains such as action understanding, action execution control, and action monitoring are thought to play an important role in joint action coordination. By the age of 3 years, children begin to differentiate various levels as underlying causes for others' actions such as psychological or biological motives, and they begin to integrate actions they have observed in others with actions from their own repertoire (Flavell, 1999; Williamson et al., 2008). During preschool years, young children acquire the ability to control their actions by overriding prepotent responses and established actions (see Garon et al., 2008, for a review). The emergence of action execution control including inhibitory response control is linked to developmental changes in the prosocial behavior of 3- and 4-year-olds (Moore et al., 1998). In addition to executive control, action monitoring plays an important role in successful joint actions with others (Bekkering et al., 2009). In the context of problem-solving amongst peers, 3-year-olds have been found to pay particular attention to their action partner's actions which are directed at solving a given task. Although younger children also watch their partner, they do not show this selective monitoring but rather general social attention (see Gauvain, 2001, for a review).

Also, the frequency of coordinated acts among peers was found to increase substantially between 16 and 32 months of age (Eckerman et al., 1989). In sum, previous studies provide us with general information on the age range within which children

are able to solve coordination tasks successfully. However, in most of the tasks used to study children's action coordination singular actions were sufficient to fulfill the required coordination demands (e.g., dropping an object in a descending tube to let another person catch it; Warneken et al., 2006). Hence, children rarely had to coordinate their actions in time with others during a continuous stream of activities. In daily life, however, many joint actions entail continuous coordination with others rather than a one-time interaction. Activities such as walking hand in hand down a busy street, seesawing on the playground or even having a conversation with another person require the continuous coordination of actions.

One recent study investigated the continuous coordination of actions between young children and an adult during social interaction by examining 2½- to 4½-year-olds' drumming behavior in social compared to non-social settings (Kirschner and Tomasello, 2009). It was the children's task to drum along with another person, a drumming machine or the sound of a drum. Results demonstrate that all children, including the youngest group of 2½-year-olds, synchronized their movements more accurately in the social condition than in the non-social conditions (Kirschner and Tomasello, 2009). Nevertheless, the social setting provided in this study was designed such that no mutual coordination between the two action partners was required. The experimenter was acting independently of the child in such a way that he provided the beat the children had to drum along with, but did not adjust his own actions to the child. So, the question remains: from which age are young children capable of coordinating their actions smoothly with another person in a truly interactive situation in which both actors' actions are mutually dependent on each other and not coupled in a strictly unidirectional way.

To investigate the development of joint and individual action coordination abilities, we tested 2½- and 3-year-old children by means of a sequential button-pressing game. The game could be played jointly with another person as well as individually. When playing jointly, the children were acting together with an adult experimenter. To keep the adult's behavior constant between children and avoid scaffolding, the adult's action timing was locked to the children's responses. By always acting 1 s after the child, the action partner played in a predictable manner which at the same time was dependent on the child and thus interactive in nature. In line with Deutsch and Newell (2005), we expected that an improvement in performance would be reflected by higher accuracy and lower variability in response timing with increasing age. We predicted an age-related improvement in the quality of children's joint action coordination consistent with changes in coordinated behavior observed throughout the third year of life (Ashley and Tomasello, 1998; Brownell et al., 2006; Kirschner and Tomasello, 2009). Concerning children's individual coordination performance we hypothesized that there would be only a marginal improvement since children acquire stable intrapersonal coordination patterns earlier in life (see Clark and Phillips, 1993; Clark et al., 1988; Brakke et al., 2007). To sum up, we predicted only minor developmental changes in individual action coordination but a significant improvement in coordination abilities in joint action for young children between 2½ and 3 years.

MATERIALS AND METHODS

PARTICIPANTS

Twenty-three young children were included in the final sample. They were recruited from a database of families who volunteered to participate in child studies. The total sample consisted of two age groups: ten 2½-year-olds (mean age = 30 months and 3 days, range = 29 months and 22 days to 30 months and 11 days; 7 girls) and thirteen 3-year-olds (mean age = 36 months and 1 day, range = 35 months and 22 days to 36 months and 9 days; 7 girls). All children were accompanied to the testing session by a parent who gave written consent for the restricted use of video recordings obtained during the experiment. Another 18 participants were tested but excluded from the analysis due to incomplete task demonstration caused by interference of the child ($n = 4$) or a procedural error ($n = 1$). Further exclusion criteria were the lack of at least one valid trial per condition ($n = 4$) or engagement of the parent (e.g., by leading the child's hand) ($n = 9$).

DESIGN

A 2×2 mixed design with one between-subjects factor (age group) and one within-subjects factor (condition) was used in the current study. Each child played the button-pressing game together with the experimenter (joint condition) and alone (individual condition). The order of conditions within a session was counterbalanced across participants such that five out of ten 2½-year-old children as well as six out of thirteen 3-year-olds started with the individual condition. All data were collected by the same first experimenter (E1) who was the joint action partner of the children.

MATERIALS AND STIMULI

We designed a simple computer game playable by repeatedly pressing two buttons in alternation. The two buttons were positioned in front of a computer screen (see **Figure 1A**) and were interconnected by a tilt mechanism. As illustrated in **Figure 1B**, pushing one button automatically lifted the other button. When a button was pushed, it sank to the surface level of the box (width = 30 cm; height = 8 cm; depth = 16 cm) in which the buttons were installed. The timing of button presses was registered for each button. At the surface level, the mechanism still registered further button presses,

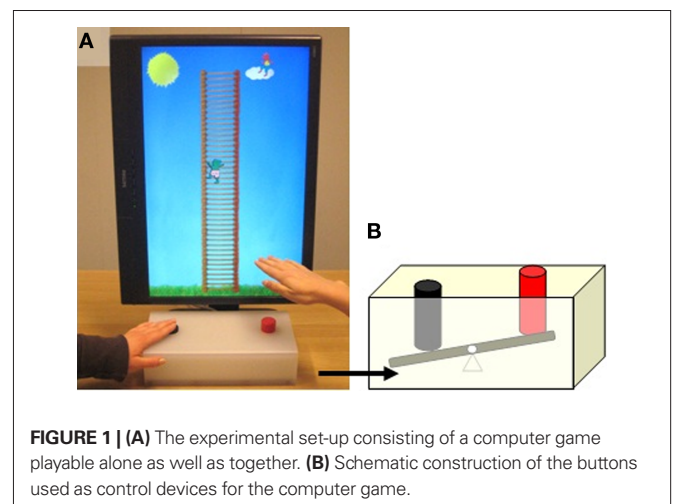


FIGURE 1 | (A) The experimental set-up consisting of a computer game playable alone as well as together. **(B)** Schematic construction of the buttons used as control devices for the computer game.

although the lower button could only be lifted again when the opposite button was pushed. We used interconnected buttons to create a situation in which two joint action partners who were both controlling one button had to coordinate their button presses in an alternating fashion. Though constant pushing of one button was possible, it hindered the other person from pushing his own button and thereby disturbed the course of the sequential game.

To make the buttons more distinct they were colored differently (left button: black; right button: red). Button presses triggered the presentation of visual and auditory stimuli programmed in Python (Version 2.5, Python Software Foundation; <http://www.python.org>). Visual stimuli consisted of a stable background scene and an animated cartoon figure of a frog in the foreground (see **Figure 1A**). The background scene showed a ladder in front of a natural landscape and a cartoon figure of a pig on a cloud at the upper right corner next to the top of the ladder. All visual stimuli were presented on a wide-screen which was rotated by 90° to the left (1200 × 1920 pixels). During the computer game the two buttons had to be pushed in an alternating sequence to move the animated frog figure up the ladder step by step. More precisely, pushing the left button resulted in displaying a frog picture which showed the frog lifting its left leg to reach the next step up on the ladder. Consistently, a right button press resulted in the frog lifting its right leg. The visual presentation of the climbing frogs was accompanied by clap tones (duration: 60 ms) which were unique for the respective button. Each trial (i.e., moving the frog from the lowermost point of the ladder to the top) consisted of 42 alternating button pushes. The goal of the game was to make the frog climb up the steps until it reached the piglet at the top. A final picture displaying the animated frog next to the cartoon figure of the piglet indicated that the goal had been achieved. In order to emphasize the successful accomplishment of the goal, a goal tune of about 2 s was presented simultaneously with the final picture.

In addition to the registration of button presses, video recordings were made throughout the experiment. A digital video camera (Sony Handycam, DCR-SR190E) was placed in the corner of the room to record children's behavior during the testing sessions.

PROCEDURE

The experiment was conducted in a quiet testing room. Before child and parent were introduced to the testing room, they were invited to spend a short period (<10 min) in an adjacent playroom. During this warming-up period parents were informed about the general course of the experimental session, while the child had the opportunity to get accustomed to the two experimenters E1 and E2. E1 was the active joint action partner of the children while E2 helped to demonstrate the joint condition. The warming-up phase was included to facilitate children's engagement in social contact with E1 during the actual testing phase.

After the short warming-up period child and parent were accompanied by E1 and E2 to the testing room. There, the parent was instructed to sit down at a table on which the set-up was installed. The caregiver was asked to sit with the child on his or her lap such that the child could comfortably reach the buttons. E1 then took a seat to the left of child and parent while E2 remained in the background. Parents were asked not to interfere throughout the testing phase. To introduce the general idea of the game, E1 pointed

to the moving character on the screen (the frog), to the ladder and to the goal location (the piglet on the cloud). She explained that the frog wanted to climb up the ladder to reach the piglet on the cloud. After this general introduction, each child was asked to engage in two consecutive conditions, an individual, and a joint condition. Both conditions were preceded by a demonstration trial.

The child's task in the individual condition was to move the frog from the bottom of the screen to the goal position at the top by pushing the two buttons in turn using the left hand for the left button and the right hand for the right button. E1 demonstrated this task by completing one trial on her own. Moreover, a verbal instruction of the task was given. After demonstration, the frog was reset to its starting position and children were invited to play on their own. The experimenter encouraged the children to play individually for several, but maximally four times. The number of trials completed varied between children, but other than one child all participants engaged in the individual condition.

In the joint condition, children were instructed to play together with E1. The sequence of button presses (i.e., left, right, left etc.) required to accomplish the goal of the game was the same as in the individual condition. However, in the joint condition, the child was asked to use only the right button with the right hand whereas E1 had control over the left button such that the child and E1 had to take turns pushing the buttons to succeed in the task. As in the individual condition, a demonstration trial preceded the actual test trials. For this purpose, E2 joined and sat down left of E1 in a position visible for the child. In the demonstration trial E1 and E2 carried out the task together by taking turns to push the buttons until they reached the goal jointly. Consistent with the individual condition a verbal explanation of the task was given during the demonstration. After one demonstration trial, E2 left the table again and the game was reset to the start. Then, the test trial was started by inviting the child to play together with E1. Again, children were allowed to play several times up to a maximum of four trials. Except for two participants, all children participated in the joint condition. Throughout the joint play E1 heard via an earphone a metronome tone which was locked to the child's response. The metronome tone consisted of three consecutive beep tones with the last beep presented exactly 1 s after the right (i.e., the child's) button had been pressed. This button-locked metronome feedback was only audible for E1. It allowed E1 to respond to the child's button presses in a consistent and predictable manner by pressing her own button approximately 1 s after the child's response.

DATA PROCESSING

We focused on two measures to test our hypotheses: *performance accuracy* and *timing variability*. Pressing the same button more than once in a row was registered as an error which reflects children's *performance accuracy*. The *timing variability* was based on the time it took children to press the right button after the left one had been pressed (either by their own left hand or by E1). For all dependent measures only right button presses were analyzed allowing a comparison of children's right hand responses between conditions.

Before calculating these two measures the data were preprocessed in the following way: the first two button presses of each trial were excluded from the data analysis to prevent a bias of large outliers at the beginning of a trial (cf. Drewing et al., 2006). Video recordings

served to identify which hands were used to push a button. For the individual condition, only trials which were executed bimanually were taken into account. The video recordings were further used to detect violations of task rules other than the registered errors (e.g., pulling instead of pushing a button). Trials in which more than half of the button presses on one side were executed in such an incorrect fashion (i.e., by pulling up a button) were subsequently excluded from the analysis. Thereby, overall five trials were excluded from further analysis. Those five trials stem from two 2½-year-olds (one of which had two contaminated trials) and two 3-year-olds. Thus, the amount of trials excluded from further analysis did not differ substantially between the age groups. In the joint condition, trials were included if the child controlled the right button with the right hand and E1 controlled the left button for at least half of the time without violated task rules. From the remaining trials all button presses violating the game rules and registered errors were excluded before calculating the timing variability. Moreover, all button presses following an erroneous response were discarded. Thereby, only button presses following a correct button press were kept for further analysis of timing variability. Consequently, the number of button presses included in the analysis differed slightly between participants. In the main analysis, we accounted for this difference by using relative measures.

Performance accuracy

To perform the sequential button pressing task accurately, the two buttons had to be pushed in turn. Therefore, a button press executed more than once in a row was counted as error. To compare children's performance accuracy between conditions the mean percentage of these errors was assessed.

Timing variability

Besides children's accuracy we investigated how stable children were in their response timing. With regard to performance in voluntary movement tasks, a decrease in variability with increasing age has been associated with improvement in performance (Piek, 2002). To determine the timing variability of children's performance we first calculated the time interval between a right and a left button press (right – left). The average time interval provided the basis for the variability measure. As variability measure we computed the coefficient of variation (COV) to account for a possible bias caused by differences in children's average time interval (cf. van Geert and van Dijk, 2002). The COV is calculated by dividing the standard deviation by the mean (SD/M). As such it offers a solution to the problem which arises when standard deviations need to be compared between samples that have different means. All data processing steps were calculated using Matlab (Version 7.0, TheMathWorks, Inc.) and statistical tests were computed with SPSS 17.0.

STABILITY OF EXPERIMENTER'S PERFORMANCE

Though E1 was provided with metronome tones to achieve a standardized performance, children's behavior such as the production of errors might have introduced additional variability to E1's performance. To ensure that no systematic differences in the performance of E1 occurred between age groups, we tested the mean time interval, (i.e., the average time it took E1 to push the button after the child's response) and E1's timing variability, against age groups. Neither

the mean time interval, $t(21) = 1.45$, $p > 0.05$ nor E1's variability in interval timing, $t(21) = 0.21$, $p > 0.05$ were found to be significantly different. Thus, there were no indications that E1 behaved differently between the two age groups.

RESULTS

Preliminary tests for order effects were conducted by including the order of conditions (individual first; joint first) as a within-participants factor in each mixed analysis of variance (ANOVA). Since the order of conditions never yielded significant differences (all $ps > 0.30$) this factor was omitted in the subsequent analyses. Note that for all reported *post hoc t* tests Bonferroni-corrections were applied to account for multiple comparisons.

PERFORMANCE ACCURACY

Mean percentage of errors

Figure 2 depicts the mean percentage of errors made by children in the two age groups (2½-year-olds; 3-year-olds) when performing the sequential button pressing game individually or together with an adult. As described above, an error reflects a child's button press on the right button when the left button should be pressed. A 2×2 mixed analysis of variance (ANOVA) with factors Age Group and Condition was used to test for differences in children's accuracy. The ANOVA yielded a significant main effect of both Age Group, $F(1,21) = 12.56$, $p < 0.05$, and Condition, $F(1,21) = 5.48$, $p < 0.05$. Children aged 2½ years produced overall a significantly higher percentage of errors ($M = 11.82\%$, $SE = 1.20$) than children of the older age group ($M = 6.16\%$, $SE = 1.05$). Furthermore, children's mean error rate was in general higher in the joint condition ($M = 12.09\%$, $SE = 1.56$) than in the individual condition ($M = 5.89\%$, $SE = 1.54$). In addition to the main effects, an interaction effect of Age Group and Condition, $F(1,21) = 5.64$, $p < 0.05$ was found. *Post hoc* comparisons revealed that 2½-year-olds made significantly more errors than 3-year-olds when they were acting jointly with the experimenter, $t(21) = 3.83$, $p = 0.001$. However, when playing on their own children's accuracy was not found to differ, $t(21) = -0.21$, $p = 0.84$. As apparent from Figure 2, 3-year-olds show a similar level of error performance in both conditions. In contrast, 2½-year-olds made more errors when playing jointly than when

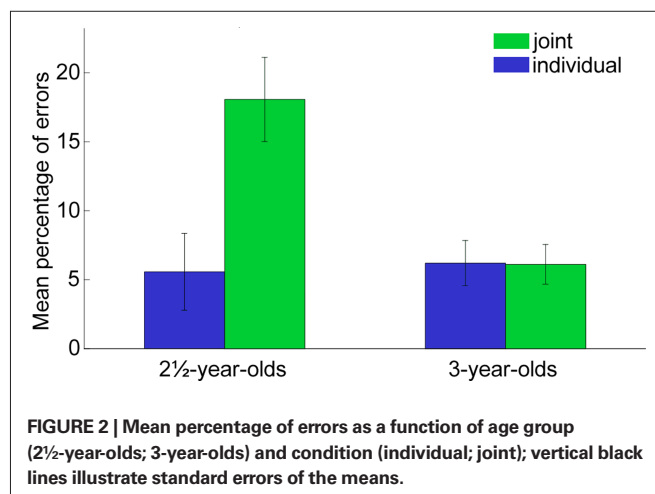


FIGURE 2 | Mean percentage of errors as a function of age group (2½-year-olds; 3-year-olds) and condition (individual; joint); vertical black lines illustrate standard errors of the means.

they acted individually. Thus, children of both age groups were equally accurate when they performed the sequential task on their own whereas 2½-year-olds made significantly more errors when playing in turns with an adult than 3-year-old children who had a similar accuracy level in both conditions.

TIMING VARIABILITY

Average time interval

Children's average time interval between button presses served as the basis for the subsequent measure of variability in response timing. Comparing the average interval timing across age groups and conditions by means of a mixed ANOVA revealed a main effect of both, Age Group, $F(1,21) = 13.28, p < 0.05$ and Condition, $F(1,21) = 10.71, p < 0.05$. With an average interval duration of around 870 ms ($SE = 46$) children of the younger age group were significantly slower than 3-year-olds who on average pushed the button after approximately 650 ms ($SE = 40$). Moreover, children of both age groups were faster in the individual condition ($M = 630$ ms, $SE = 54$) than in the joint condition ($M = 899$ ms, $SE = 49$). No significant interaction was found between Age Group and Condition, $F(1,21) = 0.14, p > 0.05$.

Coefficient of variation

The average COV for the two age groups and conditions are depicted in **Figure 3**. To examine effects of Age Group and Condition on the timing variability we conducted a two-way ANOVA. Whereas neither of the main effects (Age Group; Condition) were found to be significant (both $ps > 0.05$), there was a significant interaction effect between Age Group and Condition, $F(1,21) = 4.45, p < 0.05$. *Post hoc t*-tests revealed that 2½-year-olds were more variable in their action timing than 3-year-olds when they were acting jointly with an adult, $t(21) = 2.46, p = 0.023$. No such difference in variability was detected for the individual condition, $t(21) = -0.09, p = 0.92$ (see **Figure 3**). Thus, when acting on their own 2½-year-olds were as stable in their interval timing as 3-year-olds, whereas they were significantly less stable than the older children in their joint action coordination. Within age groups no evidence was found for a difference of the average COV between conditions (both $ps > 0.05$).

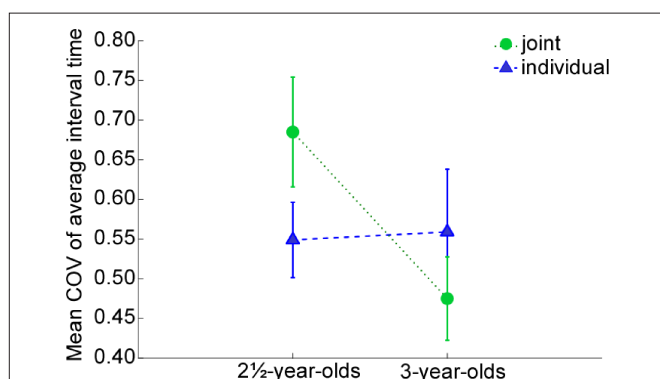


FIGURE 3 | Mean coefficient of variation regarding children's average interval time as a function of age group (2½-year-olds; 3-year-olds) and condition (individual; joint); vertical lines illustrate standard errors of the means.

DISCUSSION

In this study, we investigated the development of young children's action coordination in a repetitive button-pressing task. We compared 2½- and 3-year-olds' performance when acting either together with a joint action partner or individually. Three-year-old children showed higher accuracy in their coordination with an adult partner than 2½-year-olds. However, when acting on their own, the 2½-year-olds were as accurate in their bimanual coordination as the 3-year-old children. The same pattern was found for the variability in children's interval timing. While the 3-year-olds showed less variability in the joint condition than the 2½-year-olds, there was no difference in variability between age groups in the individual condition. These findings indicate that the ability to coordinate one's own actions with those of another person improves significantly between the age of 2½ and 3 years. In contrast to joint action coordination, no developmental changes between 2½- and 3-year-old children were found regarding intrapersonal action coordination.

Both accuracy and stability of performance are important indicators of the quality of action coordination between two people. With respect to accuracy, 2½-year-old children impeded the joint action coordination by acting significantly more often when it was not their turn. Two potential explanations could account for this higher percentage of errors in the joint condition as observed in the 2½-year-olds. Deficits in action control as well as action planning might play a role in adjusting actions properly. On the action control level, one possible reason might be the lack of response inhibition (Diamond, 2002) which makes it difficult for the 2½-year-olds to refrain from acting when it is their action partner's turn. In tasks which require young children to inhibit predominant responses, 2½-year-olds were shown to hold back their responses only slightly above chance level, whereas by the age of 3, children performed at a 90% accuracy level reflecting their advanced ability to inhibit initial response tendencies (see Diamond, 2002, for a review).

On the other hand, the children's behavior might reflect difficulties on the action planning level, namely in incorporating the other person's actions into their own action plan. Incorporating the other into one's action plan requires the understanding of the other's contribution to and importance for the common action. The 2½-year-olds might have acted more frequently when it was the other's turn because they did not yet fully integrate the adult as an essential part of the joint action. Adults have been shown to incorporate other people's actions by sharing representations of others' actions and tasks, a skill which is thought to be crucial for understanding and predicting other's actions in a social interaction (Sebanz et al., 2003; Bekkering et al., 2009). To what extent action control and action planning change between the age of 2½ and 3 still needs to be clarified.

In addition to the higher error rate, the variable temporal performance of 2½-year-olds also indicates less proficient joint action coordination. Though not mandatory for the successful execution of the game, acting in a stable temporal manner facilitates the action coordination between the two actors. While keeping a stable response timing can help to establish a smooth joint coordination, a high variability in response timing might impede smooth joint coordination. What might have caused the more variable performance of the younger children? While the children were active

throughout the individual condition by pushing either with their left or right hand they had to refrain from acting in the joint condition during their partner's turn. With respect to action control, activating one's actions after refraining from acting might have been less automatic in the younger children than in older children. This might have led to the higher variability in their action timing. Whether this effect is specific to joint action situations or whether young children have the same difficulties in a non-social context remains to be clarified.

On the action planning level, difficulties in incorporating the other person's actions into one's own action plan might account for the more variable action timing of the 2½-year-olds. As 2½-year-olds did not reliably adapt their own action timing to the other's actions, the results might suggest that the degree to which they incorporate the partner as an essential part of the common action is more limited compared to the 3-year-olds.

Interestingly, the integration of other information inherent to joint actions such as obligations and commitments toward the action partner has also been observed to emerge around the same age (Gräfenhain et al., 2009). Research by Gräfenhain et al. (2009) shows that only by the age of 3 but not earlier were children found to understand and act according to the obligations and commitments involved in joint actions. Future studies are required to determine the precise contribution of the ability to incorporate another person into one's own action plan and the ability to inhibit and reactivate actions to young children's joint action development.

With regard to the coordination of individual actions, we expected only marginal changes between age groups. In accordance with this hypothesis, no significant differences in accuracy and variability were found between the age groups in the individual condition. Previous developmental research on intrapersonal coordination found various stable bimanual movement patterns such as in- and anti-phase movements as early as 24 months of age (Brakke et al., 2007). This early proficiency in intrapersonal coordination might explain why children in our experiment did not show any drastic changes in bimanual coordination. Interestingly, our results also show that by the age of 3, children's coordination performance during joint action approaches the level of their individual action coordination. A comparable pattern has been observed in adults who can reach the same level of performance in both joint and individual actions (Knoblich and Jordan, 2003).

Since developmental changes in action coordination were specifically found for joint action coordination but not individual action coordination we would assume that planning processes crucial for successful joint actions rather than mere action control abilities contribute substantially to this development. The ability to integrate information about one's own and another's actions is emphasized as being important for acting jointly (Sebanz et al., 2006). Therefore, we believe that difficulties in incorporating the action partner into one's own action plan might be an essential factor underlying the current findings.

Although we did not have any specific predictions concerning the average interval time, children were shown to be overall slower in the joint than in the individual condition. One explanation for this finding might be an adjustment to their partner's action

timing (cf. Kirschner and Tomasello, 2009). This overall decrease in pace was found for both age groups indicating an adjustment even in the younger children. Nonetheless, alternative explanations for an overall slowing in the joint play are possible, such as higher cognitive demands imposed by the engagement of the second actor.

In general, children in the current experiment were acting with an adult action partner, who was acting in a predictable and reliable manner. Therefore, conclusions with respect to children's flexibility in joint actions as required when interacting with a same-aged peer or a less reliable adult are limited. It would be interesting to vary this aspect in a subsequent experiment to determine how young children adjust to more variable action partners in situations that resemble daily life. Previous research investigating interaction between peers indicates that young children are more challenged when acting jointly with a child of the same age than they would be with an adult partner (cf. Hunnius et al., 2009).

Action coordination lately gained interest as a crucial factor for joint action development (see Brownell et al., 2006; Warneken et al., 2006). In recent studies, young children's action coordination with an action partner was assessed in tasks requiring single incidents of coordination and by using categorical measures (e.g., Warneken et al., 2006). As a result, it was found that children around the age of 2 years scored higher in coordination ratings than 18- and 19-month-olds when collaborating with adults or peers (Brownell et al., 2006; Warneken et al., 2006). Our findings suggest that 2½-year-old children still have difficulties coordinating their actions with a joint action partner even in a simple button-pressing task. At first glance, these results seem to compete.

However, the action type and task requirements of the current study might differ from the coordination demands of the tasks used previously (e.g., Warneken et al., 2006). More specifically, current task requirements were not met by a one-time action coordination with the partner. Rather, children were required to coordinate their actions with the other repeatedly. This continuous need for coordination might cause difficulties for 2½-year-old children who could have succeeded in a one-time coordination context. The present results do not oppose findings that 2-year-old children are capable of achieving a goal together with a partner. In fact, in our experiment even the 2½-year-olds succeeded eventually when acting jointly. Still, they were less skilled than the 3-year-olds in coordinating their actions over time with their partner, even though they were as skilled as the older children in coordinating their actions individually.

Strikingly, by the age of 3, children reached a degree of proficiency in joint action coordination which was as high as their individual coordination performance. Thus, the current results indicate that children's joint action coordination skills improve considerably in the last half of their third year of life and approach adult-like relations between joint action coordination and intrapersonal coordination. Taken together, although children already seem to be able to accomplish a task together with another person at the end of their second year of life (e.g., Brownell and Carriger, 1990; Warneken et al., 2006), it takes another year of development to enable the establishment of well-coordinated joint action.

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