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The development of co-representation effects in a joint task: Do children represent a co-actor?

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abstract

When two adults jointly perform a task, they often show interference effects whereby the other's task interferes with their own performance (Sebanz, Knoblich, & Prinz, 2003). The current study investigated whether these co-representation effects can be observed in young children. This phenomenon can be used as a criterion for adult-like joint action in children, which has been under debate in existing literature due to the difficulty in identifying what mechanisms underlie the behaviours observed (Brownell, 2011). In Experiment 1, two children performed an adapted Bear Dragon task (Kochanska, Murray, Jacques, Koenig, & Vandengeest, 1996), where children were required to point to a picture when instructed to do so by one puppet and to inhibit pointing when instructed to do so by the other. In the Same Task condition, both children in a pair were asked to respond to the same puppet, whereas in the Different Task condition, they were asked to respond to different puppets. Children made more errors in the Different Task condition than the Same Task, suggesting that they were experiencing interference from their partner's task rule. In Experiment 2 children in Different and Same task conditions began with the same task as in Experiment 1 and then switched which puppet to respond to. Switch costs were lower in the Different task condition, consistent with children having already represented the alternative task rule on behalf of their partner during the pre-switch phase. Experiment 3 replicated the effect of Task in a novel computer-based paradigm with children between 4 and 5 years, but not younger. These data provide the first direct evidence that children as young as 4 years co-represent a partner's task during a joint activity, and that younger children may not be capable of co-representation.

Introduction

When working together during a joint activity, adults are proficient at predicting their partner's actions in order to perform complementary actions. This capacity for co-ordinated joint action is thought to be important for a wide range of activities including dance, sport

and music, but also more everyday activities like lifting an object with a partner or having a conversation (Allport, 1924). These behaviours are argued to be achieved through a number of mechanisms, including joint attention, action observation, task sharing, action coordination and understanding of agency (Sebanz, Bekkering & Knoblich, 2006). In turn, mechanisms may be mediated by either lower level processes such as ‘mirroring’ or simulation (Sebanz & Knoblich, 2009) or higher level mechanisms involving intention understanding and symbolic communication (Humphreys & Bedford, 2011; Atmaca, Sebanz & Knoblich 2011). Either way, joint action requires some form of ‘representation’ of the basis of a partner’s actions, whether this be representing intentions or simply motor schema. The current studies investigated whether 2-5 year-old children automatically generate such representations during joint activity.

There is a plentiful body of research on children’s ability to perform joint actions, most of which involves demonstrating children’s apparent reciprocation on games involving turn-taking. For example, children at around 18 months are able to participate in games such as throwing a ball back and forth between themselves and a partner (Hay, 1979). In research using more concrete goals (e.g. making a ball bounce on a trampoline) rather than abstract goals (e.g. maintaining interaction with a partner, as in ball throwing), children were less able to coordinate their actions with a partner at 18 months, but even so, they could succeed at above-chance at around 24 months (Warneken, Chen & Tomasello, 2006). Such evidence has led to claims that joint action occurs fairly early on in development (Carpenter, 2009).

However, there are also grounds for thinking there may be important differences between the abilities of children and adults to engage in joint action. Whereas at least some aspects of adults’ joint action processing are spontaneous or even automatic, there is evidence that young children’s engagement in joint actions typically requires scaffolding by a caregiver (Brownell, 2011). Thus, joint actions are typically learned in the context of a

parent-child dyad before they can be applied to other situations, at around 24 months. This argument is supported by Bakeman and Adamson (1984), who showed that at 18 months participants' play consisted of 25% joint activity with their mothers, whereas only 7% was with a peer.

In some cases it may also be difficult to determine whether young children's actions with others actually share a joint goal. Actions in conjunction with a partner may seem collaborative but may in fact be the product of the child trying to reach their individual goal. For example, Hamann, Warneken and Tomasello (2012) showed that two year-old children would participate in a joint task up until they had achieved their own goal of retrieving a toy, but only three year-olds would continue to participate until both themselves and their partner had retrieved a toy each. This age difference suggests the younger child may be using the partner as a way of achieving their own personal goal, rather than understanding a joint goal. In summary, while there is a rich evidence base of phenomena that imply the existence of joint action abilities in young children there is less evidence for the mechanisms by which joint actions are achieved (Brownell, 2011). Approaches that aim to discover something about these mechanisms would provide a stronger basis for comparison between children and adults' abilities than the behavioural phenomena alone.

One important phenomenon in adult joint action is the co-representation of tasks for each participant of joint activity. Adults represent the complementary task that a partner of joint activity performs, in addition to their own task and in a relatively automatic manner, which can lead to tell-tale interference effects in some circumstances. Sebanz et al. (2003) investigated this with adults by employing a modified version of the classic Simon task paradigm (Simon & Wolf, 1963). In the classic Simon task, participants are required to respond to a button on one or the other side of the keyboard in response to a simple conditional rule (e.g. left button for a green ring on a pointing finger, right button for a red

ring). However, half of the pointing fingers pointed to the side of the screen corresponding with the correct button (i.e. if the ‘green’ response button is on the left of the keyboard, the finger with the green ring points to the left side of the screen) and half on the opposite side. Thus, participants experience congruency effects whereby responses are slower when stimulus and response are spatially incompatible. Interestingly, in a ‘Go-Nogo’ version of the task, where participants are only required to respond to one of the stimulus types with one button (i.e. respond to ‘green’ rings but ignore ‘red’), this incompatibility effect disappears (Sebanz et al, 2003). Participants are able to respond equally quickly on all trials because their conditional response no longer varied on a spatial dimension, meaning that irrelevant spatial information from the position of the stimulus could not interfere (e.g. if the participant has to respond to green stimuli only, they can ignore red stimuli). Sebanz et al. investigated this further by asking participants to participate in either the original two-choice Simon task, a Go-Nogo version of the task or a joint ‘Social Simon’ version, where two participants worked simultaneously, each performing a Go-Nogo task on a single colour. In terms of an individual participant’s task, the joint version was identical to the Go-Nogo version except that another participant was present and acting on the alternative task rule. Sebanz et al. found that participants showed similar compatibility effects to when they had to make both responses themselves, despite the fact that representing their partner’s task in these circumstances was unnecessary and detrimental. In other words, participants made slower responses on spatially incompatible trials, suggesting that they represented their partner’s task in a similar way to that in which participants represented their own actions when required to respond to both buttons themselves, even though it is detrimental to their own performance.

The interference effects observed by Sebanz et al. serve as a sign that a participant is co-representing a partner’s task. Co-representation is good evidence that adults are able to perform actions that are joint in nature rather than being due to individual actions that appear

joint due to the circumstances in which they are observed. Although the mechanisms underlying co-representation are still under debate in current literature, this finding in adults can be used to set a specific criterion for joint action in children. If children also show interference effects on their performance when acting alongside a partner, this would constitute evidence that, like adults, they are generating some form of representation of their partner's action, as a motor schema or as an intentional action. Meeting this criterion will provide a basis for further investigation into the level of processing involved in co-representation and therefore joint action in young children. Additionally, the age at which co-representation effects can be found can provide information about the processes themselves.

Different assumptions about the development of joint action lead to very different predictions about the occurrence and nature of co-representation interference effects in children. One possibility is that co-representation is early-developing, perhaps because it involves a lower-level mechanism, akin to entrainment, simulation or ‘mirroring’ (Sebanz & Knoblich, 2009; Di Pellegrino, Fadiga, Fogassi, Gallese & Rizzolatti, 1992). Another possibility is that co-representation effects depend upon “theory of mind” abilities for processing the intentions or other mental states of one’s partner. This reasoning predicts early development if “implicit” theory of mind abilities are sufficient, because these may be present in the first year of life (Baillargeon, Scott & He, 2010). However, if co-representation requires explicit theory of mind abilities then this would predict later development, because such abilities only develop in early childhood (e.g. Wimmer & Perner, 1983).

We tested 2-5-year-old participants in the following three experiments, because the ability to reason about others’ mental states and actions in explicit tasks (Wimmer & Perner, 1983; Flavell, Flavell & Green, 1983) develops within this period. If co-representation relies

on explicit mental state understanding, then children below the age at which this develops (around 4 years) should not show the Social Simon Effect. However, if lower level processes are sufficient even younger children should show the phenomenon.

To create a child-appropriate method, the current study modified the Bear Dragon task (Kochanska, Murray, Jacques, Koenig & Vandegeest, 1996) into a joint task as in Sebanz et al. (2003). In the original task, children are asked to respond to a bear puppet's instructions but to inhibit those of the dragon. This task is a classic test of inhibition in the developmental literature that has been shown to successfully elicit data from particularly young children (see Carlson (2010) for a comparison of developmental sensitivity between different executive function measures. Here, 88% of young 4-year-olds passed the task). The Bear Dragon task is similar to the Simon task in the sense that it plays on an existing tendency to act upon a certain stimulus. In the Simon task, this tendency is to perform an action response that is spatially compatible with the stimulus. In the Bear Dragon task, the tendency is simply to make a response ("Go") rather than inhibit a response ("No-go"). In the joint version employed here children were required to complete this task as a pair, either with both children having to obey the instructions of the same puppet (Same task condition) or with each child obeying a different puppet (Different task condition). If children co-represent their partner in this joint task, then there should be a cost to performance when the partner is following a different rule, compared with when they are following the same rule. However if children do not co-represent, then the rule their partner is following should not cause interference.

This study is the first to investigate the development of joint action co-representation effects. The findings will not only shed light on development of joint action, but also on the level of processing that is required for this effect to occur based on the age at which it

develops and the general cognitive capabilities of children at that age. The aim of Experiment 1 was to identify whether such an effect occurs in 4-5 year-olds.

1. Experiment 1

2.1. Method

1.1.1 Participants

Participants were 40 4- to 5-year-olds (Mean age = 55.81 months, Range = 50-62 months; 23 female) from two Primary Schools in the Birmingham area. Two participants refused to participate and were thus excluded from analyses. Participants carried out one of two conditions: Same Task condition ($N=18$) or Different Task condition ($N=20$). Participants were chosen at random to be paired to complete the task together.

2.1.2 Stimuli

Stimuli consisted of two stuffed animal toys: one brown teddy bear (17x18x11cm); and one yellow duck (22x15x9cm, see Appendix A), controlled by the experimenter. Children were each given a white, laminated, A4 piece of paper featuring three printed cartoon images: One brown dog; one yellow flower; and one green car (see Appendix B). Each child received an identical copy of this page, with the dog on the top left, the flower on the top right and the car on the bottom centre. Finally, a 65x36x71cm cardboard screen was used to separate participants in order to prevent them from seeing the other's reactions and potentially imitating them or conforming to their task rules. The screen was covered in pink and blue paper.

2.1.3. Design and Procedure

Children were tested in pairs and were invited to sit on the floor, one on either side of the screen, facing the experimenter. They were then invited to wave at one another over the

top of the screen in order to ensure that the other's presence was salient. The experimenter then simultaneously gave each child a copy of the selection stimuli page and issued the appropriate instructions depending on the condition.

2.1.3.1. Different Task.

The experimenter said to both children, 'We are going to play a game with these two toys. This is Mr. Bear. He's a talking bear. Hello <Child 1>! Hello <Child 2>!' The experimenter moved Mr. Bear's arm to wave at each child as he addresses them. This was then repeated for Mr. Duck. The order of introduction of each puppet was counterbalanced across pairs alongside counterbalancing of order of presentation of puppets in experimental trials, so that the puppet that was introduced first was also the first to be presented on Trial 1. Each puppet first addressed the child who would subsequently follow his instructions. The child sitting on the right always responded to Mr. Bear and the child sitting on the left responded to Mr. Duck. Children were randomly allocated to left or right positions.

The experimenter then issued instructions to each child separately, starting with the child whose puppet was introduced first: 'Mr. Bear is going to tell you to point to some pictures. But you can only point to the pictures if Mr. Bear tells you to. If Mr. Duck tells you to point to a picture, you must stay completely still and not point to anything (crossing arms across chest for emphasis). Do you understand the game?' If Child 1 confirmed that s/he has understood, the experimenter repeated the instructions, but with the alternate puppet names, to Child 2. All children either verbally stated that they had understood or nodded in response to the question without repetition of the instructions.

The experimenter then introduced a practice run: 'Let's have a little practice.' The experimenter then held up Mr. Bear statically, in a central position facing both children, saying, 'Mr. Bear says point to the Dog.' Participants were marked as correct if they pointed

or inhibited pointing depending on their respective task rules. This practice was then repeated four times, alternating between Mr. Bear and Mr. Duck so that each puppet was presented twice. While one puppet was being presented, the other remained face down on the floor in front of the experimenter. All children continued to the main experiment regardless of their performance on the practice, but practice scores were recorded.

The main experiment was identical to the practice run, with the exception that order of presentation followed the six pre-set counterbalancing orders. On completion of the first and second blocks, children were reminded of their task rule. As in the practice run, the instructions were given twice, directed first to one participant and then to the next, whether instructions were identical (Same Task condition) or not (Different Task condition). Whether children received their instruction first or second remained the same as in the practice trial. Children were given positive feedback at the end of the experiment and were given a sticker as a reward.

2.1.3.2. Same Task.

The Same task condition was implemented rather than having an individual go-nogo condition (as in the original Social Simon task, Sebanz et al., 2003). This was in order to keep conditions as comparable as possible in terms of other distractions that may be caused by a partner's presence. Findings from the adult literature would suggest that co-representing a partner in a joint task causes interference, taking a participant below the baseline performance in an individual go-nogo version of the task (Sebanz et al., 2003). Although this reduces the conclusions that can be made regarding where the baseline lies in this paradigm, it is reasonable to assume that co-representation in the Same condition would not cause interference, whereas it would do so in the Different condition. The question of whether

carrying out the same task as a partner might even facilitate performance is one for future research.

The Same condition was identical to the Different condition with the exception that both participants were asked to respond to the same puppet. As in the joint condition, the instruction was repeated to each child, even though they were identical.

An independent samples design was implemented with two groups participating in one of the two conditions. Six counterbalancing orders were devised with six trials per block and three blocks per participant, giving a total of 18 trials. Each puppet was presented three times per block of six trials. Across the six orders, each puppet was presented an equal number of times in each position (1st-6th) within each block of six trials. Neither puppet was presented more than twice in a row in each block. Each target stimulus (Dog, Car or Flower) was requested an equal number of times by each puppet. Participants completed three blocks of six trials matched for the aforementioned factors. Total testing duration was approximately 5-10 minutes.

2.2. Results and Discussion

Out of the 40 participants 38 succeeded in attending to the task and were included in analyses. Accuracy rates were calculated based on children's response errors. Responses were recorded as correct if they performed 'go' or 'nogo' actions on appropriate trials, regardless of accuracy of picture selection. Even if participants pointed to the incorrect picture, they were still recorded as correct as long as they did so on a 'go' trial. The performance (see Table 1) was above chance (50%) for both conditions (Different Task: $t(17) = 5.72, p < .001$; Same Task: $t(19) = 3.37, p = .003$). For the Same task the proportion of correct responses was .96 for 'Go' trials and .67 for 'Nogo'. For the Different task the proportion correct was .78 for 'Go' trials and .52 for 'Nogo' trials.

The response accuracy of each trial (correct vs. incorrect) was submitted to a mixed effect logistic regression, with Participant as a random effect (i.e., random intercept) and Task (Same or Different) as a between-participant fixed effect. Here and throughout, mixed effect logistic regressions were used when a proportion (i.e., accuracy) was the dependent variable, because proportions violate assumptions of ANOVA (see Jaeger, 2008, for the advantage of such regressions over ANOVAs). These analyses were carried out with lmer function of R. For the present experiment the effect of Task was significant ($\beta = -1.48$, $SE \beta = .51$, $p < .01$), and it is clear from Table 1 that this was due to children in the Same Task condition performing better than those in the Different Task condition. To complete the model specification, the intercept was 2.29 ($SE = .39$) and the estimated standard deviation for the random intercepts across Participants was 1.37. The results indicate that the children in the Different task condition co-represented their partner's task, which interfered with their own task, leading to poorer performance than the children in the Same task condition.

A potential alternative explanation for the difference between the conditions was that participants in the Different Task condition did not understand which set of instructions they were supposed to be following, as both participants heard both instructions. Although instructions were clearly directed at the appropriate participant, it is possible that for the participants who received their instructions first, the second participant's instructions overwrote their memory of their own instructions. If this were the case, children who

Table 1

Mean proportion (SD) of correct responses in Same and Different Task conditions in Experiment 1.

	Mean (SD)
Same task	.82 (.24)
Different task	.65 (.20)

received their instructions second should perform better than those who received instructions first. However, there was little descriptive difference in performance between the two instruction order groups for the Different condition (first to be instructed, $M = .69$, $SD = .18$; second to be instructed, $M = .62$, $SD = .23$), and a mixed effect logistic regression on data from the Different condition, with Participant as a random effect and Instruction order (first vs. second) as a fixed effect found that the effect of Instruction order was not significant ($\beta = -.35$, $SE \beta = .44$, $p = .42$). Therefore order of instruction cannot account for the effect of Task in this experiment. The intercept was $.93$ ($SE = .31$) and the estimated standard deviation for Participants was $.83$.

Although the above analysis failed to find evidence for memory overload as an alternative account of the findings, this argument is based on a null result and furthermore children in the Different condition may be ‘confused’ in other ways that are not due to co-representation. Co-representation itself could be described as a type of ‘confusion’, but it is critical to distinguish between effects of co-representation (responding incorrectly due to interference from representing another’s task) and potential confusion due specifically to the increased complexity of the instructions in the Different Task condition. To further address such alternative explanations, a second experiment was carried out.

In order to rule out the possibility that children in the Different Task condition are confused about which puppet to respond to due to the increased complexity of the instruction set in the Different condition, we created a situation where co-representation of the partner’s different (interfering) task might be beneficial, but where confusion due to instructions would be detrimental. In Experiment 2, participants switched which puppet to respond to half way through the game. If the children in the Different Task condition were, in fact, representing their partner’s task in the first half of the experiment, then switch costs should be reduced in

the Different Task condition, as children already have the representation of the opposite task in mind before they switch to it. In contrast, in the Same Task condition, children have no reason to represent the partner's task as both participants share the same task, and thus the opposite task is completely novel when children switch to it. In summary, if children co-represent their partner's task, the cost of switching task rules should be higher in the Same Task condition than in the Different Task condition. In contrast if children in the Different Task condition were simply confused about which rule to follow, then the requirement to switch would be expected to confuse them further still, resulting in yet poorer performance.

3. Experiment 2

3.1. Method

3.1.1. Participants

Participants were 120 four- to five-year-olds (Mean age = 57 months, Range = 50-66 months, 59 female) from two Primary Schools in the Birmingham area. Two pairs of participants were excluded due to experimenter error and one individual was excluded on parental request, leaving a total of 115 included in analyses. Participants carried out one of two conditions: Same Task condition ($n = 60$) or Different Task condition ($n = 55$). Participants were chosen at random to be paired to complete the task together.

3.1.2. Stimuli

Stimuli were identical to those used in Experiment 1.

3.1.3. Design and Procedure

As in Experiment 1, an independent samples design was implemented with two groups participating in one of the two conditions. The same six counterbalanced sets of Bear and Duck presentation were used as in Experiment 1. Whereas Experiment 1 featured three

blocks, Experiment 2 had an added block so that there were an equal number of blocks before and after the switch. The extra fourth block had one of the six set orders that had not occurred yet in the previous three blocks. After completion of the first two blocks, children were instructed to switch task rules and thus follow the instructions of the original non-target puppet and inhibit the original target puppet.

The procedure for practice and experimental trials was identical to that used in Experiment 1, with one exception regarding experimental trials. For the first two blocks of 12 trials, the procedure was exactly the same as in Experiment 1. At the end of the second block, participants were then given the instructions, “Now you are going to switch over. So, *before* you had to point to the pictures when Mr. Bear told you to and not when Mr. Duck told you to, but *this* time you have to point to the pictures when Mr. Duck tells you to and not when Mr. Bear tells you to. Do you understand?” All participants either verbally stated that they had understood or nodded in response to the question without repetition of the instructions. Whether participants were instructed to respond to the Duck or the Bear in the switching instructions depended on the task they had previously carried out. In the Different Task condition, each child received the opposite instructions, so that both were instructed to respond to different puppets. In the same task condition, the identical switching instructions were repeated to both participants. The order in which each child received instructions was identical to the order in which they received their initial instructions before the first block. Following instructions, the final 2 blocks were administered as detailed in Experiment 1.

3.2. Results and Discussion

Pre-switch data were examined in order to test whether they replicated the main effect of Condition found in Experiment 1. Values (see Table 2) were submitted to a mixed effect logistic regression, with Participant as a random effect (i.e., random intercept) and Task

(Same or Different) as the between-participant fixed effect (Intercept = .93 ($SE = .59$), estimated standard deviations for Participants = 4.11), which confirmed this observation ($\beta = 1.62$, $SE \beta = .83$, $p = .05$). For the Same task the proportion of correct responses was .92 for ‘Go’ trials and .82 for ‘Nogo’. For the Different task the proportion correct was .70 for ‘Go’ trials and .71 for ‘Nogo’ trials.

The second prediction was that participants should show less of a switch cost in the Different Task condition than in the Same Task condition. The response accuracy of each trial (correct vs. incorrect) was submitted to a mixed effect logistic regression, with Participant as a random effect and Task (between-participant: Same or Different) and Switch (within-participant: pre-switch vs. post-switch) and the interaction between Task and Switch as fixed effects. With regard to Participants, the random intercept, random slope and the covariance between random slope and random intercept for Switch was included in the model (following Barr, Levy, Scheepers & Tily, 2013). See Table 2 for descriptive statistics. The main effects of Task ($\beta = .063$, $SE \beta = 0.37$) and Switch ($\beta = -0.18$, $SE \beta = 0.41$) were not significant. However, the interaction between Task and Switch was significant ($\beta = .66$, $SE \beta = .33$, $p = .048$). To complete the model specification, the intercept was .72 ($SE = .51$). The estimated standard deviations for random effects with regard to Participants were 3.57 for intercepts, .83 for Switch, and the covariance between intercepts and Switch was .38.

Table 2

Mean proportion (SD) of correct responses on Same and Different Task conditions for Pre- and Post-switch data in Experiment 2.

	Pre-switch	Post-switch
Same Task	.89 (.20)	.85 (.19)
Different Task	.77 (.20)	.78 (.21)

Pairwise comparisons demonstrated that the Task x Switching interaction was primarily the result of a switch cost in the Same Task ($\beta = .64$, $SE \beta = .34$, $p = .059$) but not in the Different task ($\beta = -.15$, $SE \beta = .20$, $p = .43$).

Altogether, these findings indicate that the Different task group's poorer performance in the first half (and in Experiment 1) was not simply due to confusion about the instructions. If that were the case, the Different Task group should, if anything, get proportionately worse after the switch, compared to the Same Task group, yet this was clearly not the observed pattern. There was also no evidence to suggest that our findings were an artefact of poor performance, which might have prevented the observation of a decline in performance following the switch. Inspection of mean performance in each cell of the design showed performance to be substantially above chance (lowest performance was 77% compared with 50% expected by chance), and statistical analysis showed both the Same Task and Different Task to be significantly above chance both Pre-switch (Same task: $t(59) = 17.57$, $p < .001$; Different task: $t(54) = 9.26$, $p < .001$) and Post-switch (Same task: $t(59) = 14.38$, $p < .001$; Different task: $t(54) = 10.11$, $p < .001$).

Experiment 3 was designed to test for generalisation of these effects to a new method, to enable us to test younger children, and to provide yet further evidence against the hypothesis that children were confused about the instructions. One alternative explanation for the results of Experiment 2 is that simply hearing two sets of the same instructions at the start (Same task condition) consolidates one's own task, so that a switch is difficult. Whereas hearing two different instructions (Different task) means that children do not form as strong a representation of their own task, so a switch is not as difficult. Thus, in Experiment 3, children were invited to play with the Experimenter rather than another child. This eradicated the need to instruct a second participant in the presence of their partner, therefore eliminating the potential for additional confusion about the two instructions in the Different

Task condition. The Experimenter merely stated what her job was in the game. That is, the experimenter's task was introduced as a statement of what she would do, and the child's task was introduced as an instruction. This modification makes it unlikely that two tasks were confused with each other at the point of instruction. Furthermore, children were given a practice of six trials playing the game alone, before then completing a six-trial practice alongside the experimenter. This addition provided a greater opportunity for children to consolidate their memory and understanding of their own task before the partner's task was even introduced. The third experiment also simplified children's task by reducing the number of response options from three in the previous experiments (three different pictures to point to) to one in Experiment 3 (press single button). Doing so allowed accurate recording of response times, and enabled testing younger children than in the previous two experiments. Testing younger children provides further information about the processes underlying co-representation, as children at this younger age are limited in certain cognitive capacities that may or may not be involved in co-representation. Additionally, an effect of co-representation in a younger population would provide a possible explanation for early joint action behaviours seen in previous literature.

4. Experiment 3

4.1. Method

4.1.1. Participants

Participants were 94 children (42 female) from two schools and two nurseries in Birmingham, UK. This sample remained after excluding six children for refusing to attend and one for making no response on any trial. Children were divided equally into three age groups: The Younger group ($n = 32$) ranged from 29-45 months with a mean age of 39.84 months. The Middle group ($n = 31$) ranged from 46-60 months with a mean age of 52.52

months. The Older group ($n = 31$) ranged from 60-69 months with a mean age of 63.84 months. Participants were chosen at random to be paired to complete the task together.

4.1.2. Stimuli

A computer task was devised using EPrime 2.0 to present stimulus images on a Toshiba Satellite Pro A200 laptop. The presentation sequence (see Appendix C and D for images) consisted of a fixation point (1000ms), followed by an image of a closed door (3000ms), which was then replaced by the same door open (1000ms), followed by the open door with either an image of a teddy bear or a duck within the door frame (1000ms). This was repeated, with random presentation of either the bear or the duck, for twelve trials per block, for 3 blocks. Each block was separated by a blank screen, which was used as a reminder break, where the experimenter reminded children verbally of what they and the experimenter puppet should be doing in the task ('Remember, just keep pressing the button when you see the Bear/Duck and I will keep pressing my button when I see the Duck/Bear'). Two large (2.5cm diameter circular button on a 13.5cm² base), white, child-friendly response buttons were used to record responses. The practice task consisted of a PowerPoint presentation featuring the same stimuli as in the experimental trials, but for only 6 trials. Practice trials were in the fixed order Duck, Duck, Bear, Duck, Bear, Bear.

4.1.3. Design and Procedure

Children were randomly allocated to one of two groups: Same task or Different task. They were asked to sit in front of a laptop computer which was placed either on a table or on the floor, depending on the testing facilities at each school. Participants always sat on the left side and the experimenter sat on the right. The two response buttons were placed one in front of the child and one in front of the Experimenter. Unlike Experiments 1 and 2, there was no screen between participants for this experiment. Children were told, 'You're going to play a

computer game where you're going to see some animals on the screen. Your job is to spot the Bear' (Experimenter shows the PowerPoint slide from the practice trial featuring the Bear). 'So, whenever you see the Bear, like this, you should press your button as fast as you can' (Experimenter points to the child's button). 'Can you show me how you press the button?' (Experimenter waits until child has pressed the button). 'Good. But, if you see a Duck, you shouldn't press your button.' (Experimenter shows Duck slide). 'You just stay still and don't press anything at all. Do you think you can do that? Let's have a practice.' The experimenter then begins the practice trials, controlling the speed of presentation depending on the speed of the child's responses. Positive feedback was given for every correct trial. If the child made an incorrect 'go' response, the Experimenter said 'Oops! Do you know what you were supposed to do? When are you supposed to press the button?' If the child made an incorrect 'nogo' response, the Experimenter said, 'Do you remember what you are supposed to do when you see the Bear/Duck? Do you press the button or not press the button?' Once the child had given the correct answer, the Experimenter gave positive feedback and continued to the next trial. The animal assigned to the child was counterbalanced, so half were instructed to follow the Bear and not the Duck and half vice versa. There were six practice trials.

On completion of the solo practice block, the Experimenter said 'Well done! Now I'm going to play the game too'. The protocol that followed was dependent on condition, as follows:

Different task

The following is an example of the protocol for participants who were instructed to respond to the Bear. After the child completed the practice block, the experimenter explained that she would join in the game. The, the experimenter said 'My job is to spot the Duck.'

(Experimenter shows Duck slide). ‘So, whenever I see the Duck, I’m going to press my button like this’ (Experimenter presses the button). ‘But, if I see a Bear, I’m not going to press my button, I’m just going to stay still and not press anything at all. Let’s have a practice with both of us playing together’. The Experimenter then ran the practice again, making correct responses to all trials.

On completion, the Experimenter said ‘Well done, let’s do the real thing now’. Before beginning the experimental blocks, the Experimenter asked the child, ‘Can you remind me when you have to press your button? Is it when you see the Bear or the Duck?’ Responses were recorded. The experimenter then ran the EPrime programme. Between each block, the Experimenter said ‘Well done, you’re doing really well. Remember, just keep pressing your button when you see the Bear, and I’ll keep pressing the button when I see the Duck.’ On completion of all three blocks, the Experimenter repeated the comprehension question that she posed at the start of the experimental trials and recorded responses. Positive feedback was given.

Same task

The procedure for the Same task condition was identical to the Different task, except that the Experimenter explained that she would respond to the same animal as the child rather than a different animal.

4.2. Results and Discussion

Results were analysed based on Score (overall proportion correct) and Response Times. Table 4 shows mean proportion of correct responses for each Age Group by Condition. Values were submitted to a mixed effect logistic regression, with Participant as a random effect (i.e., random intercept) and Task (Same or Different) and Age Group

(Younger, Middle and Older) as the between- participant fixed effect (Intercept = 1.62 ($SE = 1.01$), estimated standard deviations for Participants = 1.02), which found no effect of Task ($\beta = -.43$, $SE \beta = .65$, $p = .50$), Age Group ($\beta = .84$, $SE \beta = .51$, $p = .10$, and no interaction ($\beta = -.004$, $SE \beta = .32$, $p = .99$). For the Same task the proportion of correct responses was .86 for ‘Go’ trials and .95 for ‘Nogo’. For the Different task the proportion correct was .81 for ‘Go’ trials and .94 for ‘Nogo’ trials.

Responses times for correct (go-) responses were analysed. Response times were removed if they were below 250 ms or over 2 standard deviations from the mean (1713 ms). Values (see Table 5) were submitted to a 2 (Task) x 3 (Age Group) ANOVA, which found a significant effect of Task ($F(1, 88) = 9.48$, $p = .003$, partial eta-squared = .10), Age Group ($F(2, 88) = 13.67$, $p < .001$, partial eta-squared = .24) and an interaction ($F(2, 88) = 2.96$, $p = .057$, partial eta-squared = .06). Planned pairwise comparisons showed that response times were shorter in the Same task than in the Different task for the Middle ($t(29) = -2.91$, $p = .007$, Cohen's $d = 1.09$) and Older age groups ($t(29) = -2.61$, $p = .014$, Cohen's $d = .94$) but not for the Younger Age Group ($t(30) = .07$, $p = .95$, Cohen's $d = -.02$).

Table 4

Mean proportion (SD) of correct responses in Same and Different Task conditions by Age Group, in Experiment 3.

	Younger (29-45 months)	Middle (45-60 months)	Older (60-69 months)
Same task	.83 (.16)	.95 (.05)	.95 (.05)
Different task	.77 (.16)	.91 (.10)	.93 (.08)

Table 5

Mean correct Response Times (SD) in Same and Different conditions by Age Group in Experiment 3.

	Younger (29-45 months)	Middle (45-60 months)	Older (60-69 months)
Same task	998.69 (164.07)	889.85 (156.50)	756.83 (146.59)
Different task	994.35 (215.48)	1106.22 (232.36)	903.83 (194.38)

These results provide further evidence that the effects of Task found in all three experiments were not due to mere confusion over instructions, but rather were due to co-representation. Children in Experiment 3 were given the opportunity to practice their task in a solo scenario before the joint task was even introduced. Then, when the joint task was introduced, the Experimenter merely stated what she would do in the game, rather than presenting it in the format of an instruction which could be interpreted as being directed at the child or confused with the child's own instruction due to similarity in linguistic construction. Lastly, the effect found in Experiment 3 is found in response times rather than proportion correct. If children in the Different Task condition were confused purely by their instructions and mistook the partner's task as their own task, then the effect of Task should manifest itself in error rates rather than response time because such confused children should make consistent errors in performance rather than taking longer to respond.

Another potential alternative explanation is that children are responding differently in Same and Different conditions because they were imitating their partner. For example, children could feasibly respond quicker in the Same condition if they simply pressed their button as soon as they saw the Experimenter press hers. Due to the fact that a screen was not used in this experiment, and that a slight noise was made when the Experimenter pressed her button (due to her hand hitting the plastic), this is theoretically possible. However, it is unlikely for several reasons. Firstly, the Experimenter aimed make consistent, slow

responses throughout the experiment. Although clearly this would vary to some extent, she observed that children did not consistently wait to respond after she had done so. Secondly, if children were following this rule, there should have been a clear effect of Task Type in accuracy as well as response times, as imitating a partner in the Same condition should have resulted in perfect accuracy whereas imitating in the Different condition should have resulted in systematic errors. This was not the observed pattern. Lastly, the interaction of Task Type with Age Group is difficult to explain using this interpretation, as there are no reasons to think that the likelihood of imitation varies over this age range.

The results from this experiment also give new information about co-representation in even younger children. Here, children in the youngest age group (29-45 months) did not show a significant effect of task type. It is possible that this age group was a lower bound on co-representation effects in children. Further, these results suggest that this experiment captured a sensible age range to study a developmental change in co-representation effects. Further research is needed to investigate this potential lower bound on co-representation, perhaps using methods that are more sensitive for the younger age range.

5. General Discussion

This study investigated whether co-representation effects, as demonstrated in adults by Sebanz et al. (2003), can also be seen in young children. The results of Experiment 1 provide preliminary evidence that this is the case in 4-5 year-olds. Although children's performance was clearly above-chance in all conditions, they performed significantly better in the Same Task condition than in the Different Task condition, suggesting that the presence of another child doing a different task interferes with performance. The same effect was replicated in the Pre-switch phase of Experiment 2. The Post-switch phase of Experiment 2 provided further evidence that the source of interference in the Different Task condition (in

the pre-switch phase) was children's representation of their partner's task. The co-representation of the partner's task interfered with their own task in the pre-switch phase, but it reduced the switch cost in the post-phase where the previously co-represented partner's task became their own task. In contrast children in the Same Task condition, who would not have represented the different task during the Pre-switch phase, performed rather worse when required to follow the other puppet's instructions during the Post-switch phase, and this pattern differed significantly between Same Task and Different Task conditions. This difference in switch cost is a novel observation in the literature, and provides new evidence in support of the co-representation hypothesis that is relevant for research on adults as well as children. Finally, Experiment 3 introduced a new paradigm using a computerised task, which eliminated the possibility that children in the Different Task condition would confuse two instructions and mix up which task to perform. Consistent with the error rate results in Experiments 1 and 2, children in the Older and Middle Age Groups (the age range similar to that in Experiments 1 and 2) were slower to respond in the Different Task condition than in the Same Task condition. However, the Younger Age Group did not show such effects.

The method used in Experiment 3 allowed us to test younger children than was possible in Experiments 1 and 2, and found evidence for co-representation that converges with the findings of Experiments 1 and 2 only in the middle and older age groups ranging from 46-69 months. Joint action behaviours have been reported in children of a variety of ages, ranging from 12 months (Liszczowski, Henning, Striano & Tomasello, 2004) to 4 years (Grafenbach, Behne, Carpenter & Tomasello, 2009). The present findings make it plausible that joint action phenomena in children aged 4 years and up are sustained through co-representation.

It may be noted that Experiments 1 and 2 showed an effect in accuracy, whereas Experiment 3 found an effect in response times. The methods used in Experiments 1 and 2 were based closely on a developmentally sensitive test of executive control, and did not lend

themselves to the accurate recording of response times. The method used in Experiment 3 made it possible to record both errors and response times. However, the task was also substantially simpler, due to a lower number of possible response options, and this was reflected in the higher overall accuracy in Experiment 3. It is possible that this resulted in response times being the more sensitive dependent variable in this Experiment, showing a co-representation effect that was not apparent in errors. We note that this pattern resembles the original findings of Sebanz et al (2003), who also observed effects in response times rather than accuracy. In sum, we think it likely that errors and response times are both valid indicators of a co-representation effect, with the effect being observed in whichever variable is the more sensitive within a given paradigm.

The developmental pattern shown here is consistent with the possibility that co-representation involves higher level cognitive abilities, such as explicit perspective-taking or advanced executive function skills, since children in the same range as the Younger Group in this study have been shown to perform poorly on tasks measuring such abilities. However, this hypothesis requires direct testing to identify whether individual differences in theory of mind, or in executive function play a role in co-representation development, or whether these age patterns are just a co-incidence of timing. Likewise, while high accuracy in all three age groups indicated that the task was well-understood by children, strong conclusions about the age at which children are first capable of co-representation should await the development of new tasks that can test for co-representation effects in yet younger children.

We provide the first evidence of a co-representation phenomenon, previously observed only in adults, in children aged between 4 to 5 years of age. Previous evidence has shown that children are apparently capable of performing “joint activities” but leaves room for scepticism about whether such activities are truly “joint” actions rather than co-ordinated individual actions (Brownell, 2011). One criterion that has been used to uncover joint action

in adults is the presence of co-representation effects, arising from participants not only representing their own task but also aspects of their task partner's intentions, goals or actions (Atmaca, Sebanz & Knoblich, 2011). We conclude that by 4-5 years old children meet this criterion for undertaking genuinely joint activities, while younger children may not have the pre-requisite skills to do so.

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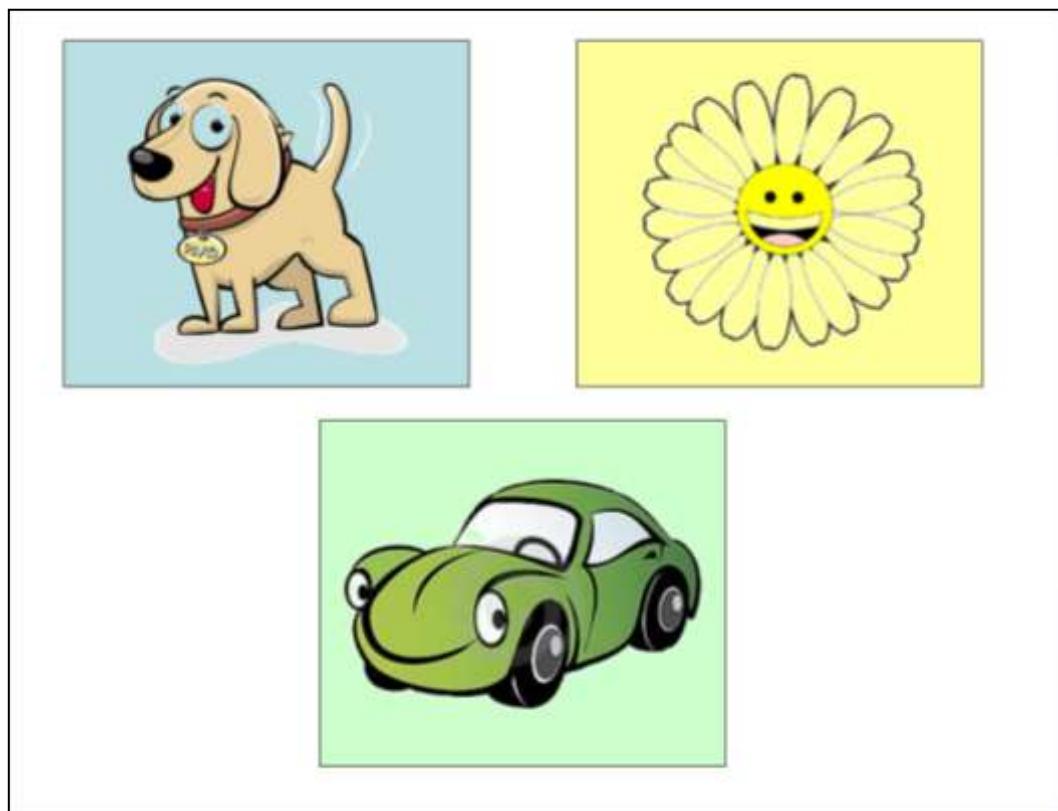
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Appendices

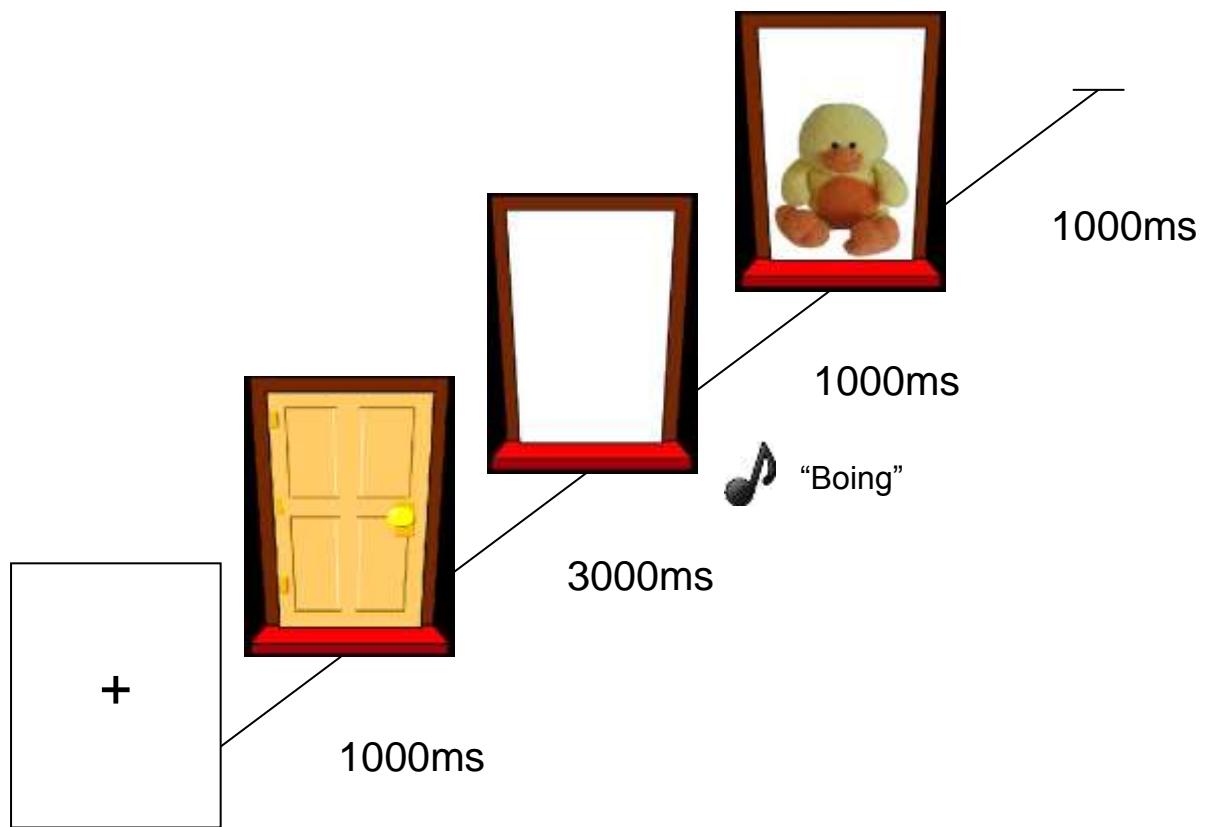
Appendix A. Puppet stimuli: Mr. Bear (left) and Mr. Duck (right)



Appendix B. Selection stimuli page: Dog (top left); Flower (top right); and Car (bottom centre).



Appendix C. Stimulus presentation for Experiment 3. Example with Duck as target stimulus.



Appendix D. Bear stimulus for Experiment 3.

