LEARNING TO ACT AS A TEAM: DEVELOPMENTAL ONSET, UNDERLYING PROCESSES AND PRE-REQUISITES OF CO-REPRESENTATION IN EARLY CHILDHOOD

by

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Abstract

Co-representation has been argued to be a mechanism in adult joint action that allows participants in a joint task to co-ordinate their actions with a partner. Substantial evidence for this mechanism has come from tasks such as the joint Simon task (Sebanz, Knoblich & Prinz, 2003), which show interference from a partner's task on one's own performance. The following studies aim to use this mechanism as a measure of children's joint action abilities and a way of directly comparing adult and child behaviours. Chapter 1 presents three studies which suggest a developmental onset of co-representation effects at around 4 years old. Chapter 2 attempts to uncover what type of representations may be formed in joint tasks at this age. Chapter 3 presents an individual differences study, suggesting that both Inhibitory Control and explicit Theory of Mind, but not Working Memory, play an indirect role in avoiding interference from co-representation. These findings contribute to the Joint Action Development literature, by demonstrating at least one way in which adult and child joint action may not be comparable. They also shed light on the adult co-representation literature, by highlighting cognitive skills that may interact with co-representation in order to reduce potential interference.

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Statement of Authorship

Chapter 2 of this thesis has been published in the academic journal, Cognition. Therefore, this chapter has been presented exactly in the form required by said journal. I am the primary author of this publication and carried out all data collection and analyses. My supervisors,

Ian Apperly and Sotaro Kita contributed to authorship by providing feedback and editing for versions of this paper leading to its final publication. Where possible, repetition of information from this chapter in other sections of the thesis has been avoided. However, some degree of overlap has been unavoidable due to the necessity of providing introductory information in the initial section of the publication.

CHAPTER 1. GENERAL INTRODCUTION

1. Introduction

Joint action is the term that has been adopted in psychological research to describe the ways in which individuals can act alongside others, producing a joint outcome. This has raised a number of questions regarding the underlying mechanisms involved in such interactions and whether individuals with limitations in cognitive capacity and skills, such as children and non-human species, can show a true understanding of joint goals and intentions. This thesis will focus on two of these questions. Firstly, it aims to draw parallels between adult and child cognition by identifying whether a phenomenon that has been found in adult participants, namely joint action or task co-representation, can also be found in children. If children show similar effects to adults then this is evidence that children's joint action abilities are comparable to adults'. Secondly, it aims to use the outcome of this investigation into co-representation to draw conclusions about the level of processing that is involved in co-representation. The following Introduction will outline four relevant areas of research that contribute to this discussion. Firstly, existing literature on joint action development will be summarised, illustrating the types of joint behaviours that can be seen in young children. Theory of Mind and Executive Functions will then be discussed as having a potential role in children's ability to represent a partner's task or actions. Lastly, co-representation will be presented as a means of investigating the processes involved in joint action in early childhood.

1.1 Joint Action and Development

The study of 'Joint Action' covers a huge range of phenomena from a huge range of scientific approaches and perspectives. To quote one of the more inclusive definitions, joint action is ‘any form of social interaction whereby two or more individuals coordinate their actions in space and time to bring about a change in the environment’ (Sebanz, Bekkering & Knoblich, 2006). This could be anything as apparently thoughtless as starlings flocking in a cloud over the Roman skyline to a group of politicians having a lively debate about the state of the economy. Either way, actions that are coordinated between individuals require some kind or kinds of mechanism that enable processing of the other’s past/present actions and possibly prediction of their future actions. This section will summarise existing findings about children’s abilities to act with a partner as well as the controversies that arise due to differing definitions and requirements for ‘true’ joint action.

Children are clearly capable of acting with others. Infants know to open their mouths when a parent raises a spoon of food, have an evident disposition to imitate others (Meltzoff & Moore, 1977), and as they grow older begin to seek out others in order to participate in joint play. From a lay perspective, and particularly from a parent’s perspective, these actions seem undeniably joint and reciprocal, thus aiding the emotional bond between caregiver and infant. Research has also backed up this folk psychology perspective to some degree. Several studies have identified scenarios in which young children take part in joint activities in both observational and experimental settings. Hay (1979) carried out observational work in which he found that children as young as 18 months were capable of participating in reciprocal games, such as throwing a ball back and forth to a partner, when interacting with a caregiver. In this case, the goals involved in the observed behaviours were abstract, in the sense that they required maintaining an interaction with a partner rather than obtaining a tangible goal.

Tasks with more concrete goals (i.e. retrieving an object from an apparatus) have also been employed to study children’s joint action abilities. Warneken, Chen and

Tomasello (2006) asked children to complete four activities with a partner. Two tasks involved problem-solving to retrieve an object from an apparatus (either a toy from an elevator and from a tube with two handles). The other two tasks were social games (bouncing a toy together on a small trampoline and dropping objects simultaneously down two parallel tubes). All tasks required two people to achieve their goal. Additionally, two of the tasks (one problem-solving and one social game) involved performing parallel roles, whereby both individuals performed identical, mirrored actions (e.g. both pulling on a handle of the tube). The other two tasks involved complementary roles (e.g. one individual pushes up the elevator and the other reaches in to retrieve the toy). 18-month-olds could participate to some degree in some of these tasks, such as the Elevator task (performance at ceiling in Role A) but were less successful at others, such as the Tube-with-handles task. 24-month-olds were significantly better at co-ordinating with a partner in three out of the four tasks. This suggests some level of cooperative ability in the second year of life. Further, children's responses to interruptions in task continuity were measured to investigate whether they would attempt to re-engage a partner if they inexplicably stopped participating in the game. The authors argue that if children do attempt to re-engage a partner, this is evidence that they have an understanding of the joint nature of the task rather than simply reacting to a partner's actions in order to effectively achieve an individual goal. In this study, all children made at least one attempt to re-engage their partner, suggesting that this is the case.

Given the above literature, we can certainly argue that children are participating in joint action, at least based on the broad definition stated at the outset (Sebanz et al., 2006). However, there has been significant debate surrounding how to define joint action, in both psychological and philosophical arenas. The main question to be agreed upon is whether it is necessary to understand a partner's intentions in order to perform a genuine joint action. One of the most commonly referenced definitions that assumes these higher level requirements comes from Bratman (1992). He argues that there are three requisites for an action to be truly joint in nature. Firstly, actors must be mutually responsive to their partner's intentions and actions. Secondly, they must be committed to the joint activity. Lastly, they must be committed to mutually supporting the actions of the other. This definition clearly states that an individual carrying out a joint action with another individual must be able to understand their intentions, interpret their actions and respond accordingly, whilst maintaining commitment to achieving the goal.

Bratman's definition hints at a further and related question, which is whether it is necessary to understand that the actors in a task share a joint goal. Butterfill and Sebanz (2011) give the following example to illustrate this requirement:

> *'Consider Ayesha and Beatrice, who carry a two-handled basket together. If their joint carrying is to be an intentional joint carrying, then it is not enough that Ayesha and Beatrice each individually intend to carry the basket. After all, their having these intentions is consistent with each planning to act alone.' (pg. 1)*

Thus, according to this level of definition, individuals acting together must both have the intention to achieve the same goal. Further, they must both understand that that goal is held jointly, as opposed to simply acting in parallel to achieve an individual goal that happens to be the same as a co-actor. Both of these definitions arguably call for quite a high level of cognitive ability in order to take part in joint actions, with a basis in intention understanding and the ability to hold a shared representation (of a goal). This should undoubtedly exclude swarming starlings over the Colosseum. What remains uncertain is whether this should also exclude infants and young children.

Although the evidence for early joint action behaviours would suggest that infants, at least from around two years, are capable of performing tasks with a partner, there are reasons to doubt that they actually have a true understanding of the joint nature of their actions. Firstly, there are alternative explanations for some of the behaviours demonstrated in joint action studies. Particularly for those studies that involve both partners performing identical actions (e.g. Hay, 1979; parallel actions in Warneken et al., 2006), it is difficult to eliminate the possibility that children are simply imitating their partner. For example, when a parent throws a ball to the child, the child may simply copy their actions and return the throw. So, what appears to be a reciprocal game may not really show any deeper understanding of the shared nature of the game, but rather rely on an intrinsic tendency to copy actions in an iterative manner. Likewise, it may be that children rely on pre-existing learned responses to the stimuli in these studies, which are often toys that are familiar to children of this age. For example, children may have learned that 'balls are for throwing'. Using this rule, there is no need for a child to understand that they are playing a joint game in order for them to show the ball throwing behaviour observed in Hay (1979).

Another reason to be wary of these early joint action studies is that there is evidence that such behaviours are heavily scaffolded in development. Bakeman and Adamson (1984) carried out a study in which infants were observed in natural play with their mothers and with peers. They found that whilst 25% of all 18 month-olds' play was joint when observed with their mothers, only 7% was joint when observed with peers. This suggests that joint play is unlikely to be spontaneous in children this young, but rather structured by their parents. Similarly, several of the studies in the joint action literature observe behaviours that occur alongside a parent (Hay, 1979) or at least an adult (Warneken et al., 2006). Thus, it should not be assumed that infants necessarily meet the specifications set out by Bratman (1992), as they may simply be performing actions that follow a parent's lead.

Another important criticism of existing joint action development literature is that it is extremely difficult to measure a child's understanding of a joint goal. In many cases, the behaviour of a child following an individual goal that happens to coincide with a co-actor would be identical to their behaviour following a joint goal. For example, in Warneken et al.'s (2006) problem-solving tasks, children may only have an individual goal in mind (to obtain the ball) and may use the adult as a social tool to achieve this goal. Hamann, Warneken and Tomasello (2012) tested this possibility by asking children to participate in a pair to retrieve two toys, one for each child. At two years, children tended to participate in the task only up until they retrieved their own goal of retrieving one of the toys. Only at three years would they continue until both they and their partner had retrieved a toy each. Even evidence of children's attempts to re-engage a partner in a task (Warneken et al., 2006) do not necessarily show an understanding of joint goals or intention understanding. For example, when performing a task using my computer, I may make attempts to re-engage said computer if it decides to stop performing its role in the task. This does not imply that I am assuming that my computer and I have a joint goal or that I think of it as an intentional agent (although see Dennett, 1989). More convincing evidence that intention understanding is involved in early joint action comes from studies that show differential behaviour dependent on whethera partner fails to perform their task role due to inability as opposed to unwillingness. Behne, Carpenter, Call and Tomasello (2005) found that 9-month-olds showed more impatient behaviours, such as reaching or looking away, when their partner's failure was due to unwillingness rather than inability. However, it is still possible that these behaviours may be observed without intention or goal understanding. If my computer fails to perform a function because it does not have the software to do so, I may be less infuriated than if it fails to do so for no good reason. This highlights the difficulties involved in this kind of research when trying to establish the existence of an understanding that extends beyond the individual. If Butterfill and Sebanz's two-handled basket example is to be fulfilled, it is necessary to establish such an understanding.

To summarise, existing joint action literature has provided evidence for joint behaviours from around the second year of life. However, if one assumes a definition of joint action that involves higher level cognition, such as intention understanding, it becomes more difficult to ascribe such behaviours to very young children. Instead, the question is raised regarding whether the behaviours we can observe at this age can be explained via simpler mechanisms that are less cognitively demanding on a young, developing mind. As Brownell (2011) points out, developmental psychologists are left in the position of arguing either that children do, in fact, have the pre-requisites for high level joint action (Carpenter, 2009), or that it is necessary to explain their behaviour in terms of lower level mechanisms that do not put excessive load on the child (see Apperly & Butterfill, 2009). The following section will illustrate current views in children's early Theory of Mind development with a view to evaluating the bases for both of these opposing arguments. By evaluating what is known about early social cognition, we can identify whether it is likely that such high level cognition may be involved in early joint action.

1.2 Early Development of Theory of Mind

Having outlined intention understanding as a key requirement for joint action understanding (at least according to Bratman, 1992), it is appropriate to identify what grounds there might be for concluding that children either have or do not have such abilities. The fact that research into ‘Theory of Mind’ has been given so much attention over the last three decades and generated such a vast quantity of findings should provide a solid basis for drawing conclusions about children’s pre-requisite cognitive abilities for understanding joint action. However, there is still a huge amount of controversy around topics within Theory of Mind and particularly surrounding the age at which such abilities develop.

Theory of Mind research catapulted into the forefront of Cognitive Development research following publication of Wimmer and Perner’s (1983) false belief paradigm. This classic task involved presenting a story to young children and acting it out with dolls. In the story a protagonist placed an object in one location and then left the room. While he was absent, another actor came and removed the object from the first location and replaced it in a second location. Children were asked where the protagonist would look for the object on his return. Results found 57% of 4-6 year-olds and 86% of 6-9 year-olds could correctly answer that the protagonist would look in the original location, demonstrating an understanding that their knowledge was different from the child’s and from reality. None of the 3-4 year-olds could pass this task, suggesting that understanding of false belief only develops after around 4 years. Since this ground-breaking finding, dozens of variations of this paradigm have been implemented in order to dig deeper into the underlying echanisms involved in mental state understanding. Two discoveries that have arisen from these investigations are relevant for the current discussion, both of which refer to the age at which mental state understanding develops. The first finding is that different types of mental state understanding develop at different ages (Lillard & Flavell, 1992). The second and rather pioneering finding is that it may be possible to measure mental state tracking in infants as young as 7 months-old, if using implicit, non-verbal measures (Onish & Baillargeon, 2005; Kovács, Téglás & Endress, 2010). By evaluating these findings it may be possible to decide whether children do, in fact, have the cognitive abilities necessary for Bratman's joint action.

Although Wimmer and Perner's original paradigm was designed specifically to measure understanding of another person's belief, an important distinction has been made between the onset of different types of mental state understanding. Lillard and Flavell (1992) carried out a series of experiments in order to test whether some types of mental state are easier to comprehend (at least in terms of being earlier developing) than others. They presented 3-4 year-old children with scenarios in a similar format to Wimmer and Perner (1983), but varying the type of mental state of the protagonist. For example, children were asked about the desire state of a protagonist, which differed from reality. Mental states included 'want', 'pretend', 'think', 'dream' and 'looks like'. These experiments showed that desire was the easiest mental state to compute, which was significantly easier than pretend, which in turn was significantly easier than belief. Dreams and appearance were equal in difficulty to belief. These findings are important to consider when contemplating the potential involvement of mental state understanding in joint action. Further investigation would be needed to identify which mental states might be useful to compute in a joint task scenario. If the type of mental state understanding necessary for joint action performance is one of those which is less cognitively demanding, then it might be more convincing that young children are capable of such a behaviour.

One other possibility is that mental state understanding is actually much less demanding and therefore much earlier developing than was thought for the first twenty years of Theory of Mind research. A recurrent criticism of false belief-type paradigms has been that they employ tasks that require a high level of both language and executive functions. Linguistic demands are placed on the child in order to understand the dialog of the stories presented to them and executive function is required in order to inhibit one's own belief (or other mental state) or knowledge of reality. Attempts have been made to reduce these demands, for example by designing non-verbal versions of the false belief task (Call & Tomasello, 1999) and simplifying the story scenarios (Baron-Cohen, Leslie & Frith, 1985). However, these have found similar developmental results to the original false belief task, leading to arguments that although language and executive functions may be intrinsically linked to the emergence of Theory of Mind (Milligan, Astington & Dack, 2007; Sabbagh, Xu, Carlson, Moses & Lee, 2006), it seems unlikely they are merely inhibiting its expression in false belief tasks.

However, one hugely innovative study from Onishi and Baillargeon (2005) dramatically revolutionised the direction of and outlook on Theory of Mind research, if not without controversy. This study used a violation of expectancy paradigm to see whether 15 month- old infants could identify a protagonist's inappropriate action based on a false belief. They were shown a video of an actor placing a piece of watermelon into a box and then later retrieving it. In the false belief condition, the watermelon moved from the original location to a different box whilst the actor was not looking. They found that infants looked longer when they saw the actor reach for the new (actual) location than the original location, suggesting that they expected the actor to reach to the (incorrect) location where she believed the object to be. Further research has even found that children seem to track the mental states of a protagonist who has no direct influence on the scene. Kovacs et al. (2010) presented 7- month-old infants with a video showing a ball rolling into view and then behind an occluder. In the false belief condition, a smurf-like character was present during this first stage and then moved off-screen. While the smurf was absent, the infant then saw the ball move out from behind the occluder and roll off-screen. When the smurf returned, the occluder was removed to reveal an empty space and infants' gaze duration to the location was measured. Results showed that infants looked longer in this condition than in a baseline where both infant and smurf believed the ball to be absent from behind the occluder. The same result was found in the condition where the infant had a false belief themselves. This suggests that infants at this age automatically track an agent's belief, even when they are not directly acting upon the scene and even when the protagonist's belief conflicts with the infant's.

These results are critically important for the debate surrounding children's joint action capabilities. If they are to be taken at face value, then they provide good evidence that infants can track mental states and therefore potentially process the intentions of a partner in a joint action scenario. However, there are still reasons to doubt whether the abilities demonstrated in these tasks are of the same quality as those required in a joint action task. Apperly and Butterfill (2009) argue that the type of belief tracking being measured in these types of 'implicit' tasks is qualitatively different to that being measured in traditional 'explicit' false belief tasks. They present a 'two-systems theory', whereby infants initially only have an implicit system for tracking mental states, which is efficient and automatic, but inflexible. They then develop a second system (at around 4 years) which is more cognitively demanding, but allows flexibility in mental state processing. This system runs in parallel to the earlier developing implicit system. Evidence for this theory comes from both adult and developmental literature. Firstly, research into adults shows that although mental state tracking is often automatic and undemanding on cognitive resources, in other circumstances it is effortful and prone to error. Apperly, Riggs, Simpson, Chiavarino and Samson (2006) found evidence that adults do not always process belief states automatically. When presented with scenarios in which a protagonist held a false belief about the location of an object and then asked an incidental question regarding this belief and also reality, participants made more errors for the belief than reality. This contrasted with a condition in which participants were explicitly asked to track the belief, suggesting that in some circumstances adults will not automatically track beliefs unless overtly instructed to do so. However, other work has also found evidence that adults sometimes do automatically track mental states. Samson, Apperly, Braithwaite and Andrews (2010) presented adults with a scene in which a number of dots was visible. An avatar was also present in the scene, which could see either the same number of dots as the participant, or a different number (due to some being hidden by a wall). Participants were slower to judge the number of dots they could see in the array when the avatar had a different perspective to them, suggesting that their self-perspective judgements were influenced by the differing perspective of the avatar. Thus, it is logical to argue that there is an implicit system which automatically and efficiently tracks mental states, but only in some circumstances. The explicit system, on the other hand, is cognitively demanding but is also flexible and transferable between different circumstances. Developmental studies are also compatible with this theory. Even children who fail explicit false belief tasks have been shown to betray an implicit understanding through looking behaviours. For example, Ruffman, Granham, Import and Connolly (2001) found that 3-year-olds would often give the incorrect response regarding the falsely believed location of an object, but simultaneously look to the correct location. Furthermore, they included a betting measure, where children were asked to bet counters based on how confident they were in their responses. Children consistently made confident bets based on their explicit answers, demonstrating their ignorance to the implicit knowledge betrayed through their eye gaze. This evidence fits with the theory that the implicit system is inaccessible, providing support for the possibility that there may be two separate systems involved in mental state tracking, one which is explicit and accessible and one which is not.

This provides a further possibility for joint action development. If it is sufficient to have an implicit understanding of mental states in order to perform joint actions, then even very young infants should theoretically have the capacity to do so. However, if it is necessary to have an explicit understanding of mental states then we should only expect joint action to occur later, coinciding with the age at which children explicit theory of mind tasks at around 4 years. Given the complexity of the scenarios outlined by Bratman (1992) and Butterfill and Sebanz (2011), it seems perhaps more likely that the latter is true. However, both possibilities require further investigation.

1.3 Early Development of Executive Functions

Now that the relevance of Theory of Mind in joint action development has been proposed, it is important to highlight one other higher level cognitive capacity that may play a further role. Executive function is the term used to describe a range of cognitive skills that develop across early childhood. There are variations in what type of skills are included in this definition, but they typically include inhibitory control, task shifting and working memory updating as a basis (Miyake, Friedman, Emerson, Witzi & Howerter, 2000). This set of abilities is hugely important for everyday behavioural control and as such, it is reasonable to assume that this would also apply to successfully coordinating actions with others. Further, there are specific reasons for thinking that certain elements of executive control might be highly relevant for such activities. The following paragraphs will outline how such elements develop in early childhood and how each might impact upon joint action performance.

Inhibitory control is a key component of Executive Function and one that is particularly salient when observing young children's behaviour. It is the term used to describe the ability to ignore irrelevant stimuli in order to focus attention on those that are relevant to the task in hand. This form of self-control can involve inhibiting external stimuli (for example, shutting out background classroom noise in order to focus on playing a game with a peer) or internal impulses (for example, suppressing the urge to steal another child's toy in order to avoid punishment from the teacher). As these examples illustrate, inhibitory control is extremely difficult for young children. Tasks that measure inhibitory control in children are usually designed to measure accuracy or response latencies to a desired stimulus when a competing stimulus is present. For example, 'go-nogo' tasks involve pressing a computer button when one type of stimulus appears on the screen but avoiding pressing the button when another type is present (e.g.the Bear/Dragon task, Kochanska, Murray, Jacques, Koenig & Vandergeest, 1996). Similarly, tasks can involve responding to one stimulus feature but ignoring a competing feature of the same stimulus (e.g. Simon task, Simon &Wolf, 1963). Other types of inhibitory control task involve measuring the amount of time a child can resist succumbing to an impulse to perform an action, such as eating a sweet if resisting eating it would result in a greater reward (Mischel, Shoda & Rodriguez, 1989) or inhibiting peeking whilst a gift is wrapped (Kochanska et al., 1996). Finally, some tasks involve controlling a motor impulse, usually by slowing down movements or reducing volume of speaking (e.g. Walk-a-Line Slowly, Whisper task (Kochanska et al, 1996)).

The role of inhibitory control in joint action participation may be more or less important depending on the type of actions that are required to be carried out by each participant. In joint activities where both participants are required to carry out identical actions, for example lifting a box together, there does not seem to be much cause for inhibiting any representation they might have of the other's intention or action (although inhibition could be necessary for behaviour control in general). In fact, in such scenarios, copying or mirroring the other's actions is likely to result in more efficient performance, therefore inhibition may actually be detrimental. However, joint actions frequently involve complementary actions to be carried out by each participant, which are different from one another or even opposite. For example, when performing a piece of music with a melody and a harmony, two singers must perform different actions in unison whilst simultaneously keeping sufficient track of what the other singer is doing to ensure coordination. In such scenarios, any tendency to mirror a partner's action would cause detrimental interference. Given existing evidence on mirror neurons (Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992) and joint action co-representation (Sebanz et al., 2003), it is clear that such interference does occur. It is thus highly likely that inhibitory control is required in order to overcome the interfering influence of a partner's actions in circumstances where complementary actions are necessary.

Task shifting or switching is another key component of Executive Functions, which involves switching from following one rule to following another during a task. This ability is typically measured using tasks featuring alternative rules about which stimulus to respond to and switching between rules either halfway through the task or on intermittent trials (e.g. Standard Dimensional Change Card Sort, Frye, Zelazo & Palfai, 1995).

Task switching may also play a role in joint action performance, particularly in tasks where participants are required to take turns rather than perform actions simultaneously. For example, if children play football together, they may take it in turns to be in goal. In order to perform one's own action/task role appropriately in both of these alternating roles (goalkeeper and goal scorer), it is necessary to switch between the two tasks, updating and avoiding interference from the alternative role each time there is a switch. Research using tasks where participants are required to play complementary roles shows that they make more errors when required to make two sequential 'Go' actions rather than a 'Nogo' followed by a 'Go' action, suggesting that they expect to take equal turns with their partner (Liepelt, Wenke, Fischer & Prinz, 2011). Greater switching ability in such tasks may aid performance, particularly when switching does not occur in a predictable pattern. This relationship between interference caused by a partner and switching capacity may also be bidirectional, in that influence from a partner may later aid participants to switch to that action themselves. For example, in the football example, participants may have an advantage at getting the ball past the goalkeeper if they have previously had experience of being the goalkeeper themselves. In other words, the experience of having represented or simulated a partner's action may help future performance on that action.

Working memory is the final domain of executive function that will be considered here. Working memory involves retaining relevant information in memory whilst carrying out a task and updating memory given new incoming information (see Carlson, 2010 for a variety of typical working memory tasks used with young children). Working memory has a clear implication for successful completion of any task where participants must follow a rule. In order to complete the task, the participant must consistently retain the task rule in mind in order to maintain or adjust her actions to achieve a goal. This applies equally if not even more so to joint actions. In these cases, both/all participants must retain their own task rule and inhibit influence from others. Thus, it follows that individuals with higher working memory capacity may be better able to complete a joint action, as a stronger memory representation for one's own rule may be advantageous in avoiding interference from other rules. However, it is vital that participants are selective in their memory representations, as stronger memory for all task rules may still result in considerable interference if inhibition is poor.

Returning to the original question of whether children have the pre-requisite skills to perform adult-like joint action, evidence in this domain suggests that children have great difficulty with all three of these Executive Function skills (Inhibitory Control, Task Switching and Working Memory) at the Pre-School age (see Carlson, 2010 for a review of performance on Executive Function tasks over development). All of these executive capacities are important to consider when studying joint action, due to the potential roles they may play in individuals' abilities to act jointly with a partner. However, it is possible and even likely that these capacities have only a mediating influence on joint action mechanisms, rather than being intrinsically linked to joint action cognition specifically. Thus it is important to ensure that any paradigms that are devised to measure joint action feature appropriate controls for the influence of executive capacities of children. For example, it is vital that poor performance on a joint action task cannot be explained simply by children being unable to process the executive requirements of the task, such as memory for instructions.

The previous two sections have highlighted the current status of research on children's early cognitive abilities in two domains: Theory of Mind and Executive Functions. In terms of Theory of Mind, it is unclear whether the types of abilities that children demonstrate very early in development are qualitatively sufficient to explain the apparently cooperative joint action behaviours that can be seen around 2 years of age. On the one hand, implicit tasks suggest some level of belief tracking even in the first year of life, which could arguably be adequate for joint action understanding. On the other hand, the requirements laid out by Bratman (1992) and Butterfill and Sebanz (2011) seem to suggest a more complex and explicit understanding of the goals and intentions of a partner. This highlights the necessity of further investigating the mechanisms underlying early joint action behaviours in order to determine what level of social cognitive processing is required in order to participate in these types of activities.

In terms of Executive Functions, existing evidence suggests that children have great difficulty with the types of behavioural control that might be necessary in joint activities. This is relevant if further investigation into joint action mechanisms is to be carried out, because it is important that children's skills are not underestimated due to the executive requirements of the task.

Now that various factors have been outlined that are likely to be involved in development of joint action, it is necessary to return to the question of whether the behaviours we see at an early age can be defined as genuine joint action in the same way as we can describe adult behaviours involving intention understanding (Bratman, 1992). In order to do this it is necessary to identify a way in which we can compare the behaviours we see in adults with those we see in children. One way of doing this is to take a phenomenon that is seen in adults which demonstrates a representation of a task partner and to see whether children also show this phenomenon. If they do so, this is evidence that children's joint action is comparable to adults in that they form mental representations (of mental states, actions or otherwise, see discussion of representation types in Chapters 1 and 3) of their partner during a task. Although this cannot directly solve the problem of whether children's joint action fulfils Bratman's criteria, it can provide a way of directly comparing adult and child joint action in terms of underlying mechanisms rather than overt behaviour. Once this has been established, the path can be opened up to more detailed investigation of the level of processing that underlies these mechanisms.

1.4 The Social Simon Effect

One phenomenon that has been meticulously investigated in the adult literature is the Social Simon Effect. This is a phenomenon whereby adult participants demonstrate interference from a partner performing complementary actions in a joint task, compared to an identical solo version. Social Simon tasks are based on modified versions of the Simon task (Simon & Wolf, 1963), which is typically used as a test of inhibitory control capacity. There are many versions of the Simon task, but the key component is the presence of a feature of the target stimulus that interferes with processing of the target feature. For example, participants may be asked to respond to the direction in which arrows presented on a computer screen are facing. However, they experience interference from the side of the screen on which the arrows are presented, so that left-facing arrows presented on the left side of the screen elicit faster responses than left arrows on the right side of the screen. Sebanz et al. (2003) found that when this task is performed as a Go-Nogo task, with participants only responding to one response option (e.g. left-facing arrows), this compatibility effect no longer occurs. However, when participants perform the same task as a pair, compatibility effects return. This is surprising, because in terms of each individual's task, the requirements are identical to the solo Go-Nogo version. Participants are still only required to process one response option and ignore the other. Sebanz and colleagues argued that the reason for these effects is that participants 'co-represent' when working with a partner on a task. In other words, simply having another person present and acting upon the alternative response option causes individuals to represent the other's task in a similar way to how they represent their own task. This is even more surprising given the fact that participants are not explicitly told to work together on the task, but rather they seem to automatically form social representations in a potentially interactive context.

If the co-representation account of the Social Simon Effect is true, then this phenomenon can be taken as evidence that individuals can form mental representations of a partner when performing a joint task. Therefore, if children also show Social Simon interference effects, then we can argue that they are capable of adult-like social representations to some degree. This can then provide insights into the behaviours that can be observed in young children, which up until now have been difficult to explain.

However, one potential problem with this reasoning is that there have been several criticisms of the Co-Representation Account of the Social Simon Effect. The main criticism comes from Dolk and colleagues, who argue that the Social Simon Effect is caused, not by social representations, but by referential coding of the alternative response option. In other words, the actions of a partner (i.e. pressing a button alongside presentation of certain stimuli) draw attention to the alternative spatial response and cause individuals to spatially code their own responses, which they do not do when this referent is not present in the solo Go-Nogo version of the task. Evidence for this account comes from experiments which have shown that the Social Simon Effect can be induced by non-social stimuli such as a metronome which beats at the same time as a partner would do in an original Social Simon task (Dolk, Hommel, Prinz & Liepelt, 2013). This clearly suggests that such effects are not social in nature and therefore demonstrating the phenomenon in children would not tell us anything about the involvement of social representation in joint action. However, there are reasons to doubt this alternative account and therefore maintain justification for implementing co-representation tasks with children.

Several studies cast doubt on the Referential Coding Account by demonstrating the pertinence of social manipulations in Social Simon paradigms. Atmaca, Sebanz and Knoblich (2011) asked participants to take part in a joint flanker task. The original

Eriksen flanker task (Eriksen & Eriksen, 1974) involves responding to a visual stimulus that is flanked on either side by irrelevant, potentially competing stimuli (e.g. HHCHH, with 'C' being the target). For example, in the individual binary choice version of the task, participants may be asked to respond to a central letter 'H' or 'K' with a right button press and a central letter 'C' or 'S' with a left button press. The general finding is that individuals respond more slowly when the letters flanking the central target letters are assigned to an incompatible response option than the target (i.e. HHCHH) than when the flankers are neutral (i.e. UUCUU) or assigned to the same response option (i.e. SSCSS). In the joint version of this task, Atmaca and colleagues asked participants to perform this task as a pair, so that one individual responded to 'H's and 'K's and the other responded to 'C's and 'S's. They found a significantly greater flanker effect in the joint condition than in an individual Go-Nogo condition (where one participant responds to only one response set, e.g. 'H' and 'K'), suggesting individuals represented their partner's task rule. More importantly, they also carried out these tasks under different social manipulations. Firstly, they repeated the task, but this time instructing participants that they were playing alongside another participant in a different room. In actual fact, there was no other participant in the task, but participants were led to believe they were taking part in a joint task. Results showed a similar difference between individual and joint conditions as in the original experiment, with participants showing a larger flanker effect in the joint condition than the individual. This result was only for participants who completed the individual task first, followed by the joint task. However, the authors point out that this is likely to be due to participants who carried out the joint task first continuing to represent a 'partner' even once they have been told they are playing alone. This is strong evidence that social factors are highly relevant for the Social Simon effect. Additionally, and even more convincingly, Atmaca et al. carried out a further experiment in which the intentionality of a partner was manipulated by introducing a mechanism that forced them to respond (a magnet that pulls the finger down to press a button) versus a condition where the partner was able to control their actions. Again, compatibility effects were stronger when partners' actions were intentional as opposed to forced. This not only suggests that social representations are necessary for Social Simon effects to occur, but specifically that intentionality understanding plays an important role.

Further evidence for the role of intentionality understanding in Social Simon effects comes from Tsai, Kuo, Hung and Tzeng (2008), who instructed participants to perform tasks either with a (believed) human partner in another room or with a computer programme. Results showed a compatibility effect in response times when participants believed they were playing alongside a human but not with a computer. Further, electrophysiological data showed the same selective compatibility effect in the human partner condition but not in the computer partner condition. Additionally, Humphreys and Bedford (2011) tested patients who had been shown to have deficits in Theory of Mind (on a non-verbal false belief task) on Social Simon task. They found no behavioural effect of compatibility either in patients with posterior parietal cortex lesions or with patients with frontal lesions, suggesting that Theory of Mind (and in this case belief-reasoning specifically) is necessary for participants to form a joint representation of a task and therefore suffer interference from another's task. All of these findings are highly relevant for the current investigation, as if co-representation involves intentionality understanding or even belief reasoning, then this should certainly satisfy Bratman's definition of joint action. Thus, there is a good basis for employing these types of tasks in an investigation of children's joint action abilities.

Having provided a justification for selecting this phenomenon to investigate children's joint action capabilities, it is necessary to outline some of the issues surrounding the Co-representation Account and specifically the nature of the representations that are proposed to form in such interactions. The original Co-representation Account suggested that participants form representations of the partner's task rule. In other words, participants form an overall representation of what the partner should do given a specific rule. However, Wenke, Atmaca, Höllander, Liepelt, Baess and Prinz (2011) argue that this may not be the only or the most important mechanism involved in Social Simon interference. They argue instead for an Actor Co-representation Account, which specifies that individuals in a joint scenario experience interference from a partner due to problems with self-other discrimination leading to confusion over whose turn it is to act. Thus, rather than forming a detailed representation of the two (or more) separate task rules, including what actions are required for each rule, they simply form representations of when it is each participant's turn to act. So, Participant A represents that it is her turn when she sees right-facing arrows, but it is Participant B's turn when she sees left-facing arrows. There is, however, no representation of *what* Participant B should do when she encounters her target stimuli. Likewise, it is possible that once the instructions have been processed by the participant and they understand that the task is split between the pair in a given way, they do not necessarily need to continue to monitor the other's responses throughout the task. In this way, Wenke and colleagues argue that Social Simon tasks may be less 'joint' than originally described, in that action planning and performance may not require iteration of joint mechanisms throughout the task.

Evidence for this account comes from a series of experiments that feature binary response options. In these experiments, each participant has not one, but two possible responses depending on the stimulus that is presented. This type of design was used to identify whether response conflict from another's task depends on the specific responses that are activated. If so, then this would provide evidence for the Task Co-Representation account. If conflict is not dependent on specific responses but only whether a partner responds or not, then this would be evidence for the Actor Co-Representation account. Three experiments in Wenke et al. (2011) failed to find any compatibility effects specific to a partner's stimulus-response mappings. For example, in Experiment 1, two participants sat facing one another with a display of three coloured discs in front of them. The central disc was the target and the two discs on either side were the irrelevant flankers. Participants each had a right and left-side response button which was assigned to a different coloured disc. For example, Participant A had to respond to blue (left button) and red (right button) discs and Participant B had to respond to yellow (left button) and green (right button) discs. Each participant encountered intra-individual trials, in which flanker discs were of the other colour assigned to said participant (for example, blue target and red flankers for Participant A) and inter-individual trials, in which flankers were of one of the colours assigned to their partner (for example, blue target and green flankers for Participant A). If participants represent a partner's specific stimulus-response mappings, they should show better performance in inter-individual trials when the colour of the flanker is assigned to the same response as the target. For example, if the target is blue (left button response from Participant A) then responses should be faster if flanked by yellow discs (left response Participant B) than green (right response Participant B). Alternatively, the opposite could be true if participants represent mappings from an allocentric perspective. However, Wenke et al. found no effect of compatibility in either direction in the inter-individual condition, suggesting that participants do not represent the exact stimulus-response mappings of their partner. However, they did find a general effect of inter- versus intra-individual conditions, whereby participants were faster when the target was flanked by 'own' colours than 'other' colours. This suggests that participants form representations about whose turn it is to act, rather than exactly what the other person's actions should be. Although the authors agree that care must be taken when making conclusions from null results, they argue that given the consistency of these null findings they should not be dismissed when drawing conclusions about representations in joint action.

Similarly, Atkinson, Simpson, Skarratt and Cole (2014) carried out a series of experiments which undermine the role of a specific action representation as opposed to task rule or goal representation. They looked at Inhibition of Return (IOR), which is the phenomenon that individuals take longer to respond to a location in trial N when they previously responded to that location in trial N-1. Welsh, Elliot, Anson, Dhillon, Weeks, Lyons and Chua (2005) had previously investigated this effect in a joint task setting and found that an individual's responses to trial N were also slower if their partner responded to the location in trial N-1, suggesting co-representation of the partner. Atkinson et al. (2014) followed on from this by varying the perceptual features of the response stimuli or alternatively the nature of the action towards the stimulus (i.e. pointing or reaching). They found that the former led to modulation of IOR effects, suggesting that the perceptual features of the stimuli are key to co-representation. However, varying the nature of the action had no modulating effect on IOR, suggesting that the action itself is not represented.

However, some researchers argue that individuals performing a joint task can represent the actions of their partner, rather than the overall task rule. Ondobaka, de Lange, Newman- Norlund, Wiemers and Bekkering (2012) found that participants' responses showed interference effects in a joint card-selection task based not only on compatibility with a partner's goal (i.e. congruent versus incongruent intention to select a high or low card) but also movement (i.e. congruent versus incongruent intention to make a left or right-hand response). They use this as evidence that individuals are capable of representing others' movements as well as their goals, depending on the circumstances (in this experiment, compatibility effects for movement were only found when goals were congruent).

The debate surrounding what is represented in co-representation is highly pertinent and worth further investigation. However, for the sake of the current research question, it is not yet necessary to decide which of the accounts is correct. Rather, it provides an interesting further question for future study in children and something to be conscious of whilst designing paradigms for use in early development. Whether children form representations of specific stimulus-response mappings or expectations of turn-taking may moderate the conclusions that are made about the extent to which joint mechanism are activated throughout a joint task. However, here we want to investigate whether children actually form representations during joint tasks at all, regardless of the nature of such representations.

2. *Summary*

This General Introduction has outlined a gap in literature on early joint action abilities in children. Although research has shown that children can participate in activities with a partner, it is unclear the extent to which they have an understanding of the joint nature of the tasks they are taking part in and what the mechanisms are that underlie these behaviours. This is further complicated by a difference in opinion amongst researchers about what constitutes a genuine joint action, particularly in terms of whether individuals in a joint scenario require intention understanding in order to show a true comprehension of the task (Bratman, 1992). Although some researchers would argue that young children are capable of such social understanding (Onishi & Baillargeon, 2005) and therefore have the capacity to perform genuine joint action (Carpenter, 2009) others would argue that we need to redefine what has been termed joint action in early development in order to account for limitations in cognitive ability at this age (Apperly & Butterfill, 2009). Such limitations may also apply to non-social cognitive skills, such as Executive Function capacity. In order to investigate this directly, this thesis takes the approach of selecting an adult phenomenon that tells us about the representations formed during joint activities and applying this to children. If children perform as adults do, and show interference effects that signify automatic representation of a partner when performing a task together, then we can argue that children are capable of forming social representations in joint action that are like adults'. Additionally, given the evidence that such effects in adults are dependent on intentionality understanding, similar effects in children would be a step towards fulfilling Bratman's (1992) criteria for joint action, even at an early age.

CHAPTER 2: EXPERIMENTS 1-3

THE DEVELOPMENT OF CO-REPRESENTATION EFFECTS IN A JOINT TASK: DO CHILDREN REPRESENT A CO-ACTOR?

Presented in its published format

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CHAPTER 3: EXPERIMENT 4

WHAT FORM DO JOINT REPRESENTATIONS TAKE? AN INVESTIGATION OF THE DEVELOPMENT OF 'WE-REPRESENTATIONS'

1. Introduction

The Social Simon Effect is a well-established phenomenon in adults and co-representation is a well-supported interpretation of this phenomenon. However, controversy still surrounds how these representations of a task partner should be described and explained. As was discussed in the General Introduction to this thesis, questions have been raised as to whether the nature of effects are social or not (Dolk et al., 2013), whether they involve representations of the partner's actions or task and what is the role of expectations of turn- taking (Wenke et al., 2011). One interesting point of discussion is whether the representations involved in a joint task are actually qualitatively different than the addition of a self-representation and a representation of the other person. In other words, perhaps the nature of a joint task representation actually involves a single representation of what 'we' are doing, rather than two representations of what 'I' and 'you' are doing which may interfere with one another. The following will outline several theories that touch on the idea that there may be a stage of shared representations in development, or in fact that such representations are present throughout development and are only activated during interactive activities. Each of these theories gives a different prediction for children's development of such representations. This will be discussed with a view to introducing the current study, which was designed to investigate the nature of representations within the age group at which co- representation was found in Chapter 2 (4-5 years).

Vygotsky (1978)'s classic theory of the Zone of Proximal Development specifies that children only learn about the world through interactions with others, who aid children in gaining knowledge that would be unattainable on their own. He argues that children first take part in actions with a more able partner and then internalise these abilities so that they can become part of the child's individual repertoire. For example, if a child attempts to reach for an object this is likely to result in a parent interpreting this as a communicative gesture and thus passing the object to the child. This starts out as a reflex action in the child, but is gradually internalised so that the child understands the communicative impact of the action it performed. Hence, a pointing gesture evolves and can be used by the child to indirectly obtain items via a caregiver. As such, children gain mastery of mediating processes such as tool and sign use that develop from more basic processes and are shaped through social interaction. This theory highlights the importance of a stage of interaction which leads to later mastery of actions by oneself.

Tomasello and colleagues have built on this idea, forming their theory of shared intentionality (Tomasello, Carpenter, Call, Behne & Moll, 2005; Tomasello & Rakoczy, 2003). They argue that children initially have certain individualistic cognitive skills, such as gaze following, social manipulation, group activity and social learning (Tomasello & Carpenter, 2007), which are then built upon through the development of shared intentionality at around 1-2 years old. Thus, skills that start out as individual in nature become understood as shared with others. For example, group activities below the age of 1-2 years are similar to those displayed by non-human primates, in that behaviours can be co-ordinated in a group (such as group hunting in chimpanzees) but do not involve understanding of the shared goals of the group. Instead, co-ordination occurs due to individuals reacting to the behaviour of others with the individual intention of achieving a personal goal. It is only once shared intentionality develops that children understand that the group activity involves all participants sharing a goal or intention (Hamann et al., 2012). Tomasello and colleagues argue that this is what makes humans different from other species and thus able to develop such sophisticated cultures and societies.

Other theories have not only underlined the importance of dyadic or collective interactions for development, but have also specified the direction of learning between individuals. Simulation Theory, for example, assumes that understanding of others' mental states comes from understanding of one's own mind, which is then projected onto the other person (Gordon, 1986). Individuals use external information about the experience of others to generate a simulation of what they themselves would think or feel if they were in that situation. Thus, it is knowledge of oneself that allows understanding of others. This fits with extensive evidence that both children and adults make egocentric errors in perspective-taking (Piaget & Inhelder, 1956; Borke, 1975; Keysar, Lin & Barr, 2003), as it seems reasonable that if individuals apply knowledge of themselves to others, they are likely to make errors if others have different knowledge or experience than themselves.

Specifically, Meltzoff (2007) outlines a 'like me' framework for simulation. He argues that understanding of self-other similarities is the foundation of social cognition. Thus, children initially experience a close relation between action and perception, through imitative acts where the child's own action matches the action they perceive in another individual (Meltzoff & Moore, 1977). They then experience the mental states that are associated with the action they are performing, such as happiness when imitating a smile. Only then can they map these personal experiences onto the other person, to understand that when they are smiling, they are also likely to be experiencing happiness 'like me'. Importantly, he also argues that this relation is bi-directional, so that while children can estimate others' mental states by comparing their external actions to the child's own actions, they can also learn about the consequences of to-be-performed actions by observing others perform them first. It is unclear from this theory whether the starting point, when action and perception overlap, involves self-other distinction or whether perception and production of action are united in a single representation. Either way, individual representations of self and other are achieved at some point in development, which enables mapping from one to the other.

A further theory of social cognition that starkly contrasts with Simulation and 'like me' theories is Prinz's (2012) Open Minds theory. He, instead, proposes a 'like-you' framework, whereby individuals develop understanding of themselves only through understanding of others. He argues that embodied mirroring processes allow children to see themselves from the outside (much like physical mirrors) and thus understand their own actions from an external perspective. For example, a parent imitating a child's facial expressions provides the child with an image of what their expressions look like from the outside, which they can then associate with the physical sensations of motor processes they experience internally. Thus, children first understand others as agents in control of their actions and then apply that knowledge to their own self when they see their actions mirrored in others.

Although these two theories differ in terms of the directionality of learning between self and other, they both agree that representations of self and other are separate, and as such can develop at different times, one leading on from the other. However, there are reasons to think that interactive activities may involve qualitatively different representations and mechanisms from those involved in understanding 'self' and 'other' in isolation. Such joint activities may provide us with additional information or opportunities for learning than non-interactive activities. For example, some research on joint decision-making suggests that problem- solving efforts are more productive in a group than as an individual, beyond merely an additive value. Bahrami, Olsen, Latham, Roepstorff, Rees and Frith (2010) asked pairs of participants to make individual perceptual judgements about visual information on a screen.

If participants' responses did not match within a pair, they were required to discuss their response and make a joint decision. They found that pairs were more accurate when working together than the best participant of the pair when working alone (although only when partners were permitted to communicate their confidence in their answers to one another). Additionally, 3-6 year-old children have been shown to perform better on a toy-building task when they had previously completed the task in a cooperative, turn-taking manner with the Experimenter than when they had previously completed the task with each individual completing all steps alone (Sommerville & Hammond, 2007). These types of studies provide evidence that there are differences and often benefits of working in an interaction over and above working alone, for both adults and children.

Interactionist theories have highlighted the importance of considering the qualities of social interactions between individuals rather than studying individual processing of social scenarios in isolation. Gallagher (2011) argues for a strict form of Interactionism which focuses on the low level embodied processes that occur between actors in an interaction, such as those based on the Mirror Neuron System (Di Pellegrino et al., 1992). Gallagher argues that understanding others' mental states does not involve any kind of mentalizing processes, as suggested by traditional accounts (e.g. Simulation Theory: Gordon, 1986; Theory Theory: Gopnik & Meltzoff, 1997). Rather, he argues that mental state understanding involves extracting information from the embodied processes involved in interactions (such as entrained movements where actors automatically synchronise their movements with one another) which provide external cues about emotions and intentions. Importantly, he states that these shared processes are unique to interactions and do not exist in non-interactive situations. Thus, the whole of all participants in an interaction is other than the sum of their parts (Koffka, 1935). Michael (2011) takes a more inclusive standpoint, arguing for a version of interactionism that does not exclude the presence of mentalizing abilities alongside embodied processes. He argues that embodied processes can actually contribute to mentalizing about another's mental states, in that an individual can notice the responses they make in an interaction, based on low-level embodied mechanisms and interpret them using higher level mechanisms in order to understand the other person through the qualities of that interaction. In this way, it is the product of the interaction that provides the information necessary to read the mind of a partner.

Gallotti and Frith (2013) recently drew on these existing approaches to specify a modified version of interactionist theories of social cognition. They argue for what they term a 'we- mode', into which individuals enter when they are taking part in an interaction. As such, certain mechanisms are present in the individual that are only activated in circumstances where there is social interaction or even merely the suggestion of potential social interaction. Evidence for this 'we-mode' comes from studies showing co-representation of a partner in joint tasks, even when individuals are not specifically instructed to take note of their partner's task or actions (Sebanz et al., 2003). More specifically, a phenomenon known as the GROOP effect demonstrates the importance of group context on actors' imitative behaviours. When a single actor was asked to imitate the finger-tapping movements of two hands on a screen, mimicry increased when the hands on the screen belonged to a single individual rather than from two individuals (even though participants always saw one right and one left hand. This was also the case for two participants imitating hands from two individuals (optimized mimicry) as opposed to from one individual, showing that the group context in which actors are required to act affects how they process task stimuli in imitation (Tsai, Sebanz & Knoblich, 2011). This suggests that when acting in a group, individuals make representations of the task at the group level, rather than at the individual level. In other words, I represent what 'we' are doing, rather than simply what 'I' am doing.

This last theory of 'we' representations brings up a number of developmental questions. Several of the theories of mindreading highlighted here have involved some specification of an overlap in self versus other representations at some point in development. Meltzoff's 'like me' framework stipulates an initial stage of imitation where perception and production of action overlap. Although it is not clear what kind of representation or representations this involves, it is possible that this could involve something similar to the 'we' representations described by Gallotti and Frith (2013). If this is the case, this theory would imply a development from 'we-mode' to self-other distinction later in development. This would fit with evidence that children only develop self-other distinction around the second year of life (Amsterdam, 1972) and that self-other distinction is related to cooperative abilities in joint action tasks (Brownell & Carriger, 1990). Similarly, Prinz's (2013) theory also argues for a stage of action-perception overlap, caused by embodied mirroring processes that occur during interactions. This then leads to self-other distinction, but in this case the direction of learning goes in the opposite direction, from 'other' to 'self. However, both of these theories put less emphasis on this initial stage of self-other overlap as being a way of forming joint representations to aid cooperation and more on its role as a route to learning about oneself or another. Thus, it is unclear whether this initial stage of overlap would fall into the 'we-mode' category as outlined by Gallotti and Frith (2013).

The Interactionist arguments outlined above, however, provide a clearer example of the relevance and distinctiveness of joint representations, explicitly stating that they are unique to interactions rather than being present solely in the mind of the individual. However, these theories do not make predictions about how such representations might change over development. Given that embodied mirroring processes can be seen in even very young children (Meltzoff & Moore, 1977), one might expect that the types of joint mechanisms described by stricter Interactionists (Gallagher, 2011) are present and stable throughout development. However, if we take Michael's (2011) version of Interactionism which includes a role of higher level processes, we should expect more of a developmental curve depending on general cognitive capacity.

The experiments from Chapter 2 (Milward, Kita & Apperly, 2014) demonstrate that co-representation of a partner occurs by at least 4 years old. However, it is unclear whether such representations fit the description of 'we' representations as outlined by Gallotti and Frith (2013) or whether children are actually forming two separate representations of 'self' and 'other' which interfere with one another but are not encoded at a group level. Different theories make different predictions about the nature of these representations. Simulation Theories and the 'like me' framework do not make explicit predictions about whether the initial stages of interactions (i.e. when action perception and production overlap through imitation or mirror processes) consist of single or dual representations. Investigating this would help to describe these stages in more detail. Interactionist theories that only allow for low-level embodied processes would predict qualitatively different mechanisms in interactive contexts throughout development, as long as mirror processes are established.

Michael's (2011) modified version of Interactionism would predict some change in type of representation over childhood, due to the role of higher level mechanisms that use embodied processes as input for mindreading. This could perhaps see a change to dual representations of 'self' and 'other' when such higher level mechanisms are mediating interactions, in contrast to single 'we-mode' representations when only low level mechanisms are operating. In theory, these could both continue into development, so that even adults with greater cognitive capacity may enter into 'we-mode' in certain circumstances. Such a prediction would be in line with a two-systems account of Theory of Mind (Apperly & Butterfill, 2009), by which both low and high level mindreading systems are in place from the early years and into adulthood.

The current study investigated whether 4-5 year-olds's co-representation of a task partner involves 'we' representations or separate 'self' and 'other' representations. The method built on the paradigm employed in Experiment 3 of Chapter 2, which featured a computerised version of the Go-Nogo Bear Duck task where children either followed the same task rule as their partner (Same condition) or the opposite rule (Different condition). Additionally, it included the switching element that was used in Experiment 2 to control for confusion accounts of Task effects. Thus, each participant took part in a Pre-switch phase followed by a Post-switch phase in which they were required to switch to the alternative task rule. In Experiment 2 a switch cost was found in the Same condition but not in the Different condition, suggesting that forming a representation of one's partner's task in the Pre-switch phase gives participants an advantage when they are then asked to switch to that rule. The present experiment also introduced a new factor in order to explore representation types in this paradigm. This was the Experimenter Presence condition in which the Experimenter, playing the role of partner to the child, either stayed for the whole game or left after the switch had been introduced. The logic behind this manipulation was that if children represented the task at a group level in the Pre-switch phase, then the departure of their partner after the switch should eliminate any advantage of the Different condition. In other words if the partner leaves, the task can no longer be represented at the group level (i.e. 'we') and therefore should incur a cost of switching to the individual level. However, if the Experimenter stays, the results of Experiment 2 should be replicated (i.e. switch cost in the Same condition but not in the Different condition). By including the Switch condition in the computerised paradigm, we also attempted to replicate the findings of Experiment 2 with a new paradigm.

2. Method

2.1 Participants

Participants were 106 4-5 year-olds (Mean age = 58.08 months, Range = 51-65 months) from two Primary schools in the Birmingham area. Two participants were excluded due to experimenter error and five for never responding on any trial. Remaining participants (*N* = 99) participated in one of 4 conditions: Same Stay (*n* = 26); Same Leave (*n* = 26); Different Stay (*n* = 24); or Different Leave (*n* = 23).

2.2 Stimuli

Stimuli were identical to those used in Experiment 3 with the exception of a slight change to the EPrime programme design. For this experiment, the game consisted of 2 blocks of 12 trials. Each block was separated by a blank screen, during which the new instructions were presented. An Observer was also present during this experiment, who remained seated behind the computer screen for the entire procedure.

2.3 Design and Procedure

Children were brought to the testing area and introduced to the Observer as follows, ‘This is Julia/Leila, she’s just going to help me load up some of the games.’ The practice stages followed, which were identical to Experiment 3, so that all children carried out a solo and then a joint practice. The Experimenter then said, ‘Ok, let’s have a go at the real one now’, after which the Observer loaded up the first block of trials on the laptop. The animal assigned to the child was counterbalanced across conditions, so that half had to spot the Duck first and half the Bear. All examples given here are for children who were asked to spot the Duck in Block 1. While the game was loading, the Experimenter asked children a comprehension question, ‘Can you just remind me when you had to press your button? Was it when you saw the Duck or the Bear?’ Responses were recorded. If children answered incorrectly, the Experimenter corrected them, ‘No, do you remember? You have to press the button when you see the Duck’ All children then carried out Block 1 according to whether they had been assigned to a ‘Same’ or ‘Different’ condition. Children in the Same condition were required to press their button on presentation of the same animal as the Experimenter, whereas those in the Different condition had to press it for the opposite animal. Instructions were identical to Experiment 3 for this block. On completion of the first block, the Experimenter gave neutral praise and then asked a second, identical, comprehension question and recorded responses, giving corrections where necessary. She then presented the following instructions ‘Now we are going to do something different. This time, your job is to spot the Bear. So, whenever you see the Bear, you should press your button as fast as you can. But, if you see the Duck, you shouldn’t press your button, you just stay still and don’t press anything at all. Do you think you can do that?’ The remainder of the instructions were dependent on whether the participant was in the ‘Stay’ or ‘Leave’ condition. For the Stay condition, the Experimenter said, ‘Ok great, let’s have a go at that one then’. For the Leave condition, the Experimenter said, ‘Ok great. I just have to pop outside for a moment, do you think you can carry on without me? I’ll be back soon.’ The Experimenter then left the room. For both Stay and Leave conditions, the Observer loaded up the next block of trials on the laptop. For the Leave condition, she did this once the Experimenter had left the room. Participants then completed the second block of trials with the new rule, so that each child completed a Pre-switch and a Post-switch block. Upon completion, the Experimenter returned to the room, gave neutral praise and then asked a final comprehension question.

3. Results and Discussion

Results were analysed based on Score (overall proportion correct) and Response Times. Children’s accuracy (see Table 3.1) was above chance (50%) for all conditions (Same Stay: Pre-switch $t(25) = 8.50$, $p < .001$, post-switch $t(25) = 12.11$, $p < .001$; Same Leave: Pre-switch $t(25) = 6.54$, $p < .001$, post-switch $t(25) = 6.08$, $p < .001$; Different Stay: Pre-switch $t(23) = 7.45$, $p < .001$, post-switch $t(23) = 6.07$, $p < .001$; Different Leave: Pre-switch $t(22) = 4.99$, $p < .001$, post-switch $t(22) = 4.14$, $p < .001$). Values were submitted to a mixed effect logistic regression, with Participant as a random effect, Task (Same or Different) and Experimenter Presence (Stay or Leave) as the between- participant fixed effects and Switch (Pre- or Post-switch) as the within-participant fixed effects (Intercept = 1.48 (*SE* = .38), estimated standard deviations for Participants = .74), which found no effect of Task (β = .10, *SE* β = .55, *p* = .85), Experimenter Presence (β = .23, *SE* β = .55, *p* = .68, or Switch (β = -.22, *SE* β = .21, *p* = .31) and no interactions (Task*Experimenter Presence: β = -.67, *SE* β = .79, *p* = .38; Task*Switch: β =.15, *SE* β = .31, *p* = .64; Experimenter Presence*Switch: β = -.*10*, *SE* β = .31, *p* = .73; Task*Experimenter Presence*Switch: β =.44, *SE* β = .43, *p* =

Table 3.1.

Mean (SD) *proportion for correct responses on Same/Different and Stay/Leave Task conditions for Pre- and Post-switch blocks.*

	Pre-switch	Post-switch
Same Stay	.78 *(.17)*	.82 *(.13)*
Same Leave	.75 *(.19)*	.76 *(.22)*
Different Stay	.74 *(.16)*	.70 *(.16)*
Different Leave	.72 *(.21)*	.69 *(.22)*

.30). Planned pairwise comparisons showed no effect of Task for pre-switch trials only (β = .12, *SE* β = .23, *p* = .60).

Response times for correct (go-) responses were analysed. Response times were removed if they were below 250ms. Response times were recorded within a 1000ms window. Values (see Table 3.2) were submitted to a 2 (Same vs. Different) x 2 (Stay vs. Leave) x 2 (Pre- vs. Post-switch) mixed ANOVA, in order to identify whether the predicted Task*Experimenter Presence*Switch interaction was present. This found no significant effect of Task (F(1, 91) = 2.00, p = .16, partial eta squared = .03), Experimenter Presence(F(1, 91) = 1.70, p = .20, partial eta squared = .02) or Switch (F(1, 91) = 2.16, p =.15, partial eta squared = .03).There were no significant interactions (Task*Experimenter Presence: F(1, 91) = .00, p = .97, partial eta squared = .00; Task*Switch: F(1, 91) = .06, p = .80, partial eta squared = .00; Experimenter Presence*Switch: F(1, 91) =.11, p = .75, partial eta squared = .00; Task*Experimenter Presence*Switch: F(1, 91) = .01, p = .94, partial eta squared = .00). Planned pairwise comparisons showed were carried out in order to identify whether the effect of task (Same versus Different) from Experiments 1 and 2 could be replicated in the pre-switch phase of this experiment. However, there was no effect of Task for pre-switch trials

Table 3.2.

Mean (SD) *response times (ms) for correct responses on Same/Different and Stay/Leave Task conditions for Pre- and Post-switch blocks.*

	Pre-switch	Post-switch
Same Stay	772.34 *(133.70)*	759.62 *(112.07)*
Same Leave	749.63 *(119.08)*	742.84 *(116.29)*
Different Stay	804.75 *(138.89)*	780.13 *(124.31)*
Different Leave	753.70 *(135.64)*	748.55 *(119.16)*

only (t (88) = 1.52, p = .13, Cohen's D = .32).

4. General Discussion

This experiment failed to find the Task*Switch*Experimenter Presence interaction that was predicted if children form 'we' representations of the task at a group level. However, the fact that this experiment also failed to find a Task*Switch interaction or an effect of Task for pre-switch trials makes it impossible to form conclusions based on the absence of this interaction. If the aforementioned effects had been found, then the absence of an interaction might have indicated that joint task representations at this age are dual in nature, in that they consist of separate representations of self and other. If this were true, we would expect to find a switch cost in the Same but not the Different condition regardless of whether the Experimenter was present in the post-switch phase. In other words, having represented 'me' versus 'you' in the pre-switch phase, I can still benefit from having previously represented 'you' when I then have to switch to 'your' task in the post-switch phase. This would not be the case if I had represented 'our' task in the pre-switch phase, as the absence of of my partner means the post-switch phase is represented as a totally different, solo task. However, this experiment's failure to replicate effects of co-representation makes it impossible to draw conclusions about such representations.

It is possible that this is simply due to an insuffiency in sensitivity of the task to these effects. Given that the Switch condition has never been implemented with the computerised version of the Bear Duck task, this is certainly possible. Additionally, in the current experiment fewer trials were administered (two blocks of 12 trials rather than three blocks in Experiment 3). Given that both experiments had a similar sample size (Experiment 3, N = 94; Experiment 4, N = 99) it is possible that the current experiment lacked the power of Experiment 3.

Another likely possiblity is that a difference in methodology could have hidden effects that were present in this experiment. Whereas in Milward et al. (2014) responses were recorded even after the stimulus had disappeared from the screen (after 1000ms), an error in the current study resulted in these late responses only being recorded for pre-switch trials. Therefore, for all participants, only responses that were made while the stimulus was on the screen, within a 1000ms time frame, could be analysed in the overall ANOVA. Given the distribution of scores, it is highly likely that responses were made after this cut-off point. This is clear from looking at pre-switch responses including this window from 1000-2000ms (see Table 3.3). 74 out of 103 participants (4 participants were added to this analysis who had previously been excluded for not responding in the 1000ms time frame) made at least one response within this later time period, with a total of 82 responses being made overall. Correct responses were re-analysed including correct responses made after 1000ms in an independent samples t-test. However, even with these data there was still no significant effect of Task Type (t (96) = -1.31, p = .19). Likewise, no significant main effect of Task Type was found for accuracy when including this additional data (t (97) = -1.64, p = .11). Nonetheless, it is

Table 3.3.

Mean (SD) accuracy and response times (ms) for correct responses on Same/Different and Stay/Leave Task conditions for the Pre-switch block, including 1000-2000ms time window.

	Accuracy	Response Times
Same Stay	.89 *(.18)*	882.64 *(190.72)*
Same Leave	.84 *(.18)*	861.87 *(204.615)*
Different Stay	.91 *(.13)*	975.23 *(212.48)*
Different Leave	.86 *(.24)*	930.66 *(216.00)*

possible that had these data also been available for the post-switch trials, there might have been an interaction with Experimenter Presence. Therefore, it would be fruitful to repeat this experiment with a longer response recording time frame in order to identify whether any effects were hidden in the current data.

Another improvement that could be made to this task in the future is to increase the sensitivity of the dependent measures. Although Response Times have been shown to be informative in this task (Milward et al., 2014), this is a measure that can cause problems when testing a young population due to the variation in their responses and easy distractability. A more sensitive measure might help to overcome these problems. From observing children whilst participating in the task, one can see that they often make hand movements towards the response buttons but manage to resist their impulse before they actually press the button. The fact that this information was not recorded means that a lot of informative data was lost. Further experiments that could record these 'half-responses' would be very valuable, particularly for this type of task that produces relatively small effect sizes. 'Half-responses' could be measured using video recording or motion tracking technology.

A further possibility is that the 'Experimenter Presence' manipulation is not appropriate for testing the presence of 'we' representations. It is possible that once a certain type of task representation has been formed, it does not change as long as the task continues. For example, if participants form a 'we' representation on hearing the task rules, but do not then continue to monitor the responses of their partner, they may not be affected by their partner leaving (Wenke et al., 2011). Given the evidence that individuals can represent a partner's task even when they are not in the same room (Atmaca et al., 2011; Tsai et al., 2008), it is reasonable to argue that a representation involving the other person could remain active even when they are no longer present. One solution to this problem would be to modify an existing paradigm that has been used to investigate 'we' representations in adults, such as the GROOP effect (Tsai et al., 2011), and modify this for children. Although this task has the disadvantage that it has not yet been used with children and therefore may take some time to develop, it has the advantage that it has been shown to be effective in measuring representation type, which the current paradigm has not.

Although this failure to replicate findings from Milward et al. (2014) should not be ignored, they should also not necessarily cast doubt on the three previous experiments that have found solid effects in line with the Co-representation Account. For reasons stated above, there is a high possibility that methodological differences may have made effects more difficult to uncover in the current experiment. Further, the question of the nature of representations is still highly relevant to current research and efforts should be made to investigate this further. One possibility would be to run this experiment again, but making alterations based on the issues referred to above.

CHAPTER 4: STUDY 5

INDIVIDUAL DIFFERENCES IN CHILDREN'S CO- REPRESENTATION. THE ROLE OF THEORY OF MIND, INHIBITORY CONTROL AND WORKING MEMORY

1. Introduction

Results from the Chapter 2 (Experiments 1-3) provide evidence for a possible cut-off point in development where co-representation effects do not occur. As already discussed, this cut-off point needs further investigation in order to ensure that the lower-bound cannot be pushed down using different tasks. However, it is intriguing to consider the possibility that this is a set stage during which co-representation develops. If this is the case, it is pertinent to ask what other cognitive skills may be involved in this onset, particularly as this period (4-5 years) has been shown to be an important stage of development for various abilities. This chapter will discuss the potential role of three cognitive skills on co-representation, all of which show considerable development at around this age. The skills are Theory of Mind, Inhibitory Control and Working Memory, each of which will be addressed in a separate section. This is with a view to presenting an individual differences study to measure these roles empirically.

1.1. Theory of Mind

As outlined in the General Introduction, Theory of Mind undergoes a major stage of development around the age of 4 years, when children are able to pass false belief tasks (Wimmer & Perner, 1983). The fact that this age coincides with the age at which co-representation has been found in this thesis is worth further investigation. Co-representation researchers have already discussed the involvement of mental state understanding for co- representation and have carried out studies that have provided some support for a link between the two. Humphreys and Bedford (2011) found that patients with lesions associated with Theory of Mind deficits did not show spatial compatibility effects in a joint Simon task whereas they did so in an individual version. These patients showed deficits on measures of false belief understanding, suggesting not only that Theory of Mind but specifically belief comprehension is necessary for co-representation.

Other studies looking at mental state understanding and the Social Simon effect have focussed on intention understanding as a pre-requisite for co-representation. Tsai et al. (2008) found behavioural and electrophysiological effects of compatibility when participants were told they were performing a Simon task with a human partner, but not when told they were playing alongside a computer. Likewise, using a joint Flanker task, Atmaca et al. (2011) found that participants only showed compatibility effects in a joint task when their partner's actions were intentional rather than when they were controlled by a magnet. Although these tasks suggest a role of mental states in co- representation, they do not specify anything as arguably complicated as belief processing.

Intentions are plans that an individual makes to perform a certain action in order to achieve a goal. Intention understanding has been argued to develop much earlier than belief understanding, at around 1-2 years old (Tomasello et al., 2005). Tomasello and colleagues argue that at this age infants can understand that an individual is animate and their actions are self-produced (Woodward, 1998), that individuals have goals and that they can choose an action plan accordingly (Gergely, Bekkering & Kiraly, 2002). It is these three capacities that enable infants to understand intentions, the final stage of which was shown at 14 months by Gergely et al. (2002). In fact, Bratman's definition of joint action specifically determines intention understanding as a pre-requisite for genuine comprehension. Therefore, if intention understanding develops so early, it cannot explain why co-representation has been found to develop only around 4 years. Either intentionality is not the only requirement for co- representation, or co-representation should be found at an earlier age.

However, one possibility is that understanding of an individual's intentions is not enough in a joint action context. Instead, there may need to be some shared representation of joint goals or intentions. Tomasello et al. (2005) argue that shared intentionality is what separates humans from other species. This involves not only understanding another individual's goals and intentions, but understanding them in context alongside one's own goals and intentions and co-ordinating with one another to build a joint action plan to achieve a joint goal. However, Tomasello and colleagues argue that this shared intentionality is not an additional step in development, but rather it develops in stages alongside development of individual intention understanding via humans' intrinsic motivation to share psychological states. This means that when infants develop the ability to understand another person's choice of plan in the pursuit of a goal, they also develop the ability to collaborate interactively with that person and understand joint goals and intentions. Thus, this does not help to explain the difference in developmental onset of intention understanding and co-representation.

One further reason for doubting the role of Theory of Mind as a developmental pre-requisite for co-representation is that implicit tasks have shown belief-tracking capacity from as early as 7 months (Onishi & Baillargeon, 2005; see General Introduction for literature review). Given that the Bear Duck tasks used in this thesis do not involve any explicit instructions to track the partner's mental states or even actions, their requirements seem more similar to the implicit violation of expectancy paradigms that have found early belief tracking than to the false belief paradigms that have found understanding at around 4 years.

Thus, various sources suggest the level of mental state understanding that has been suggested to be necessary for co-representation is already present much earlier than the age at which the studies presented here have found such effects. However, the results from these studies remain controversial. Many researchers would argue that this evidence of early Theory of Mind could be explained through simpler mechanisms than mental state representation (see Low & Perner, 2012). Likewise, it has been argued that the behaviours seen in implicit belief tracking paradigms demonstrate a different type of cognitive ability to that which is elicited by explicit false belief paradigms (Apperly & Butterfill, 2009). Further, research has not yet outlined how these early 'implicit' behaviours might be related to other cognitive skills, such as language and executive functions. In contrast, explicit paradigms have been extensively investigated in relation to such skills (Milligan et al., 2007; Sabbagh et al., 2006) providing a basis for making predictions about how they might relate to co- representation. Given these arguments alongside existing evidence for the role of belief reasoning in co-representation (Humphreys & Bedford, 2011) and the age at which co-representation has been suggested to develop, the rational next step is to investigate the role of mindreading and other cognitive skills that develop around this age.

1.2 Inhibitory Control

Inhibitory control clearly plays an important role in the Simon task, both in individual and joint versions. The original Simon task is often used as a measure of inhibitory control, with participants with greater capacity being better able to resist the interfering spatial stimulus- response link and therefore make fewer errors and faster responses. Likewise, in joint versions of the task, the presence of the other person causes this interference to return (arguably due to co-representation) and thus inhibition is required again to resist responding to it. In the Bear Duck tasks employed here, both tasks involve playing alongside a partner.

However, the Same task should not require inhibiting the other person's task/action (although inhibition is required in general to complete the task), because there is no competition between participants' responses. If anything, inhibiting one's partner should slow responses. In contrast, the Different task should require inhibition to resist interference from the partner's (different) task. Therefore, it is possible that individual differences in performance on the Different task could be modulated, not only by the level to which a person co- represents a partner, but by their capacity for inhibiting the representation of the other person in order to avoid interference.

1.3 Working Memory

Working memory is also necessary for both individual and joint Simon tasks. Participants must remember their task rule and maintain this whilst completing the task. If they are to co-represent, they also need to remember the other person's task rule, particularly in version of the task where participants cannot see each other. This is likely to be highly important in real world joint action scenarios, which often require adaptation of actions in order to co-ordinate with a partner. In order to do this it is necessary to understand the partner's role in the task. It is vital to further investigate the role of Working Memory in the current paradigm, given the potential issue of memory for task rules that have been discussed in previous chapters. One possible explanation for the task effects in Experiments 1 and 2 was that participants benefitted from hearing instructions twice in the Same condition as opposed to the Different condition, where the two sets of instructions issued to each participant were different from each other. This was dealt with in Experiment 3 by presenting the partner's (in this case Experimenter's) role as a statement rather than an instruction. However, it is still possible that this statement could have aided memory for the participants' own task in the Same condition. By identifying the role of working memory in both conditions in the current study, direct evidence can be obtained as to whether working memory has a confounding influence on the tasks implemented in this thesis.

1.4 Individual Differences

Each of these cognitive skills has been subject to extensive investigation in terms of individual differences in children's abilities and how these differences relate to other cognitive constructs as well as real world outcomes. Relations between measures of Executive Function were outlined in the General Introduction, with findings pointing to the existence of an overall umbrella construct ('Executive Function') which covers individual domain-specific constructs (e.g. Inhibitory Control, Working Memory and Set Shifting). Accordingly, tasks within a single domain (e.g. Inhibitory Control) should correlate strongly with one another, but should also show weaker correlations with tasks from other domains (e.g. between Inhibitory Control and Working Memory). Executive Function has also been investigated in terms of its relation to Theory of Mind, with findings suggesting a significant relationship between the two (Sabbagh et al., 2006; Carlson, Moses & Breton, 2002). Thus, children with more developed executive functions skills also tend to show greater Theory of Mind ability. Although the exact nature of this relationship is controversial (see Moses, 2001), the relevant point for the current discussion is that a relationship exists that accounts for shared variance in individual performance on tasks measuring these different skills. Co- representation, in contrast, has not yet been investigated in terms of its relationship with other cognitive skills. The question of which capacities might be involved in co-representation is particularly pertinent when looking at children's behaviour, as it can help to explain the developmental trajectory that we see in early co-representation tasks. For this reason, the following experiment investigates the relationship between individual differences in Working Memory, Inhibitory Control, Theory of Mind and co-representation. Specifically, it focuses on which cognitive skills predict individual performance on the computerised co- representation task from previous experiments in this thesis. The three cognitive constructs were chosen based on the rationale outlined in the preceding sections.

In order to increase validity of the measures used, multiple tasks were administered for each cognitive construct. Tasks were taken from existing studies that have looked at individual differences in Executive Functions and Theory of Mind that have used a similar age range to that in the current study. Working Memory was measured using Backward Digit Span and Counting and Labelling tasks, based on Carlson et al. (2002). Inhibitory Control was measured using Day Night (Gerstadt, Hong & Diamond,1994) and Pictures tasks (Burns, Riggs & Beck, 2012). The Day Night task was converted into a computer task in order to measure response times as well as accuracy.

Since the relationship between Theory of Mind and development of co-representation has not yet been studied, it is not clear which type of mental state representation might be involved. For this reason, a scale made up of three tasks was implemented in this study. This was based on Wellman and Liu's (2004)'s Theory of Mind scale, which was originally made up of five tasks. They produced a scale using Rasch analyses, whereby tasks were set in an order from easy to difficult with the expectation that children passing a given task should also pass all tasks preceding it in the scale. The final scale consisted of the following tasks: Diverse Desire, Diverse Belief, Knowledge Access, Contents False Belief, Real-Apparent Emotion. Given that the age group used in our study was at the top end of the sample used in Wellman and Liu (2004), the three tasks at the top end of the original scale were selected for the current measure of Theory of Mind. This was with the intention that tasks could be first combined to create a composite Theory of Mind score, adding power to overall analyses, as well as being broken down into separate Theory of Mind tasks if overall analyses produced a significant effect.

Additionally, age and receptive vocabulary were measured as control variables, in order to ensure that variance in individual performance was not due to more general abilities or development, rather than a specific relation to the constructs of interest. For example, Executive Function and Theory of Mind may improve with age in a similar way to co- representation, but this does not signify a relationship between the two. Likewise, improvements in language ability may incur variance in performance on all tasks, simply because they involve verbal instructions. Controlling for these variables makes conclusions regarding target relationships easier to draw.

2. Method

2.1 Participants

Participants were 115 4-5 year-olds (Mean age = 61.68 months, Range = 48-69 months) sampled from Birmingham's Think Tank Science Museum (n = 30), two Primary schools in the Birmingham area (n = 18) and three from the Northamptonshire area (n = 67). Two participants from Northamptonshire schools failed to complete all tasks and were excluded from analyses. All other participants carried out all tasks and all conditions of each task in a within-subjects design.

2.2 Design and Procedure

Children were tested in a separate room, quiet corridor area or reading corner of the schools. Tasks were divided into two 15-20 minute sessions, in order to give children a rest between blocks. Depending on school classroom routines, there was a period of a minimum of 1 hour to a maximum of 20 hours between completing the first block and starting the second session of tasks. Tasks consisted of one co-representation measure

(CR) three Theory of Mind measures (ToM), two Working Memory measures (WM), two Inhibitory Control measures (IC) and the British Picture Vocabulary Scale (BPVS). Tasks were administered in a fixed order, so that individual differences in performance between participants cannot be due to order effects. Session 1: Bear/Duck (CR); Knowledge Access (ToM); Contents False Belief (ToM); Real-Apparent Emotion (ToM); Backward Digit Span (WM). Session 2: Day Night Stroop (IC); Counting and Labelling (WM); Pictures (IC); BPVS.

2.3 Measures

2.3.1 Receptive Vocabulary Measure

The British Picture Vocabulary Scale (BPVS II: Dunn, Dunn, Whetton & Burley, 1997) was fully administered to all children. Children worked through a booklet featuring four pictures per page. For each page the Experimenter articulated a word and the child was required to point to the correct picture that corresponded to the word. Responses were recorded as correct or incorrect. Pages were divided into sections and children were tested to failure upon scoring 8 or more errors within one section. A total raw score was calculated based on the number of the last item tested before failure minus the total errors made over all sections.

2.3.2 Working Memory Measures

Backward Digit Span. The methodology for this task was taken from Carlson et al. (2002). Children were introduced to a puppet called Ernie and told, ‘Ernie is being very silly. Everything I say, he says backwards! Like this, if I say the numbers “1, 2” he says “2, 1”! Do you think you can do what Ernie has done and say things backwards?’. Participants then had a two-digit practice trial, on which they were corrected if they got the answer wrong, followed by three test trials with 2, 3 and 4 digits respectively. Participants obtained a score out of four.

Counting and Labelling. The methodology for this task was taken from Carlson et al. (2002). Children were presented with three toys (a bike, a pineapple and an elephant). The Experimenter said, ‘We are going to play a game now. I am going to show you what to do and then it will be your turn. I am going to do three things. First I am going to count all of my toys, ‘one, two, three.’ The Experimenter points to each toy as she counts. ‘Second I am going to name all of my toys. Bike, pineapple, elephant’ (pointing as she labels). ‘Third I am going to count and then name my toys together. One is a bike, two is a pineapple, three is an elephant. Now, here are some more toys’. Experimenter places three new toys (a lamp, a suitcase and a banana) in front of the child. ‘Can you do the same as I have done? First can you count them?’ Experimenter waits for child to count and corrects if necessary. ‘Second can you name them?’ Experimenter waits and corrects if necessary. ‘Third can you count and then name them together?’ The Experimenter does not correct on this final test trial. This is then repeated for a further trial with new toys (a pig, a tractor and a strawberry). Children are scored as correct if they get all of the items in the correct order for each of the two test trials, giving a total out of two.

2.3.3 Inhibitory Control Measures

Day Night Stroop. This task was adapted from the classic Day Night Stroop task (Gerstadt et al., 1994). The original task required children to say the word ‘Day’ when presented with a picture of the moon and stars and ‘Night’ when presented the sun. However, here a computerised version of the task was developed which inverted the input and response required by the child. Thus, children were required to press a button with a picture of the moon and stars on when they heard a recorded voice say the word ‘Day’ and to press a button with a picture of the sun on when they heard ‘Night’. This should produce similar inhibitory demands as the original task, whilst allowing not just accuracy but also response times to be recorded as dependent measures. Participants completed four practice trials and 16 test trials. Trials commenced upon completion of the previous trial, giving no time limit on responses.

Pictures task. This task was identical to that used in Burns et al. (2012). Children participated in a computer game in which they saw a picture of either a monkey or a cat appear on the screen. They were required to press one of two buttons, one of which corresponded with the cat (and displayed a sticker with the same cat picture) and one with the monkey (displaying a monkey sticker). These buttons were placed 20cm apart, with one on the left and one on the right hand side of the laptop screen. Pictures on the computer were also displayed either on the left or right hand side, so that half of the trials (n = 10) were congruent with the side on which the corresponding animal button was situated and half were incongruent. Participants completed a total of four practice and 20 test trials.

2.3.4 Theory of Mind Measures

Theory of Mind measures were taken from Wellman and Liu’s (2004) Theory of Mind scale. Only three of the original tasks from the five-task scale were employed, due to the smaller age range being tested here and the age-appropriateness of selected tasks.

Knowledge Access. Participants were shown a Lego drawer and asked, ‘What do you think is inside the drawer?’ The Experimenter then opened the drawer to reveal a plastic monkey, ‘Let’s see…Look, there’s really a monkey inside!’ She then closed the drawer, ‘Ok, so what is in the drawer?’. After the child’s response, the Experimenter said, ‘Polly has never seen inside this drawer. Now here comes Polly.’ A plastic doll was then brought into view. The test question, ‘So, does Polly know what is in the drawer?’ was then asked, followed by the memory check question, ‘Did Polly see inside the drawer?’ In order to score correctly, children had to respond ‘No’ to both of these questions.

Contents False Belief. Children were presented with a plaster (‘Band-Aid’) box. They were first asked, ‘What do you think is in the plaster box?’ after which the box was opened to reveal a toy pig, ‘Look, it’s really a pig inside!’ The box was then closed and the child was asked, ‘Ok, so what is in the plaster box?’ Once the child had answered, the Experimenter said, ‘Peter has never seen inside this plaster box. Now here comes Peter.’ A different plastic doll was then brought into view and the test question was asked, ‘So, what does Peter think is in the box, plasters or a pig?’ This was followed by the memory check question, ‘Did Peter see inside the box?’ Children had to respond ‘Plasters’ and ‘No’ respectively in order to score correctly on this task.

Real-Apparent Emotion. Children were told a story about a boy who wanted to hide how he felt about an event. In the story, another child had called the boy names, which had made him feel sad. However, he tried to hide how he felt so that the other children would not think he was a baby (See Appendix E for full script). Children were asked a memory check question, ‘How did the boy really feel when everyone laughed, did he feel happy, sad or ok?’ They were given a sheet with three faces on (one happy, one neutral and one sad) which they could point to in response. They were then asked the test question, ‘How did he try to look on his face when everyone laughed, did he try to look happy sad or ok? Children had to respond with a more negative emotion for the memory check question than for the test question in order to gain a score of 1.

2.3.5 Co-representation task.

This task was modified from the computer task employed in Experiment 3 in order to make it suitable for use within-subjects. The EPrime programme from Experiment 3 was altered to display two rather than three blocks of 12 Bear and Duck trials. This was in order to allow an equal number of blocks before and after the switch. A second EPrime programme was designed which had an identical structure to the first programme, but rather than presenting Bear and Duck stimuli, they presented pictures of a Pig and a Penguin (see Appendix F). This was so that representations of stimuli from the first (Same) task could not influence those in the second (Different) task and to aid children's understanding of the different rules for each task. Pilot data found an effect of Task Type (Same versus Different) in a within-subjects design only when the Same condition was presented first and the Different condition was presented second. This is unlikely to have been caused solely by children getting tired or bored and thus declining in performance over time, because if this were the case then such a decline should also occur when the Same condition is presented second. Therefore, it is argued here that order effects were caused by factors related to co-representation. For this reason, tasks were presented in a fixed order with the Same condition first and then Different condition second. Each child completed both conditions, with a different version of the EPrime programme (Bear/Duck or Pig/Penguin) for each condition. The order of presentation of each programme was counterbalanced so that half of the participants completed the Bear/Duck version in the Same condition and half in the Different condition, and likewise for the Pig/Penguin version. Children completed the solo practice, joint practice and Same condition as in Experiment 3. Once the Same condition had been completed, children were asked a comprehension question and then given the instructions for the Different condition, (example given is for Same task with Bear as target, Different task with Pig as child's target) 'Now we're going to do something different. This time your job is to spot the Pig. So whenever you see the pig, you should press your button as fast as you can. But, if you see the Penguin, you shouldn't press your button. You just stay still and don't press anything at all. My job is to spot the Penguin. So whenever I see the Penguin I'm going to press my button as fast as I can. But, if I see the Pig, I'm not going to press my button, I'm just going to stay still and not press anything at all.' A further joint practice was then administered using the new stimulus set and new rules. The second EPrime programme was then loaded and children completed the Different condition, followed by a comprehension question.

3. Results and Discussion

Results will be presented in three stages. First, results from each task will be summarised in relation to original expectations of performance based on previous literature. Composite measures will then be described and correlational analyses carried out to identify relations between all measures. Lastly, regression analyses will be carried out in order to identify the contribution of factors to co-representation.

3.1 Summary of task expectations

Means and standard deviations for all tasks are presented in Table 4.1. Results will be discussed below according to predictions made based on previous literature using these tasks.

3.1.1 Receptive vocabulary.

BPVS scores were in the average range (Dunn et al., 1997).

3.1.2 Working Memory Measures.

Backward Digit Span. Mean performance (see Table 4.1) was slightly below that found in

Table 4.1. *Descriptive statistics for all tasks*

Task	Mean score *(Standard Deviation)*		
Receptive Vocabulary			
BPVS Raw Score	54.12 *(11.24)*		
Working Memory	Accuracy		
Backward Digit Span (0-4)	1.63 *(1.40)*	-	-
Counting and Labelling (0-2)	0.95 *(.94)*	-	-
Total (0-6)	2.59 *(1.99)*	-	-
Inhibitory Control	Accuracy	RTs	Correct RTs
Pictures: Congruent	94 *(11)*	1228.96 *(197.59)*	1240.94*(204.83)*
Incongruent	90 *(13)*	1359.79 *(213.75)*	1393.87*(210.70)*
Day Night Stroop	86 *(25)*	1591.55 *(294.79)*	1618.49*(325.50)*
Total (combined composites):			
Correct		.15 *(1.58)*	
Incorrect		.04 *(3.05)*	
Theory of Mind	Accuracy		
Knowledge Access	82 *(38)*	-	-
Contents False Belief	57 *(50)*	-	-
Real Apparent Emotion	27 *(45)*	-	-
Total (0-3)	1.66 *(.90)*	-	-
Co-representation	Accuracy	RTs	Correct RTs
Same task	85 *(11)*	720.69 *(119.16)*	727.32 *(116.90)*
Different task	83 *(13)*	747.23 *(99.37)*	751.25 *(101.30)*

Carlson et al. (2002) for four year-olds (Mean = 1.95, SD = .78) and five year-olds (Mean = 2.88, SD = 1.02).

Counting and Labelling. Mean performance (see Table 4.1) was slightly below that found in Carlson et al. (2002) for four year-olds (Mean = 1.44, SD = .81) and five year-olds (Mean = 1.69, SD = .60).

3.1.3 Inhibitory Control Measures.

Day Night Stroop. Accuracy and Response Times (RTs) were recorded for this task. Responses with RTs below 250ms and above 3 standard deviations from the mean

(6335.77ms) were excluded. Current participants showed higher accuracy (see Table 1) than children in Gerstadt et al. (1994) at age four (Mean = 68.8), four and a half (Mean = 63.1) and five years (Mean = 78.1). This is likely to be due to children responding more quickly in Gerstadt et al. (1994) at age four (Mean = 1650ms), four and a half (Mean = 1180ms) and five years (Mean = 1230ms). In order to combine accuracy and RTs in a composite measure, values were converted into z scores and signs were reversed for RT z scores so that, as for accuracy, higher scores signified better performance. Z scores for accuracy and RTs were then added together. This was as an alternative to inverse efficiency scores, which are argued to be unsuitable for scores with error rates over 10% (Bruyer & Brysbaert, 2011).

Pictures. Accuracy and RTs were recorded for both Congruent and Incongruent conditions of this task. Mean accuracy and correct RTs were descriptively better on Congruent than Incongruent trials (see Table 4.1) in line with predictions made based on Burns et al. (2012). This difference was significant using paired samples t-tests (Accuracy: $t(111) = -3.28$, $p = .001$; Correct RTs: $t(111) = 9.58$, $p < .001$). Speed-accuracy scores were then created in the same way as for the Day Night Stroop. In order to create a total score for the Pictures task, the composite score for the Incongruent condition was regressed onto that for the Congruent condition and from this, residuals were calculated for the expected score on Incongruent trials given the score on the Congruent trials. This calculation was used as an alternative to subtraction efficiency scores, where the control condition is subtracted from the experimental condition in order to produce a difference score. Based on DeGutis, Wilmer, Mercado and Cohan (2013), it is argued that this is a superior method of calculating the variance of an experimental condition whilst controlling for shared variance with a control condition, as it statistically removes this shared variance. In contrast, by subtracting a control condition from an experimental condition, the resulting difference score will still correlate with the control condition as it retains shared variance with this measure. In this case, variance that is unique to the Incongruent condition is the most interesting, as it is in this condition that inhibition is required, unlike in Congruent trials.

3.1.4 Theory of Mind scale.

Relative performance on each of the Theory of Mind tasks (see Table 1) was as expected based on Wellman and Liu (2004). Overall performance on Knowledge Access was greater than Contents False Belief (t (112) = 5.50, p < .001) and Real Apparent Emotion (t (112) = 10.02, p < .001) and Contents False Belief was greater than Real Apparent Emotion (t (112) = 4.99, p < .001).

3.1.5 Co-representation.

Accuracy and RTs were recorded for Same and Different conditions. There was a descriptive difference between the two conditions for both Accuracy and RTs (see Table 1). Paired samples t-tests highlighted a significant difference between conditions for correct RTs (t (107) = -2.56, p = .01) but not for accuracy (t (111) = 1.66, p = .10). This replicates the effect of Task Type in RTs in a previous version of this task (Experiment 3 in Milward et al. 2014) which found a between-subjects difference in Task type, and pilot data which found a within-subjects difference. In order to create a composite score for co-representation, RT and accuracy values for each condition were converted into z scores and combined within each condition to create a speed-accuracy composite. Next, residuals were calculated in the same way as for the Pictures task, by regressing the Different task composite onto the Same task composite. In this case, variance that is unique to the Different condition is the most interesting, as it is in this condition that co-representation is expected to show an effect of conflict with a partner, as opposed to the Same condition.

3.2 Correlations

First, where there were multiple tasks within a single domain (Working Memory, Inhibitory Control and Theory of Mind), task means were entered into Spearman's Rank correlational analyses. Mean totals for Backward Digit Span and Counting and Labelling correlated significantly (r (113) = .42, $p < .001$) and were therefore combined to create an overall Working Memory score. Mean totals for Day Night Stroop and Pictures Residual Score did not correlate (r (111) = .02, $p = .83$). For this reason, further analyses included both a total Inhibition score (by adding Day Night Stroop composite and Pictures Residual Score) as well as each of the individual Inhibition measures independently. Of the three Theory of Mind tasks, only Knowledge Access and Contents False Belief correlated significantly (r (111) = .39, $p < .001$). For this reason, the three Theory of Mind tasks were analysed separately as well as including a total Theory of Mind score by adding all three task scores.

3.2.1 Age and Receptive Vocabulary Correlations

An overall Spearman's Rank correlation matrix can be seen in Table 4.2. Age in months correlated with Receptive Vocabulary, Working Memory Total and Day Night Composite. Receptive Vocabulary correlated with all three Theory of Mind, Theory of Mind Total, Working Memory Total, Day Night Composite and Co-representation. This is consistent with existing literature demonstrating the development of Working Memory, Inhibition and Theory of Mind at this age (Carlson, 2010; Carlson et al., 2002), as well as the role of language and the importance of controlling for this in experimental studies (Milligan et al., 2007).

Table 4.2.

R values for correlations between Age, Receptive Vocabulary, Theory of Mind, Working Memory, Inhibition and Co-representation

	Age (months)	BPVS Raw Score	Knowledge Access	Contents False Belief	Real Apparent Emotion	Theory of Mind Total	Working Memory Total	Day Night Composite	Pictures Residual	Inhibition Total	Co-representation Residual
Age(months)	-	-.30**	.10	.13	.08	.14	.46**	.19*	.01	.16	-.02
BPVS Raw Score		-	.26**	.35**	.22*	.40**	.47**	.26**	-.12	.11	.20*
Theory of Mind											
Knowledge Access			-	.39**	.03	.62**	.33**	.06	-.10	-.01	.18
Contents False Belief				-	.14	.81**	.35**	.20*	-.06	-.10	.18
Real Apparent Emotion					-	.57**	.12	.07	.11	.17	.17
Total						-	.38*	.17	-.00	.14	.25**
Working Memory											
Total							-	.39**	-.11	.27**	.21*
Inhibition											
Day Night Composite								-	.02	.81**	.32**
Pictures Residual									-	.55**	-.08
Total										-	.21*
Co-representation											
Co-representation Residual											-

Note: *$p < .05$ **$p < .01$

3.2.2 Executive Function and Theory of Mind Correlations

Working Memory Total and Inhibition Total correlated with each other significantly (r (107) = .27, p = .005). This correlation was weaker than that found between the two Working Memory measures (r (113) = .42, p < .001), which is in line with Miyake et al. (2000)'s prediction that Executive function measures should correlate with one another, but more strongly between measures of the same type of Executive component. However, Inhibition measures in this task did not correlate with one another. This was unexpected, given that they are both conflict inhibition tasks, where participants are required to inhibit a conflicting stimulus in order to respond to a target. However, the Day Night task in this study did not feature congruent trials as a control measure, whereas the Pictures task did so. Therefore, the composite scores for each task are slightly different, in that the Day Night composite does not control for factors that may be involved in performance beyond inhibitory control. Additionally, whereas the Day Night composite is determined by a participant's ability to retain in mind and act upon a rule that conflicts with a prepotent response, the Pictures task measures ability to switch between inhibiting a prepotent response on incongruent trials whilst acting consistently with it on congruent trials. Further, the competing element in the Pictures task is spatial, whereas the Day Night is conceptual. In conclusion, there are reasons to explain the lack of correlation here, although it was unexpected given previous findings that within domain executive function tasks are correlated (Miyake et al., 2000).

Two of the Theory of Mind measures correlated with Working Memory total (Knowledge Access: r (111) = .33, p < .001; Contents False Belief: r (111) = .35, p < .001). Contents False Belief correlated with Day Night Composite (r (111) = .20, p = .04. These results remained similar once Age in months and Receptive Vocabulary had been partialled out (significant correlations between Working Memory total and Knowledge Access (*r* (104) = .25, *p* = .01) and Contents False Belief (*r* (104) = .34, *p* < .001) and between Pictures Residual Score and Real Apparent Emotion (*r* (104) = .21, *p* = .03)). This is in contrast to Carlson et al. (2002)'s finding that Inhibition, but not Working Memory correlates with Theory of Mind. It is possible that these different results are due to differences in task. However, the Contents False Belief task used here made up part of Carlson et al.'s Theory of Mind measure, Inhibition tasks were of the same type (Conflict Inhibition) in both studies and the Working Memory measures employed here were identical to two of the three used by Carlson et al. Again, it is possible that the lack of correlation with inhibitory measures is due to the differences in task type outlined above.

3.2.3 Co-representation and cognitive measures

The Co-representation Residual Score correlated with Theory of Mind Total (*r* (106) = .25, *p* < .01), Working Memory Total (*r* (106) = .21, *p* = .03), Day Night Composite (*r* (106) = .32, *p* = .001) and Inhibition Total (*r* (101) = .21, *p* = .03). Regression analyses were carried out in order to identify which relationships remained significant predictors once other variables were entered into the same model.

3.3 Regression analyses

The Co-representation Residual Score was used as the final dependent variable, given that it has been shown to be a good measure of the experimental condition whilst controlling for variance explained by the control condition (DeGutis et al., 2013). A multiple linear regression was carried out with Co-representation Residual Score as the dependent variable and Age in months, BPVS raw score, Inhibition Total, Working Memory Total and Theory of Mind Total as the predictor variables in a single model. The overall model was significant (*F* (5, 97) = 3.63, *p* = .005) with Inhibition Total and Theory of Mind Total as the only significant predictors within the model (Inhibition Total: β = .12, *t* = 2.34, *p* = .02; Theory of Mind Total: β = .20, *t* = 2.13, *p* = .04). In order to identify whether these two significant predictors added independent explanatory power to the overall model beyond that shared between the two variables, two hierarchical regressions were carried out adding first Inhibition Total and then Theory of Mind total in the second step. The first model entered Age, BPVS, Working Memory Total and Inhibition Total into the first block, with Theory of Mind Total in the second block. This showed a significant improvement in the model with the addition of Theory of Mind (*R square change* (1, 97) = .04, *p* = .04). A second hierarchical regression entered Age, BPVS, Working Memory and Theory of Mind Total into the first block, with Inhibition Total in the second block. This showed a significant improvement by addition of Inhibition Total in the second model (*R square change* (1, 97) = .05, *p* = .02). This indicates that both Inhibition and Theory of Mind contribute independently to individual scores on the Co-representation Residual Score. In other words, variance in performance on the Different task, having controlled for factors shared with the Same (control) task is predicted by both individual Inhibitory Control and Theory of Mind ability.

4. General Discussion

Firstly, these results replicated the effect of co-representation found in Milward et al. (2014). There was a within-subjects difference between Same and Different task performance. It is valuable to note that these effects can be measured in a within-subjects design as well as between subjects, as this will broaden the type of methodologies that can be implemented in future research on this topic. The results of regression analyses suggest independent roles of both Theory of Mind and Inhibitory Control in the Bear Duck task, as originally predicted. However, whereas the direction of the relationship with Inhibitory

Control was as expected (better Inhibitory Control results in less conflict on the Different Task), the direction of the relationship with Theory of Mind was in the opposite direction to that predicted. Specifically, better Theory of Mind predicted better performance on the Different Task relative to the Same Task, rather than the other way around. Additionally, although Working Memory correlated with the Residual measure of the Bear Duck task, this was not found to contribute once other factors had been included in a regression model. Each of these findings will be discussed in the following paragraphs.

The lack of contribution of Working Memory to the overall model suggests that Working Memory does not have a role in the Different task that is independent of its role in the Same task. This provides further evidence that differences between task conditions in this and other experiments are not due to stronger memory representations for the Same task than the Different task, caused by emphasis on instructions in the former. The version of the task used in this study was modified from previous versions in order to attempt to control for the possibility that hearing instructions twice in the Same condition could strengthen participants' memory for their task. Thus, in this version, the Experimenter merely stated what her role was in the task, rather than issuing two sets of instructions to two participants. However, it is still possible that hearing this statement could have strengthened the child's memory for their own task. Therefore, the finding in this experiment that working memory does not have a role in the Different task over and above that in the Same task provides further evidence that task effects are due to co-representation rather than memory limitations.

The finding that Inhibition has a role in the Different task is directly in line with the prediction that inhibitory control is required in order to avoid interference caused by co-representing a partner. In these studies, conflict caused by the different task is used as a way of measuring co-representation. However, it is important to note that co-representation may be involved in both Same and Different conditions, but that in the Same condition co-representation does not cause conflict. Therefore, the finding that Inhibition is related only to the Different task does not necessarily mean that co-representation does not occur in the Same task. Nonetheless, it is a good way of showing that co-representation occurs in such joint tasks and that inhibition is required to improve performance in cases where roles are complementary.

These results also show a relationship between Theory of Mind and co-representation in a surprising direction, given the previous finding that co-representation effects may have a lower bound around 4 years. This study suggests that Theory of Mind actually helps children to perform better on co-representation tasks, rather than impeding them as originally predicted. Despite this relationship being unpredicted, it makes sense if one considers the nature of the tasks implemented in the Theory of Mind scale used here. All three of these tasks involve being able to separate one's own mental state from that of a protagonist. In the Knowledge Access task, one's own knowledge must be separated from that of a naïve protagonist. This is similar for the Contents False Belief task, although knowledge is replaced by belief. In the Real Apparent Emotion task, one needs to separate one's own knowledge of the protagonist's true emotion from that portrayed on his face. When considered in this way, it seems reasonable that Theory of Mind actually aids children to avoid conflict from a co-actor in a shared task. Thus, the findings here suggest an indirect role of Theory of Mind on the ability to avoid conflict from representations of a partner, rather than the originally predicted direct role in co-representation itself.

These findings therefore do not support the findings from Humphreys and Bedford (2011) that false belief understanding is necessary for co-representation. Additionally, it fails to provide an explanation for the apparent cut-off point where co-representation effects cease to be found in this thesis. Further research should try to identify alternative cognitive abilities that develop at around this age that may explain the lower-bound. This makes it all the more important to find new paradigms to study co-representation effects in young children, to ensure that the cut-off point cannot be pushed to a lower age with more sensitive tasks. If this were the case, it might open up further opportunities for investigating the role of relevant stages of cognitive development on co-representation, such as self-other understanding, intentionality and joint goal understanding and lower level perception-action links.

Even though these results have failed to provide an explanation for the onset of co-representation, they still make an important contribution to understanding of the processes involved in performing joint tasks. In a task where co-representation has been shown to occur (through a Same versus Different task effect), Inhibitory Control and Theory of Mind processes are clearly active and essential for efficient performance. Developing Theory of Mind allows children to separate representations of self and other in order to hold both in mind simultaneously without detrimental interference. Inhibitory Control additionally provides an opportunity for children to overcome any potential interference that such representations may cause when a task partner is performing a complementary rather than identical role. Given the important increase in cognitive capacity in these two domains at around the age tested here, it remains important to consider whether the behaviours shown at a much earlier age are comparable to adult behaviours. What seems more likely is that several different processes emerge over the course of development (see Carpenter, 2009; and Brownell, 2011 for some examples) that help children to build up a more sophisticated understanding of joint action, of which two such stages are likely to be the development of Inhibitory Control and explicit Theory of Mind.

To conclude, these results demonstrate the importance of both Theory of Mind and Inhibitory Control in co-representation. It is hypothesised that these two cognitive capacities both play independent roles in the Bear Duck task, although both influence performance in the same direction. Thus, Theory of Mind is argued to aid children in separating representations of self and other, whilst Inhibition is argued to help avoid interference caused by co-representation of a task partner performing a complementary role. These findings fail to explain the apparent cut-off point in co-representation development at around 4 years, which should be tested further to ensure that effects cannot be found at a younger age with more sensitive tasks. Such findings would aid further investigation into the cognitive processes that underlie co-representation itself, which could be investigated in future individual differences studies with young children.

CHAPTER 5: GENERAL DISCUSSION

At the outset, this thesis presented two key questions that remained unanswered by previous literature on joint action. The first question was when children show co-representation (either of task or actor) in the way that adults have been shown to do so. If children also co- represent, this can be used as a criterion for comparing adult and childhood joint action, which has been difficult to do in the past given the problems in identifying key requirements for joint action understanding, such as joint goal or intention understanding (Bratman, 1992). The second question was regarding the level of processing that is involved in co- representation, which has been heavily debated in the adult literature. Here it is argued that if very young children co-represent, this would suggest that co-representation is underpinned by fairly simple cognitive mechanisms, which develop early in childhood. If young children do not co-represent, then it is likely that more complex cognitive skills are necessary for this tendency to develop. This thesis reported five experiments that aimed to shed light on these questions. In Chapter 2, three experiments were presented using variations on two tasks that found co-representation effects in children aged 4-5 but not in children aged 2-3. In Chapter

3, the nature of these representations was investigated by manipulating the presence or absence of the task partner, in order to see whether children represent joint tasks at a group level or whether representations of self and other are independent and separable. Chapter 4 presented an individual differences study to examine the cognitive skills that are involved in co-representation, given the age at which it appears to develop. These findings will be summarised and critically analysed in more detail in the following sections, followed by a discussion of the overall conclusions and contribution of this thesis and concluding with ideas for future research on this topic.

In Chapter 2, Experiment 1 implemented a simple 'Simon Says'-like task, where two 4-5 year-old children played a game together where they were asked to respond to the instructions of one or other of two puppets by pointing at pictures on a page. This experiment found that children made more errors when their partner was told to respond to a different puppet to the one they themselves had to respond to (Different Task condition) than when both children responded to the same puppet (Same Task condition). This was argued to be evidence for co-representation at this age, as co-representing a partner should cause interference in the Different Task but not in the Same Task condition. Although control analyses were carried out in order to check that children were not confused by hearing two different sets of instructions in the Different Task, a further experiment was also carried out to find more direct evidence for the co-representation explanation. This experiment repeated the paradigm implemented in Experiment 1, but added a task switch half way through the game, where participants had to switch from one task rule to another. In the Different Task, this meant switching to the rule that one's partner had been following in the previous block. Thus, if children co-represented their partner in the Different Task condition, they should gain a benefit from having previously represented the alternative task rule. The findings confirmed this prediction, in that children in the Different Task condition did not show a switch cost on performance whereas children in the Same Task condition did so. However, a further possibility was that hearing two sets of instructions did not confuse children about which task they were supposed to be following, but rather that it consolidated their memory for their own task in the Same Task condition (where the same set of instructions are repeated twice) more so than in the Different Task condition (where one's own instructions are given only once). So, Experiment 3 aimed to overcome this problem by putting the Experimenter in the role of the child's task partner, which enabled her to give only one set of instructions (to the child) and merely state what she herself was going to do in the game. Experiment 3 also employed a new version of the task, which was simplified and computerised in order to test younger children. Therefore, Experiment 3 not only allowed further controlling for alternative explanations of the co-representation account, but also allowed testing of 2-3 year- olds to identify whether there was a lower-bound on co-representation over development. Results, again, showed evidence for co-representation in 4-5 year-olds, suggesting that the previous findings where due to co-representation rather than alternative accounts such as confusion or memory overload. However, no such effects were found at the Younger age group (29-45 months), suggesting that co-representation may be a skill or tendency that develops around the age of 4. This, at present, is a tentative conclusion given the fact that results have only been found with two versions of a similar task. Further research should try to push this lower-bound down using different types of task to ensure that results are not task- specific.

Chapter 3 presented a large study that aimed to investigate the nature of the representations that are formed during co-representation. The computerised task from Experiment 3 was modified to include the switching element from Experiment 2 and add a further factor, 'Experimenter Presence'. This new manipulation involved half of participants continuing the post-switch phase alongside their task partner, as in Experiment 2. For the other half of participants, their task partner (the Experimenter) left the room after the switch instructions had been given, but before the post-switch trials had been initiated. It was hypothesised that if participants formed what have been termed 'we' representations (i.e. representations at the group level) then the switch cost that disappeared in Experiment 2 in the Different Task condition (presumably due to a benefit of representing the alternative task in the pre-switch phase) should return when one's task partner leaves the room. This is because if ‘our’ task is represented in the pre-switch phase, then the departure of one’s partner should make the post-switch phase a novel (individual) task with no benefit to be gained from a previous representation of the task at a group level. Unfortunately, this experiment failed to replicate the effect of Task Type or the interaction with the Switch manipulation, leaving no possibility for drawing conclusions regarding representation type. Reasons for this failure to replicate are discussed in Chapter 3, including duration of response windows, task sensitivity and appropriateness of the Experimenter Presence manipulation.

Chapter 4 presents an individual differences study that aimed to uncover the cognitive skills that underlie co-representation in 4-5 year-olds. The main factors that were investigated were Working Memory, Inhibitory Control and Theory of Mind, with Age and Receptive Vocabulary as control variables. This study found that both Inhibitory Control and Theory of Mind, but no other variables, significantly predicted a measure of Different Task variance having controlled for shared variance with the Same Task. It was concluded that Inhibitory Control is likely to play an indirect role in co-representation effects, whereby better Inhibitory Control allows children to better overcome the interfering effects of representing a partner in a joint task. The role of Theory of Mind, however, was not as initially expected, due to the discovery of a relationship in the opposite direction than originally predicted. Rather than finding that children with better Theory of Mind were more likely to co-represent, this study actually found the inverse relationship. Although this finding was unexpected, it makes sense if considering the nature of the task used in the Theory of Mind battery employed here. Accordingly, it seems that children who are able to separate their own knowledge or beliefs from that of another person are also more able to separate competing representations of another person's task or actions in a joint game such as the Bear Duck task. This finding helps to broaden existing knowledge about the processes involved in joint action and specifically highlights the importance of two cognitive skills that are arguably underdeveloped at the age at which many studies have shown evidence for what appears to be joint action understanding at around 1-2 years. Thus, it seems likely that several processes are involved in joint action understanding which develop over early childhood, some of which may not be fully developed until later on in the pre-school years.

Unfortunately, these experiments fail to find an explanation for the apparent lower-bound on co-representation effects at around 4 years. The two cognitive skills found to relate to performance on the joint task used here did not seem to affect co-representation itself, but rather the ability to avoid detrimental interference in circumstances where a partner's actions or task differ from one's own. Thus, further research is needed to identify whether this finding of a lower-bound is stable across different tasks, and accordingly what processes are directly involved in the onset of this phenomenon.

Overall, the experiments in this thesis have contributed to debates on both joint action development and the underlying processes of co-representation. In terms of joint action development, the current finding that co-representation appears to have a lower-bound around age 4 years suggests that co-representation is not a mechanism used by younger children when performing the 'joint' tasks seen in existing studies. This clearly does not mean that there are not other mechanisms that children use to perform such behaviours (see Brownell, 2011 and Carpenter, 2009 for a review of alternative mechanisms for early joint action), nor that these mechanisms do not allow the level of understanding required by certain definitions of joint action (Bratman, 1992; Butterfill & Sebanz, 2011). However, the fact that a process that has been shown to play a major role in the joint action abilities of adults is not used by young children casts doubt on the degree to which early and mature joint action understanding can be compared. The variation between different definitions of joint action understanding in existing literature causes difficulties in assessing whether the capacities of children can be deemed 'true' understanding. However, by outlining ways in which early and later developing cognition can be directly compared, rather than setting different goal posts for what is meant by genuine understanding, a clearer picture of development can be achieved.

In terms of understanding the processes underlying co-representation this thesis has made some important contributions, although these are perhaps less clear-cut than those made to the joint action development literature. The finding that co-representation may have a developmental lower-bound implies that children younger than 4 years may not have the cognitive capacity to co-represent. Accordingly, this indicates that co-representation may require higher level skills, which are later developing. This supports existing evidence that certain social conditions (Atmaca et al., 2011; Tsai et al., 2008) and subsequently inferred social cognitive processes are necessary for co-representation to occur. However, the results from the individual differences in Chapter 4 failed to identify which, if any, such processes are directly involved in co-representation development, despite producing interesting findings regarding the processes involved in joint action performance in general. These results are a stepping stone to further questioning the processes involved in joint action in general, whether they can be compared between adults and children, and what level of cognition is required for co-representation as a specific mechanism for joint action.

However, what remains unclear is the nature of representations formed in joint scenarios. As outlined in the General Introduction, several different suggestions have been made regarding the nature of joint representations in co-representation tasks, including representations of actions (Sebanz et al., 2003), turn-taking (Wenke et al., 2011) or even non- social explanations (Dolk et al., 2013). Chapter 3 aimed to shed light on this question, but unfortunately did not elicit any interpretable results. Thus, the question of what is represented in co-representation remains unclear. The nature of 'me', 'you' and 'we' representations is an interesting question for future research and novel ways of uncovering information about representation type would be greatly beneficial to existing literature. Discovering whether both children and adults form 'we' representations and when they do so would provide insight into how representations of a partner in joint action work to produce the most effective result. For example, it may be that forming a representation at the group level helps individuals to understand the relations between self and other actions in order to integrate them appropriately and alter one's own behaviour accordingly. This may provide more information than simply representing 'self' and 'other' without including information about how the two link together. This question is of particular interest in the study of children's development, as it could provide an important contribution to the debate on how children learn from or about other people. As outlined in Chapter 3, several conflicting theories have been put forward to explain how children form representations of self and other and in particular the direction in which this learning occurs. One possibility is that children first gain understanding of their own actions, intentions, beliefs etc. and then map these onto other people based on visual cues to their behaviour (e.g. Meltzoff, 2007). An alternative is that children first gain understanding of others, which they associate with external signs displayed by other people. They then come to associate these outward expressions of inward mental states with their own actions, and thus come to understand their own mental states (Prinz, 2012). By uncovering what types of representations are held by young children and when (or if) they develop further types of representation, further evidence can be gained to add to these debates.

In addition to providing information that informs some of the questions presented at the outset, the experiments and subsequent discussions presented here also open up some further questions and avenues for future investigation. One such question concerns the sensitivity of the measures employed in these studies. A key issue surrounding the conclusion that co-representation has a lower-bound is that it is possible that effects were not observed below 4 years due to a lack of sensitivity or appropriateness of the tasks used. There are reasons to believe that the tasks used here were, in fact, appropriate for even this younger age group. One reason is that the distribution of data from the Younger age group was similar to that in the Middle and Older year-old groups. Standard deviations for each group were similar, suggesting that the absence of an effect in the Younger group was unlikely to be due to increase variation caused by noise in the data. Additionally, proportion correct in the Younger group was above chance, suggesting that the lack of an effect in response times was unlikely to be due to a lack of understanding of the task in younger children. However, it remains possible that the tasks used here were simply not able to detect co-representation effects in younger children, perhaps due to them being smaller than those for older children. Future research should attempt to test this by designing alternative paradigms that can be employed with the age group used in the Younger group in this study. One way of doing this would be to design tasks that are more realistic in terms of their similarity to games that young children participate in in their natural environment. Some of the tasks used in the joint action development literature achieve a more naturalistic design, and thus could be modified in order to test co-representation effects at a young age. This would also have the advantage of making the results from co-representation experiments more comparable to those seen in these studies. Replication of a cut-off point for co-representation using this type of task would add confidence to the results seen in the studies here.

Another improvement that could be made to the current design would be to improve the dependent measures that identify co-representation effects. Although response times have been frequently used as evidence for co-representation in adult samples, it is much more difficult to gain analysable data from young children using this measure. Here, we have been able to do this, but the results have not always been replicable and effect sizes have been relatively small. One way of improving this would be to use a measure, such as motion- tracking, that is more inclusive in its measurement of responses. It was observed in the current experiments that children often made ‘half-movements’ towards a stimulus, but managed to refrain from actually pressing the response button at the last moment. This indicates a considerable loss of data caused by the inability to measure these half responses. One option that is more economical than motion-tracking, is to implement two button-based response measures. Accordingly, children should keep a button pressed down at all times and release it in order to press another, target response button. Thus, both the time taken to initiate an action, as well as the time taken to complete the action would be recorded. However, it seems unlikely that children of this young age would be disciplined enough to keep a button pressed throughout the whole experiment. Thus, motion-tracking is likely to be a more effective method given the current population.

Another avenue for future research, given the current evidence of a role of Theory of Mind in this type of joint task, is to introduce social manipulations to tasks with children to identify which are the key features of the social environment that are relevant to forming representations in a joint task. Such manipulations have been introduced in several studies on adult co-representation, some of which were outlined in the General Introduction. These manipulations have included co-actor presence and intentionality of the co-actor (Atmaca et al., 2011), identity of the co-actor (computer versus human; Tsai et al., 2008) and group membership of the co-actor and perspective-taking (Müller, Kühn, van Baaren, Dotsch, Brass & Dijksterhuis, 2011). It would be interesting and informative to identify whether these social factors also influence children's co-representation in a joint context. This could not only serve to increase confidence in the current conclusion regarding the importance of social cognition in avoiding interference from co-representing a partner, but also further illuminate the specific types of social understanding that are required.

One exciting possibility is that there may be a difference in co-representation depending on whether children are acting alongside a peer versus a parent or caregiver. Evidence has shown that children show more 'joint action' behaviours when playing games with a caregiver rather than a peer (Bakeman & Adamson, 1984). Although there is doubt over whether these behaviours constitute a genuine understanding of joint action, they still highlight a potential difference in terms of social learning from a joint context dependent on the identity of the co-actor. There are reasons to think that joint action in general or co- representation in particular might be more likely to occur when children act alongside an adult caregiver. According to Vygotsky's Zone of Proximal Development, children develop their cognitive skills through interaction with caregivers, who have a higher level of cognitive ability than the child. These skills that are learned in an interactive context then become internalised and can thus be used individually. The experiments in this thesis featured either a peer or an adult stranger as the co-actor in a joint task. Potential differences in performance due to co-actor identity cannot be identified in these experiments, as different tasks were used for different co-actor types. It would be interesting to design a version of the paradigm that could directly compare performance alongside a peer versus an adult and even more interesting if that adult were the child's caregiver. A finding that demonstrated earlier development of co-representation of a caregiver than a peer would provide evidence for a mechanism for internalisation and learning from experts in a joint context.

Another avenue for further investigation is to dig deeper into the types of Theory of Mind representations that are relevant for separating representations of self and other. The individual differences study in Chapter 4 uncovered a relationship between performance on a complementary joint task and a Theory of Mind scale, made up of three different tasks. These tasks measured slightly different types of Theory of Mind ability. These were Knowledge Access, Contents False Belief and Real-Apparent Emotion. Although it was the overall score from all three tasks that significantly predicted co-representation here, it is possible that one or other of the tasks played a more important role. None of these tasks correlated with co-representation when analysed individually, however it is possible that there was not enough variation within each individual task to show an effect, given the binomial nature of scores. There are reasons to suspect that some of these tasks might be more closely related to performance on the current paradigm than others, due to the demands of the task. For example, the Contents False Belief task required children to hold in mind two competing representations of a mental state (own knowledge versus other's belief). In contrast, the Knowledge Access task only required children to acknowledge that the other had different knowledge to their own, without having to represent what that knowledge was exactly. In this sense, the Contents False Belief task seems more similar to the co- representation task, in that to co-represent a partner and experience the corresponding interference one arguably needs to hold specific information about both one's own task and one's partner's task in mind at once. In contrast, the ability to understand simply that one's partner is doing 'something different' to themselves, may not necessarily help children to avoid interference from specific task rule representations. This is related to the question from the adult literature on what type of representations are involved in co-representation tasks, in that if co-representation requires specific knowledge of *what* is being done (Sebanz et al., 2003), then perhaps false belief may be a more analogous skill. In contrast, if co- representation requires understanding merely *when* something is being done (Wenke et al., 2011), this may be more related to Knowledge Access-type tasks, as specific representations of the identity of the hidden object/nature of action to be performed are not represented and therefore do not conflict with one another. Real-Apparent Emotion also involves holding in mind two competing representations in the same way as the Contents False Belief task, but is made more complicated by the fact that the 'reality' state is also an emotion, as well as the fact that some understanding of deception is required in order to understand the behaviour of the protagonist in portraying an inaccurate facial expression. These details seem less comparable to the co-representation task, where there is no state of 'reality' or deception involved. Thus, it seems likely that the Contents False Belief task is the most relevant to avoidance of co-representation, although this is merely speculative given the lack of correlations with individual tasks in the current data.

Additionally, it is possible that types of mental representation other than those included in the current task might be relevant to co-representation. Given the existing debate on pre-requisites for joint action, intentionality understanding seems an obvious example. Understanding of another's intention involves knowing that they plan to carry out a certain action in order to achieve a given goal. In the case of joint action, it is necessary to keep this representation of a co-actor's intention in mind alongside a representation of one's own goals and action plans, or even in a single representation at the group level (see earlier discussion on 'we' representations). Intention understanding is generally accepted to develop relatively early on in childhood, at around 1-2 years (Tomasello et al., 2005; Gergely et al., 2002). This is certainly much earlier than many other mental states such as explicit false belief. Although shared intentionality has already been proposed as a framework for children's joint action development (Carpenter, 2009; Tomasello et al., 2005), its relationship (or lack thereof) with co-representation has not yet been directly tested in children. Given the specifications of existing definitions of joint action (Bratman, 1992, Butterfill & Sebanz, 2011), which include either joint goal or intentionality understanding, it would be helpful to identify the role of these skills in co-representation, in keeping with the idea that this phenomenon allows us to directly compare behaviour with adults. This would also add to the debate in the adult co- representation literature on whether intentionality understanding is necessary for co- representation.

In conclusion, the five experiments presented in this thesis contribute to the two main research questions proposed at the outset. Firstly, they provide evidence for a lower-bound on co-representation in development, whereby children younger than about 4 years do not show the same interference from a co-actor as adults have been shown to. Further evidence indicates that this tendency can be more easily overcome as both Theory of Mind and Inhibitory Control capacities develop with age. This contributes to the debate in joint action development research regarding whether early joint behaviours are really showing a true understanding of the joint nature of the task, by demonstrating that children are not comparable to adults for at least for one mechanism of joint action. Thus, it might be necessary to redefine what we observe in these early development studies in order to account for children's limited cognitive capacity. Further, this also provides some insight into the nature of co-representation itself. Although the relational nature of representations is still uncertain given the null results of Experiment 4, Experiment 5 provides evidence regarding the requirements for overcoming co-representation, by highlighting the role of Theory of Mind and Inhibitory Control. However, these results fail to uncover a direct relationship between any particular cognitive skill and co-representation itself, consequently leaving the question open as to why there might be a lower limit on the phenomenon in development.

Joint action can be defined in different ways, which causes confusion over how it develops and who is capable of participating in it. Here, it is argued that a good way of reconciling existing data in the face of different definitions is to directly compare the abilities of adults and children and identify ways in which they differ. If the goalposts for children are lowered, the important differences and developments over maturation may be missed. The current results indicate that one such difference is in ability to co-represent, with younger children apparently incapable of doing so, perhaps due to limitations in key cognitive capacities. Additionally, once this tendency has developed, its detrimental side effects must be overcome under the right circumstances in order to perform efficient joint actions, which this research suggests may involve at least two higher level cognitive skills. Children, like flocking starlings, thus appear to fall short of the full set of interactive abilities that are established in later development. What remains to be seen is how they finally come to achieve this and to what purpose each process serves in building up from 'simple' dyadic interaction to complex society formation.

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Appendices

Appendix E. Real-Apparent Emotion script for Chapter 4, Individual differences study.

Initially, children see a sheet of paper with three faces drawn on it – a happy, a neutral, and a sad face – to check that the child knows these emotional expressions. Then that paper is put aside, and the task begins with the child being shown a cardboard cutout figure of a boy drawn from the back so that the boy's facial expression cannot be seen.

"Look, I have got some faces for you. Can you point which one is happy? And which one is okay? And which one is sad?

This story is about a boy. I'm going to ask you about how the boy really feels inside and how he looks on his face. He might really feel one way inside but look a different way on his face. Or, he might really feel the same way inside as he looks on his face. I want you to tell me how he really feels inside and how he looks on his face.

This Story is about Matt. Matt's friends were playing together and telling jokes. One of the older children, Rosie, told a mean joke about Matt and everyone laughed. Everyone thought it was very funny, but not Matt. But, Matt didn't want the other children to see how he felt about the joke, because they would call him a baby. So, Matt tried to hide how he felt."

Then the child gets two memory checks.

"So do you remember?"

"What did the other children do when Rosie told a mean joke about Matt?

____

"In the story, what would the other children do if they knew how Matt felt?"

____

Pointing to the three emotion pictures.

"So, how did Matt really feel, when everyone laughed? Did he feel happy, sad, or okay?"

____

"How did Matt try to look on his face, when everyone laughed? Did he look happy, sad or okay?

____

Appendix F. Pig and Penguin stimuli for Chapter 4, Individual differences study.