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Studies of adults can inform accounts of theory of mind development.

Abstract

There is strong evidence that developments in children's theory of mind (ToM) at 3 to 4 years are related to developments in language and executive function. However, these relationships might exist for two reasons. First, language and executive function might be necessary for the mature ToM abilities that children are in the process of developing. Second, language and executive function may be necessary for developing ToM, but have no necessary role in mature ToM. It is difficult to distinguish between these possibilities if we only study young children. Studies of adults can provide direct evidence about the role of language and executive function in mature ToM. Recent work suggests that impaired executive function has multiple roles in adult ToM, but that severely impaired grammar can leave ToM structurally intact. While studies of children report that ToM correlates with both language and executive function, findings from adults suggest that these relationships should be interpreted in importantly different ways.

Introduction

To understand development it is useful to know what develops. For many topics studied by developmental psychologists a related literature on adults provides an account of the terminus towards which children are heading that informs accounts of development. Theory of mind (ToM) is a notable exception, where research on children's ability to reason about beliefs, desires, intentions and knowledge (e.g., Astington & Baird, 2005; Astington, Harris & Olson, 1988; Lewis & Mitchell, 1994; Mitchell & Riggs, 2000) has proceeded with relatively little regard for how older children and adults successfully perform analogous reasoning tasks (e.g., Friedman & Leslie, 2004). Yet, important clues about adults' ToM abilities come from a long history of research in social psychology (e.g., Gilbert, 1998) and recent research inspired directly by developmental investigations of ToM is providing evidence directly related to phenomena observed in studies of children. This research on adults should be of interest to developmental psychologists studying ToM for at least two reasons. First, an account of the mature system is necessary for us to know when development is complete. Even after children pass developmentally sensitive theory of mind tasks, it seems highly plausible that their abilities will be slower and less flexible than those of adults (c.f., Apperly et al., under submission; Blakemore, 2008; Epley, Morewedge & Keysar, 2004). Later improvements in speed and flexibility may contribute to explaining later developments in children's social cognition and communication. Second, an account of the mature system provides critical information for interpreting why we observe developmental relationships between theory of mind and other abilities such as executive function and language. It is this second role for data from adults that we explore in the current paper.

Our primary focus will be the ability to reason about false beliefs, since this is by far the most widely studied aspect of ToM (e.g., Wellman, Cross, & Watson, 2001; Wimmer & Perner, 1983). In one such task a story character, Sally, places her marble in a basket,

then goes outside to play. In her absence, a second character, Anne, moves the marble from the basket to a box, with the result that Sally has a false belief about the marble's location. Children are then asked test questions that require them to infer Sally's false belief in order to say where Sally thinks the marble is located, or to predict where Sally will first look to find her marble (Baron-Cohen, Leslie & Frith, 1985). Developmental studies reveal a reliable transition in children's ability to reason about beliefs at 3 to 4 years, when children first pass standard false belief tasks (e.g., Wellman et al., 2001)¹. They also show that children's performance on false belief tasks is reliably associated with independent measures of language (e.g., Astington & Baird, 2005; Milligan, Astington & Dack, 2007) and executive function (e.g., Carlson, Moses & Hix, 1998; Perner & Lang, 1999; Sabbagh, 2006). A large amount of attention has been paid to which aspects of executive function (working memory, inhibitory control, hierarchical relationships) or language (grammar, semantics, pragmatics) are most strongly associated with this developmental transition in false belief reasoning, and to the direction of the causal relationships. In comparison, little attention has been paid to whether these relationships exist because language or executive function are necessary for the process of development, or because they have a necessary role in the mature system that children are developing. This is a fundamental question about the reasons behind the relationships that we observe in children, but one that is impossible to address without data from adults.

The distinction that we wish to draw between the reasons why developmental relationships might be observed can be thought of by using the analogy of constructing a building. Let us suppose that construction of the building requires both cement for joining the bricks and scaffolding to support the walls while they are being built. If we observe the process of construction, we will learn that both cement and scaffolding are necessary. The rate of construction will correlate with the rate at which cement and scaffolding are used, and if we intervene upon the process of construction by restricting the supply of materials,

construction will be slowed whether we restrict cement or scaffolding. However, although observing the building's construction will inform us about things that we would not otherwise learn (e.g., the necessary role of scaffolding in construction), it is equally true that if we never observe or intervene upon the finished building we might never find out that scaffolding was *only* necessary for construction, whereas cement was a permanent necessity². So it goes for ToM. If we only ever study children while they are developing the ability to reason about beliefs then it will be difficult to find out whether language or executive function are necessary only for development, or whether they are necessary in children's belief reasoning because they are an integral part of the mature system.

In the following sections we will review data on the role of executive function and language in adults' belief reasoning. These data lead us to suggest that executive function and language are involved in the development of belief reasoning for quite different reasons: A critical reason why executive function is involved in development is because, like cement, it is an essential part of the belief reasoning capacity that children are developing; grammar is not an essential part of the mature capacity but may, like scaffolding, be a necessary condition for its successful construction.

insert Table 1 near here

False belief reasoning and executive function.

Executive function and its role in development.

"Executive function" refers to a suite of cognitive processes involved in flexible goal-directed behaviour. These processes are typically taken to include working memory, inhibitory control, resistance to interference, set-shifting, and planning, and are particularly

important in situations that are novel, ambiguous or “ill-structured” (e.g., Burgess, Gilbert et al., 2005; Goel & Graffman, 2000; Hughes, 2002; Shallice & Burgess, 1996). Given the diversity of these processes there are clearly multiple ways in which executive function might be involved in theory of mind in both children and adults.

A variety of explanations have been given for the association between children’s performance on false belief tasks and measures of executive function (e.g., Carlson & Moses, 2001; Leslie, Friedman & German, 2004; Mitchell, 1996; Russell, 1996; Zelazo, Muller, Frye & Marcovitch, 2003). “Emergence” accounts place executive function in the role of scaffolding in the above analogy, and suggest that executive function is necessary for children to learn abstract concepts such as belief, perhaps by enabling disengagement from the immediate objects of attention (e.g., Carlson & Moses, 2001; Russell, 1996). Other accounts place executive function in the role of cement: that is to say, a lasting feature of the system under construction. Although they do this in different ways, these accounts all entail that belief reasoning will involve executive function in adults as well as in children. “Competence” accounts argue that reasoning about false beliefs requires the capacity (in working memory or other aspects of executive function) to construct mental representations with a certain level of complexity (e.g., Andrews, Halford et al., 2003; Frye, Zelazo & Palfai, 1995; Russell, 1996;). Until children have sufficient capacity they would be unable to reason about beliefs. “Expression” accounts point out that doing useful work with belief concepts (whatever their origin) might make quite specific performance demands. To ascribe a false belief, children may need to overcome default ascription of true beliefs (e.g., Leslie et al., 2004) or to resist any tendency to respond on the basis of their own knowledge rather than what the other person believes (i.e., to avoid a “reality bias” or “curse of knowledge”: e.g., Birch & Bloom 2007; Carlson & Moses, 2001; Mitchell, 1996; Russell, 1996). Finally, it is also clear that executive function will play a role in handling the completely incidental demands that false belief tasks make upon memory and

attention (e.g., Bloom & German, 2000). To date it has proved very difficult to distinguish among these possibilities with data from children. Can data from adults help?

Evidence from cognitive investigations of neurologically intact adults.

Background from social psychology. There is a long tradition within social psychology of studying social cognition in adult participants. Such work suggests that executive control processes are involved in a wide range of social cognition, often in the role of moderating or modifying more automatic processes of “person-perception” (see e.g., Gilbert, 1998 for a broad overview). For example, Macrae, Bodenhausen, Schloerscheidt and Milne (1999) found that the well-known memory bias for counter-stereotypic information during impression-formation was dependent upon the availability of executive processes. If participants’ executive functions were taxed with a secondary task while they formed impressions of a new person they were less likely to remember counter-stereotypic information in subsequent recall, compared with information consistent with the person’s stereotype. The authors concluded that processing the new person as an individual (with counter-stereotypic traits) rather than on the basis of a general stereotype required executive function. In a similar vein, social psychologists have examined participants’ ability to interpret behaviour (e.g., target person fidgets awkwardly) on the basis of underlying traits (e.g., target is an anxious person). Participants are less likely to attribute a general trait such as anxiety if they know that the person fidgeting awkwardly was being asked embarrassing questions, but taking account of such “situational constraints” appears to require executive resources (e.g., Gilbert, Pelham & Krull, 1988). More closely related to work on ToM, substantial bodies of evidence suggest that when making judgements about what others might feel (e.g., Van Boven & Loewenstein, 2003) or believe or know (e.g., Nickerson, 1999) participants often begin with their own feelings, beliefs or knowledge and adjust towards those of the target. The same observation has

been made by researchers working from the ToM tradition, who found that adult participants tend to underestimate the likelihood that a listener will change their belief on the strength of an incorrect message when the adult participant knows that the message is incorrect (Mitchell, Robinson, Isaacs & Nye, 1996). There is evidence that adjustment to the target is effortful and often inadequate, resulting in judgments that are egocentrically biased; all the more so if participants are placed under cognitive load (e.g., Epley, Keysar et al., 2004). Altogether, these studies provide clear evidence suggesting that social cognition in adults makes significant use of executive function, yet this has so far had little impact on accounts of the development of ToM. We believe that this is a mistake, but we are also cautious about moving from this evidence to direct conclusions about the involvement of executive function in particular aspects of ToM.

An important reason for caution is that there are significant differences between the cases most commonly studied in the social cognition and ToM traditions. Social psychologists have commonly studied adult participants' inferences about enduring traits and beliefs (whether the Bob is an anxious person; whether he believes in capital punishment), and participants are often asked to make these inferences on the basis of scant behavioural evidence or brief descriptions, and often in cases where the target's characteristics (e.g., race, class, age or gender) might make a significant difference to the inference. In contrast, developmental research on ToM has commonly studied children's inferences about more temporary desires and beliefs (e.g., whether Sally thinks the marble is in the basket), typically in cases where these desires and beliefs are specifically warranted by the situation (Sally did not see the marble move), and typically in cases where the target's characteristics (omniscience aside) make no difference to the inference. These differences mean that executive function might have both common and distinctive roles in the cases typically studied in the social psychology and ToM traditions. The potential consequences of these differences are compounded by the fact that executive

function is normally thought to be multi-faceted (e.g., Carlson & Moses, 2001; Miyake, Friedman et al., 2000; Shallice & Burgess, 1996). Moreover, the relationship between different facets of executive function and task performance is complex: merely quantitative increases in difficulty of the very same task may result in qualitative differences in the executive processes recruited (e.g., Stuss, Toth et al., 1999).

In short, if our aim is to use data from adults to inform accounts of children's abilities, we should have most confidence in our conclusions when the tasks and judgements involved are as similar as possible. For this reason, our particular focus will be on evidence from recent studies using tasks that are similar to those used with children (indeed, they have often adapted the tasks used with children to make them suitable for work with adults). These recent developments go some way to bridging the gap that has existed between the literatures on social cognition and ToM.

Investigations of adults inspired directly by studies of children. A key problem in investigating false belief reasoning in adults is that in normal circumstances we would not expect adults to make errors on the first order false belief tasks passed by many 4 year old children or even the 2nd order false belief tasks (i.e., John thinks that Sally thinks...) passed by many 7 year olds (e.g., Stone et al., 1998; Perner & Wimmer, 1985). One approach is to make the tasks yet more complicated, and indeed, adults often make errors when asked to evaluate statements that require inferences about mental states with multiple embeddings (e.g., "Bob thinks that John knew that Mary wanted to go to the shop"; Kinderman, Dunbar & Bentall, 1998; Rutherford, 2004). However, it is difficult to tell if such errors are due to increased demands on belief reasoning, or increased difficulty in processing the longer stories and test questions with multiply embedded clauses. Consequently it is difficult to disentangle any roles that executive function would play in these tasks.

Another approach is to present adults with 1st order or 2nd order belief reasoning problems while simultaneously taxing working memory or other components of executive function with a concurrently presented executive task. Second-order belief reasoning can be disrupted in this way (Mckinnon & Moscovitch, 2006; see also Bull, Phillips & Conway, in press), but once again it is difficult to be confident that this is because executive function has a role in belief reasoning rather than in adequate comprehension of the rest of the task.

Two recent studies have extended the work on reasoning biases in adults' perspective-taking in the social psychology literature to tasks directly similar to those used with children. These studies have revealed that although adults can give a correct answer on false belief tasks, they nonetheless show evidence of bias in these judgements. Friedman and Leslie (2004) found that when a character's false belief should make the character equally likely to look in one of two possible locations, adults were biased to choose the location that would in fact satisfy the character's desire to avoid an object (the opposite bias from that observed in children). Birch and Bloom (2007) found that adults underestimated the probability that a character would search incorrectly on the basis of a false belief, suggesting that adults suffer a "curse of knowledge" or "reality bias" similar to that observed in the pattern of errors made by young children. The latter case in particular is consistent with the hypothesis that adults overcome a cognitive bias that they share with children with the (imperfect) application of executive control processes (see e.g., Epley et al., 2004, for a similar claim). However, the role of executive processes in these reasoning biases needs to be established directly in future work.

A different approach is to keep the belief reasoning tasks as simple as possible and to assess not only error rates but also processing time. Using this approach, German and Hehman (2006) presented adults with short stories followed by test questions that required inferences about beliefs and desires. Adults were slower and more error-prone when

inferring some combinations of mental states (e.g., false belief plus negative desire) compared to other combinations (e.g., true belief plus positive desire). This is a similar pattern to that observed in children's errors (e.g., Friedman & Leslie, 2004). The authors argue that the more difficult combinations of belief and desire make higher demands on inhibitory control than the easier combinations, and indeed, individual differences in these processing costs were correlated with individual differences in processing speed and inhibitory control as measured on independent tasks. However, it remains unclear from German and Hehman's (2006) study whether inhibition was required in the process of inferring the beliefs of the story character, in holding this information in mind, or in using this information to respond to the test questions. Addressing this issue requires the development of new paradigms that separate these processes. A number of studies have devised such paradigms.

Belief inferences. Apperly, Riggs, Simpson, Chiavarino and Samson (2006) attempted to isolate the processing costs of making a belief inference. Participants watched a series of videos involving a male actor moving (or not moving) an object from one box to another in the presence or absence of a female actor (who consequently had either a true or a false belief about its location). Participants were required to monitor the location of the object and to indicate its final position at the end of each trial. They were also required to respond to unpredictable probe questions about what was happening in the videos. Response times to these probes were the critical measure of the cost of processing information about the videos. Of particular interest were the processing costs for questions about where the object was located, and the woman's false belief about its location.

In one condition participants were explicitly instructed to keep track of where the woman thought the object was located, and where it was really located. Thus, when they were presented with the probe questions, participants should have already done the work

of inferring the woman's belief, as well as monitoring reality. Consistent with this, response times to probes about reality and probes about the woman's false belief did not differ in this condition. In another condition, participants needed to monitor reality (in order to point to the object's location at the end of each trial) but were given no explicit instructions to monitor the woman's beliefs. In this condition, response times to belief probes were significantly slower than response times to reality probes. The authors argue that this processing cost for false belief probes reflects the need to infer the woman's belief ad hoc in response to the probe. These results imply that beliefs are not inferred automatically when a participant attends to a stimulus that affords belief inferences. They also imply that beliefs *can* nonetheless be made online, in this case voluntarily, in response to experimental instructions. Of course, this does not mean that participants need always be instructed to make a belief inference. As with other forms of bridging inference we would suppose that beliefs (and other mental states) would often be inferred spontaneously, depending on the participants' objectives (i.e., whether or not a belief inference was relevant to their current interpretation of behaviour) and on the availability of cognitive resources for this processing (see e.g., McKoon & Ratcliffe 1998 for a detailed discussion of the conditions under which bridging inferences are made during reading). Nonetheless, the data from Apperly et al. (2006) suggests that executive control processes play an important role in the guidance of belief inferences in at least some circumstances.

Holding false beliefs in mind. Inferring what someone thinks is not the only ToM problem that may make executive demands. Whether we infer what someone thinks, or are simply told what they think, it is still necessary to hold this information in mind, and not confuse it with what we might think or know ourselves. This seems to be demanding for three-year-old children, who are prone to egocentric, "realist" errors even when they only need to repeat back someone else's false belief that has just been described for them (de Villiers & Pyers, 2002; Flavell, Flavell, Green & Moses, 1990; Wellman and & Bartsch,

1988). Apperly, Back, Samson and France (2008) investigated whether the same might be true for adults. Participants read two briefly-presented sentences. One described someone's belief (e.g., "He thinks the object on the table is red") and the other described an aspect of reality. In the "false belief" condition, the reality described was in conflict with the belief (e.g., "Really, the object on the table is blue"). In the "unrelated" condition, the reality described was not in conflict with the belief (e.g., "Really, the object on the chair is blue"). Shortly after reading the sentences, participants were presented with a picture probe that depicted the man's belief or the real situation, and had to judge whether it accurately depicted the information in the corresponding belief or reality sentence. These judgements were faster and more accurate in the unrelated condition than in the false belief condition, and this was true whether the probe depicted belief or reality. That is to say, false beliefs were harder to hold in mind, resulting in slower judgements both about belief and about reality. These interference effects suggest that holding false beliefs in mind may require executive control. However, we do not think that this is a case where executive control helps participants "express" their underlying belief reasoning competence by compensating for a cognitive bias: a "reality bias" or "curse of knowledge" would only have predicted interference on belief judgments but not reality judgements. Instead, we suggest that this could be an instance of executive involvement in a basic aspect of adults' belief reasoning "competence" to hold in mind an uncontaminated record of a false belief and the corresponding reality.

Using false beliefs. Even if we are successful at inferring what someone else thinks when appropriate, and not confusing this with what we know to be true ourselves, actually using this information to guide online social interaction and communication may pose a significant challenge. Keysar, Lin & Barr (2003) gave adult participants a simple perspective taking task that would not itself elicit errors, and then examined participants' ability to take account of this perspective in an online task. Participants followed the

instructions of a speaker whose visual perspective meant he could not see all of the objects visible to the participant. The speaker instructed participants to move objects around a 4*4 matrix (e.g., "Move the large cup"). Identifying the speaker's intended referent required participants to select among the items that only the speaker could see (in this case, a small and a medium sized cup, plus filler items), and ignore items that he could not see, even if they were a better potential referent from the participant's perspective (in this case, the biggest of the three cups). Using an eye-tracker, Keysar, Lin & Barr (2003) found that participants frequently looked (incorrectly) at objects that fit with the speaker's message, but that he did not know about, and indeed participants sometimes selected these incorrect objects for their manual response. The same pattern was observed in a second experiment in which the speaker was misinformed (i.e., had a false belief) rather than ignorant about the foil item.

The important point here is that the adult participants were perfectly competent at perspective-taking, and had sufficient time to calculate what the speaker could and could not see. Nonetheless, when *using* this information to guide interpretation of the speaker's instructions they suffered significant interference from their own perspective. Epley, Keysar et al., (2004) argue that correction of this egocentric bias requires effortful cognitive control processes. Consistent with this, other recent work finds a significant correlation between adults' error rate on a computer-based adaptation of Keysar et al.'s task and independent measures of executive function (Qureshi, Apperly & Samson, 2007). Thus, these findings provide another example of a role of executive function in the "expression" of belief reasoning in adults.

Neuropsychological evidence from adults.

Studying the pattern of spared and impaired abilities that follow from adult-acquired brain injury has the potential to provide useful evidence about whether executive function

is necessary for belief reasoning in the mature system of adults. However, the existing literature provides a rather mixed pattern of evidence. Although it is undoubtedly the case that patients are often impaired both on tests of executive function and on tests of belief reasoning (e.g., Channon & Crawford, 2000; Stone, Baron-Cohen & Knight, 1998), and that manipulating the availability of memory prompts can make a significant difference to some patients' performance on false belief tasks (Stone et al., 1998), it is typically unclear whether executive function impairment is affecting belief reasoning *per se*, or just making it difficult for patients to meet the incidental demands that false belief tasks often make on comprehending a story or maintaining accurate memory for a sequence of events. Interestingly, there is evidence that false belief reasoning may survive significant impairment of at least some aspects of executive function assessed by tests of planning and verbal fluency (Bird, Castelli et al., 2004). This suggests that belief reasoning in adults may not depend upon these specific aspects of executive function. However, the more general conclusion that belief reasoning in adults does not depend at all on executive function is not warranted for two reasons. Firstly, investigating the link between executive function and belief reasoning requires testing patients on a much larger set of executive function tasks. Secondly, it may be that belief reasoning relies on a specific combination of executive processes. Impairment to one of these processes could be detected by independent executive measures but these measures would probably not detect problems in orchestrating the various executive processes (which themselves may be unimpaired). A more powerful approach for neuropsychological investigations of belief reasoning may be to manipulate or control for relevant aspects of executive function *within* the belief reasoning tasks themselves (e.g., Apperly et al., 2005).

Interference from self-perspective. One such series of studies has investigated WBA, a man with a brain lesion that principally affected a large portion of his right frontal lobe (Samson, Apperly, Kathirgamanathan & Humphreys, 2005; Samson, Apperly &

Humphreys, 2007), resulting in (among other things) significant impairment on many tests of executive function. WBA was tested on a non-verbal (video-based) unexpected transfer false belief task that corresponded closely to the tasks used most commonly with 3- to 4-year-old children (Samson et al., 2005). Over multiple false belief trials WBA responded below chance. WBA's difficulty was not with the incidental executive demands involved in following the events in the video sequence because he performed well on separate control trials in which he had to monitor a similar sequence of events but did not need to ascribe a false belief. Rather, WBA's executive deficit led him to show the strongly egocentric "reality-based" response pattern commonly observed in 3-year-old children on such tasks.

A second experiment tested whether WBA's difficulty was with the task of representing someone else's belief, or instead with resisting interference from his own point of view. This study adapted a false belief task devised by Call and Tomasello (1999). Unlike the standard unexpected transfer task, in which the participant knows the relevant state of reality (e.g., the location of an object) about which the target has a false belief, Call and Tomasello's task is "reality-unknown". The participant's job is to locate a hidden object on the basis of a clue given by someone who has a true or false belief about the object's location. The clue is always useful, provided the clue-giver's true or false belief is taken into account. The critical consequence of this design is that, at the point in the false belief trials when the participant must infer that the target has a false belief about the location of an object, the participant does not know the object's true location. Thus, the task retains the need to ascribe a false belief, but substantially reduces any need for executive control to resist interference from one's own perspective. WBA was able to perform above chance on false belief trials of this task. It appears that WBA is able to ascribe false beliefs in principle, but may frequently be unable to do so in practice³ because of interference from his own perspective. It seems highly likely that WBA suffers such interference because of an impairment to processes that are "executive" in nature. The fact that WBA can ascribe

beliefs in some circumstances suggests that his particular set of executive impairments have not affected his belief reasoning competence, but this case suggests that some aspects of executive function may be fundamental to the expression of belief reasoning in the mature system in the specific conditions where the interference from one's own perspective needs to be resisted.

Working out how and when to infer a belief. A second series of studies suggests that executive processes may have further roles in belief reasoning. An initial investigation of 12 patients on the reality-unknown false belief task found seven individuals who were not above chance on false belief trials (Apperly, Samson, Chiavarino & Humphreys, 2004). Three of the patients nonetheless performed perfectly on control trials that made very similar demands on memory and pragmatic understanding to false belief trials. Because the false belief task was "reality-unknown" these patients could not have failed on false belief trials because they could not resist interference from knowledge of reality. (Further evidence that the deficit in these patients may be different in kind comes from the fact that all three patients had overlapping lesions to left Temporo-Parietal Junction and Posterior Parietal cortex (Samson, Apperly, Chiavarino & Humphreys, 2004). This is quite distinct from the right frontal lesion in WBA).

A follow-up study using a reality-unknown false photograph task⁴ found that the three patients were not above chance on false photograph trials, but were above chance on control trials (Apperly, Samson, Chiavarino, Bickerton & Humphreys, 2007). This finding suggested that the patients' deficit was not strongly specific to the domain of ToM or belief reasoning, but in fact extended to a task with no ToM content but similar reasoning processes.

A further study has sought to specify the nature of these problems more precisely for one of the three patients, PF. Samson, Apperly and Humphreys (2007) devised a novel false belief task involving a container with expected contents (e.g., a pizza box) that turned

out to have an unexpected content (e.g., a passport) that was then swapped for a second unexpected content (e.g., scissors). Depending upon how much of this scenario was witnessed by a target character, that character could have different true or false beliefs about the contents of the box. Two features of this task were particularly relevant for the current discussion. First, in the event that the target character saw the first unexpected content (passport) but not the second (scissors), there were two plausible ways in which a participant could mistakenly identify the character's belief: by judging egocentrically (character thinks there are scissors in the box); or by judging that the character's false belief will be determined by what the character currently sees (character thinks there is pizza in the box). Interestingly, PF's errors were almost never egocentric. Instead, she often judged that a character would think the box's contents corresponded to the appearance of the box, not reality, nor the item that the character had seen in the box. This pattern is further evidence against the view that PF's errors were the result of difficulty resisting interference from self-perspective (Apperly et al., 2004, 2007), and contrasts markedly with the performance of a second patient, WBA, who did show a strong tendency for egocentric errors on the same task (Samson et al., 2007).

The second relevant feature of this task was that it was novel to PF, and did not resemble false belief tasks on which she had previously been tested. Interestingly, although her overall performance on the task was not above chance on trials where an appearance-based strategy yielded the incorrect answer, PF only made such errors in the initial block of trials. After a short break she performed without error on the second block of trials. This surprising success suggests that PF does not have a fundamental metarepresentational deficit (c.f., Stone & Gerrans, 2006), and that she has the competence to represent beliefs in at least some circumstances. The authors' interpretation was that PF's difficulty was with working out when to deploy the strategy of maintaining and updating representations of what people think (or the relationship between

a photograph and reality), and working out what information was relevant to calculating the content of the representation. If she was able to solve this aspect of the task then, as in the second block of trials of this most recent study, she was then capable of representing someone else's false belief. The problem of working out when and how to think about beliefs has been rather overlooked in previous investigations of children and adults but we think it is potentially very important. In everyday life many instances that require belief reasoning will be unfamiliar (unlike block 2 of a multi-trial experiment) and noticing that a belief inference is necessary, and then working out what information bears upon that inference, is likely to make significant executive demands. These demands are clearly distinct from the problem of resisting interference from knowledge of reality, suggesting that they lead to a distinct role for executive control in belief reasoning.

Evaluation.

There is overwhelming evidence that executive function has many direct roles in adults' belief reasoning, and not merely in handling the complex event sequences or complex questions of some adult-appropriate belief reasoning tasks. We observe a variety of processing costs, errors, or biases that arise from the need to infer beliefs, to resolve interference between a represented belief and known reality, and to use a representation of what someone else thinks or knows as the basis for predicting how they will behave or interpreting what they say. There is evidence that individual variation in these costs, errors or biases may be related to individual variation in executive function measured on independent executive tasks or tasks that make similar reasoning demands but do not require belief ascription.

Some effects – such as the costs of holding false beliefs in mind (Apperly et al., 2008) – may be fundamental to the mental representation of beliefs, and hint that belief reasoning competence may depend upon executive function. Other effects suggest that

executive function has a continuing role in the “expression” of belief reasoning by enabling participants to resist interference from self-perspective – as in the case of WBA, who seems able to ascribe false beliefs in principle, but is often overwhelmed by interference from his own perspective (Samson et al., 2005, 2007), or the neurologically intact adults who suffered interference from their own perspective when interpreting instructions from a speaker with a different perspective (Keysar et al., 2003). Finally, there are effects such as PF’s difficulty working out how and when to infer beliefs (Samson et al., 2007), and evidence that beliefs are not inferred automatically (Apperly et al., 2006), that suggest a broader role for executive function in the flexible control belief reasoning abilities. These latter effects do not fit easily with the notions of expression or competence arising from developmental research. However, we suggest that questions about how, when and whether beliefs are inferred are a worthwhile topic for investigation in children, because they may contribute to explaining improvements in children’s social abilities well after they have achieved success on the most developmentally sensitive tasks.

Altogether, it seems clear that one reason why we observe relationships between belief reasoning and executive function in young children is that executive function is an indispensable component of the mature system that children are developing. Of course, this in no way contradicts the hypothesis that executive function is also involved in the emergence of belief reasoning. Indeed, we believe that it remains a plausible and important possibility that some of the roles served by executive function in the developing system will not be necessary in the mature system. However, this possibility is not well-supported by current evidence, where the diverse roles of executive function in adults’ belief reasoning seem more than enough to account for why executive function is related to belief reasoning in children. Support for emergence accounts would come from evidence that executive function plays a role in children’s belief reasoning that is not also

apparent in adults. Investigating whether there are indeed such uniquely developmental phenomena is an important direction for future work.

False belief reasoning and language

A large number of studies show relationships between language and children's developing ability to reason about beliefs (Milligan, Astington & Dack, 2007). There is evidence that conversational pragmatics may be an important factor in children's developing ToM abilities (e.g., Dunn & Brophy, 2005; Harris, 2005; Siegal & Beattie, 1991). Children's performance on false belief tasks is related to semantic development as measured by their ability to evaluate the certainty implied by different mental state terms (e.g., "know" is more certain than "think": Moore, Pure, & Furrow, 1990). However, it is also related to more general measures of semantics (e.g., Milligan, Astington & Dack, 2007; Ruffman, Slade, Rowlandson, Rumsey, & Garnham, 2003), so the specific role of mental state verbs is unclear. There is also evidence of a role for grammar, though it remains hotly debated whether the more important factor is general syntactic development (e.g., Astington & Jenkins, 1999; Ruffman, Slade, Rowlandson, Rumsey, & Garnham, 2003), or more specific aspects of grammar, such as embedded complement clause sentences (e.g., John said that Aldrin was the first man on the moon: de Villiers & Pyers, 2002) or relative clause sentences (Smith, Apperly & White, 2003). Children with delayed language as a result of deafness or autism may also be late to pass false belief tasks, though it remains controversial whether this is driven by delay in specific aspects of embedded complement syntax (see e.g., de Villiers, 2006; Tager-Flusberg & Josef, 2006) or by reduced conversational/pragmatic experience (e.g., Woolfe, Want & Siegal, 2002).

As with executive function, researchers often distinguish between possible roles for language that are not mutually exclusive but are importantly different. One possibility is that language serves the role of scaffolding in our original analogy; that is to say, language

may be necessary for the emergence of belief reasoning but not necessary once the ability to reason about beliefs has developed. Another possibility is that language serves the role of cement in our original analogy, and may do so in one or more ways: language may be a necessary component of belief reasoning competence; it may be necessary for “expressing” the underlying non-linguistic concepts; and it may also be important for performance on false belief tasks, which make incidental language demands because they are typically presented as verbal stories with verbal questions. As with executive function, to distinguish among these possibilities it may be helpful to examine the roles of language in adults’ belief reasoning.

Evidence from cognitive investigations of neurologically intact adults.

Only one study to date has sought to examine whether language is necessary for belief reasoning in healthy adults. Newton and de Villiers (2007) gave participants non-verbal true and a false belief reasoning problems and at the same time required them to “shadow” spoken sentences (i.e. constantly monitor a stream of speech while repeating back what has just been heard). Participants performed worse in the false belief reasoning problem (in which belief reasoning was necessary) than in the true belief problem (in which belief reasoning was not necessary). In another condition participants undertook the same true and false belief reasoning problems while simultaneously performing a task in which they monitored and produced rhythms. The rhythm task was much less disruptive of belief reasoning, and participants’ false belief reasoning was significantly more disrupted by the language shadowing task than by the rhythm task.

These findings clearly indicate that adults’ belief reasoning can be disrupted by concurrent performance of a language task. However, it does not follow that adults’ belief reasoning requires language. First, the presence or absence of language was not the only factor that varied between the language and rhythm secondary tasks – the language task

required continuous performance whereas the rhythm task required participants to listen to the rhythm and then repeat it back. Gaps in performance on the rhythm task may have given participants a critical opportunity to complete the reasoning necessary for the false belief task. Second, the language task may have been more disruptive because it made greater demands on memory and executive function than the rhythm task, rather than because it made language demands. This possibility is not ruled out by the authors' suggestion that the language and rhythm shadowing tasks were matched in the degree to which they disrupted performance on a separate test where participants judged whether faces in an array were oriented in a consistent or inconsistent manner. This is because the false belief tasks make clear demands on the participants' ability to maintain and update a representation of a story scenario, whereas the visual judgement task does not. Third, these concerns notwithstanding, Newton and de Villiers' (2007) results so far only give a general indication that language plays some role in adults' belief reasoning – it remains unclear whether syntax or semantics are most important, or whether the role of language is in the expression of belief reasoning, the competence to reason about beliefs, or even in providing an efficient way of representing information in the non-verbal reasoning problems. Dual-task methods of this kind clearly deserve further empirical investigation, but for the time being these findings do not permit firm conclusions about the role of language in belief reasoning.

Neuropsychological evidence from adults.

There have been relatively few investigations of belief reasoning in patients with impaired language. One reason for this is that the highly verbal nature of many belief reasoning tasks means that many patients with language impairment cannot be tested reliably. Nonetheless, the development of tests more suitable for patients has made this possible in a number of studies.

Semantics. We know of only one investigation of a patient with selective language problems that has tested understanding of the semantics of mental state verbs, and this revealed no impairment in comprehension of either mental state verbs or theory of mind (Apperly, Samson, Carroll, Hussain & Humphreys, 2006).

Pragmatics. There is tentative evidence that patients with right hemisphere lesions may be sensitive to the pragmatics of belief reasoning problems in a similar way to young children (Siegal, Carrington & Radel, 1996; Siegal & Beattie, 1991). Siegal et al. (1996) found that 8/11 patients with right hemisphere lesions (compared with 5/6 patients with left hemisphere lesions) gave an incorrect response on a “standard” question about where someone with a false belief will look for a hidden object, on which they had to make the pragmatic inference that the experimenter intended them to say where the person would *first* look. A second group of patients received a variant of the same task in which the need for the pragmatic inference was obviated because the experimenter explicitly asked where the person with the false belief would first look (c.f., Siegal & Beattie, 1991). On this variant of the task, 5/6 patients with right hemisphere lesions gave the correct answer (as did 5/5 patients with left hemisphere lesions). Interpretation of this finding must be cautious, because the groups of patients were only matched on age, education and time post-onset (and not, for example, on executive or language abilities), and the right hemisphere group that performed less well on the false belief judgements also performed less well on control trials, indicating that their general understanding of the false belief task may have been poorer than that of the other groups. However, we may tentatively conclude that, as for children, the ability to understand pragmatics of the test scenario and test questions contributes to adults’ ability to reason about beliefs. Importantly though, this in no way excludes the possibility that pragmatics and conversational experience also contributes to the emergence of belief reasoning abilities (e.g., Dunn & Brophy, 2005; Harris 2005).

Grammar. Three studies of patients who have significantly impaired grammar provide much stronger evidence to inform the relationship between language and belief reasoning. Varley and Siegal (2000) and Varley, Siegal and Want (2001) report two patients, SA and MR, who show significant and disproportionate grammatical impairment on standard language tests following left hemisphere lesions. Nonetheless, SA performed above chance on a series of false belief tasks with reduced demands for language comprehension, and MR gave 5/5 correct responses on fully non-verbal false belief tasks based upon picture-strip cartoons.

Apperly et al. (2006) examined a third patient, PH, who, like the patients studied by Varley et al., has significant and disproportionate grammatical impairment following a left hemisphere lesion. This investigation extended the earlier studies in two ways. First, PH was assessed on several novel tests of grammar (embedded complement clauses and relative clauses) and semantics (mental verbs) that show the most specific relationships with belief reasoning in children. Second, PH was assessed on fully non-verbal tests, not only of 1st order belief reasoning but also more complex 2nd order belief reasoning. The 1st order tasks were the same as those used by Apperly et al. (2004) and Samson et al. (2003; 2005), and were described earlier. In the 2nd order task, PH had to predict where a female actor would search for a hidden green object. PH watched as a male actor showed one female actor (“the helper”) in which white cylindrical box the green object was located. Neither the PH nor a second female actor (“the searcher”) could see where the green object was. The helper then pretended to leave the room (neither the man nor the searcher could see that the helper was in fact still inside the room). The man then swapped the two white cylindrical boxes. The helper pretended to re-enter the room (by opening and closing the door) and indicated one of the white cylindrical boxes as the one containing the object. In order to correctly predict where the searcher would look, PH needed to realise that the searcher falsely believed that the helper had a false belief and

that the searcher would thus search in the opposite white cylinder to the one indicated by the helper. Because PH could see that the helper only pretended to leave the room, he could infer that the helper had a true belief about the object's location. The 2nd order ToM question was whether PH could also work out that the searcher would (wrongly) believe that the helper had a false belief. This was clearly a complex task, but could be presented entirely non-verbally by establishing at the outset that on every trial (including a large number of filler and control trials) PH would be asked to judge where the searcher would search.

As already mentioned, PH was unimpaired on the test of ToM semantics. However, on the tests of grammar, PH was unable to understand relative clause sentences or adverbial clause sentences (based on the adverb "before"). He was also unable to understand sentences with an embedded complement clause that described someone's false belief. Thus, it was found that PH was impaired on precisely the aspects of grammar that have been most closely implicated in children's developing belief reasoning. In light of this it was striking to find that PH performed above chance (indeed with only a single error) on both reality-known and reality-unknown 1st order nonverbal false belief tasks (described above) and without error and significantly above chance on the 2nd order nonverbal false belief task. Together with the two earlier studies, this seems strong evidence that fundamental belief reasoning competence in adults is independent of grammar⁵.

Evaluation.

Much work remains to be done on the relationship between language and belief reasoning in adults. The only really clear finding to date concerns the relationship between grammar and belief reasoning, but here the findings are strikingly different from those in studies of children. In children, grammatical abilities are significantly correlated with belief reasoning, earlier grammatical ability is a significant predictor of later belief reasoning

ability, delayed grammatical development may lead to delayed belief reasoning, and training in grammar may lead to improved belief reasoning (see Milligan et al., 2007 for a recent review). Whether on its own or in combination with other aspects of language it is commonly thought that grammar is closely involved in children's developing ability to reason about false beliefs. An influential interpretation of these findings is that children need grammar for false belief reasoning because grammatically structured representations are the medium in which belief reasoning is conducted: that is to say, grammar is necessary for belief reasoning competence (e.g., e.g., de Villiers & Pyers, 2002; de Villiers & de Villiers, 2002). The fact that patients with severely impaired grammar can succeed on 1st and even 2nd order false belief tasks seems very strong evidence against this interpretation. Grammar in general, and embedded complement clauses in particular, do not seem necessary for belief reasoning competence. Note that this interpretation would not necessarily be undermined by future reports of brain-damaged adult patients showing a co-occurrence of impaired grammar and impaired false belief reasoning. Patterns of dissociation allow much more confident interpretation than patterns of association, even if such dissociations occur less frequently. This is because associations of deficits are much more difficult to interpret as they may result from impairment of a common underlying process or from impairment of two distinct processes (Caramazza, 1984). The fact that the dissociation of spared false belief reasoning from impaired grammar has been replicated in three patients from two different laboratories using several different methods of assessment suggests that these findings can be interpreted with considerable confidence.

It is vital to emphasise that we are not arguing against language having a major role in belief reasoning (and ToM more generally). Language is central to much social interaction, and many of the clues about how and when to infer beliefs (see earlier section on executive function) are likely to come from language and communication. It is also true that much of what we learn about other people's beliefs comes directly from what they tell

us, and it seems plausible that certain beliefs can only be represented linguistically (e.g., Carruthers, 2002). Thus, impairments to language, including difficulty with the grammatical structures most relevant to belief reasoning, are likely to have drastic effects on everyday social understanding in adults. These roles are also likely to be part of the explanation for why language is important in children's belief reasoning – that is to say, grammatical structure, lexical semantics and conversational pragmatics may enable the appropriate expression of children's belief reasoning abilities for a wider range of beliefs across a wider range of contexts. The question is whether these roles are the full explanation for the role of language in children's belief reasoning. We think that they may not be.

Milligan et al.'s recent meta-analysis of studies examining language and belief reasoning in children (Milligan et al., 2007) suggests that the effects of language are robust over rather different kinds of belief reasoning task, which vary in the demands they make upon the comprehension of language in general, or embedded complements in particular. Thus, it seems that language does more than help children meet the incidental performance demands of a given belief reasoning task. It is also relevant to note that twenty five years of research on children's belief reasoning has refined the tasks to bring them within children's linguistic and pragmatic abilities. So while it is highly plausible that language will be involved in the flexible expression of children's belief reasoning abilities, it is much less clear that language abilities are the limiting factor in the expression of belief reasoning on the simplest developmental tasks (e.g., Wellman et al., 2001). This leaves us with the possibility that grammar (and potentially other aspects of language) may be necessary for the *emergence* of belief reasoning. Like the scaffolding of a building, grammar may be essential for the construction of mature belief reasoning abilities. The result of this developmental process is a capacity for belief reasoning that can take input from language, and must, perhaps, use language to represent the content of some beliefs.

But just as scaffolding can be removed once a building is complete, the mature capacity for belief reasoning is not essentially dependent upon grammar.

Conclusions

Thirty years of research on ToM has taught us a great deal about the development of belief reasoning but has rather neglected adults. However, research on adults is rapidly bridging the gap between developmental work on ToM and work in the social psychology tradition, using the tools of cognitive psychology, neuropsychology and neuroimaging (for recent reviews of neuroimaging work, see Frith & Frith, 2003; Saxe, Carey & Kanwisher, 2004). All of this work owes a significant debt to the ideas and paradigms developed in research on children. Our argument in this paper is that the flow of information should not be in one direction only. We believe that insights into the nature of mature belief reasoning that are emerging from studies of adults can be of great value in understanding children's developing belief reasoning. Studies of development show that children's belief reasoning is dependent upon both executive function and language. However, studies of adults lead us to interpret these effects in very different ways. One key reason why children's belief reasoning is related to their executive function is because executive function is an integral part of the mature capacity for belief reasoning that they are in the process of developing. The same cannot be said for grammar, where adults' belief reasoning competence can remain intact despite significant loss of grammatical abilities. In this case, the data from adults suggest that grammar may be necessary for the construction (i.e., emergence) of children's belief reasoning. Quite clearly, this is not the end of the story. Much remains to be learned about the roles of executive function and language in adults and in children. Our contention is that the mutual constraints of data from children and from adults should play a more prominent role in future investigations of belief reasoning, and theory of mind more generally.

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Footnotes

1. Recent studies suggest precocious false belief reasoning abilities in children as young as 13 months when indirect measures, such as looking time or eye direction, are employed (Onishi & Baillargeon 2005; Surian, Caldi & Sperber 2007). It is currently unclear whether these studies tap the same ability as the tasks widely used with 3 and 4 year old children, which require explicit judgements about false beliefs (Perner & Ruffman 2005). Whatever the correct account for these precocious abilities, this does not alter the fact that 3- to 4-year-olds' ability to make correct explicit judgements about false beliefs is reliably associated with aspects of language and executive function. Our target in the current paper is interpretation of these latter effects.

2. The idea that something may play a necessary role in the development of a process, function or structure but not in its mature state occurs elsewhere within cognitive development and beyond. For example, there is evidence that amygdala lesions in childhood but not adulthood may lead to impaired performance on advanced ToM tasks, suggesting that the amygdalae may be involved in the development of ToM but not ToM processing in the mature system (Shaw et al., 2004). Elsewhere, in developmental biology the dorso-ventral polarity of the early vertebrate embryo is given by a structure called the notochord (see Wilson & Maden, 2005, for a recent review). In most vertebrates chemical signalling from the notochord is critical in successful formation of the neural tube during development of the central nervous system. However, during later development the notochord typically regresses and does not serve any such patterning function in the mature organism.

3. Of course, he may in fact ascribe a false belief in all cases but is then unable to use this information to guide his actions or judgements because of interference from his own perspective.

4. This follows a very similar approach in developmental investigations (e.g., Charman & Baron-Cohen, 1992; Leekam & Perner, 1991; Leslie & Thaiss, 1992; Sabbagh, 2006; Zaitchick, 1990). However, it has long been suggested the false photograph tasks used in these investigations were flawed because the photograph was not in fact false and so the false photograph task was not well matched to the false belief task (e.g., Perner, 1995). The validity of this concern seems validated by recent investigations of typically developing children (e.g., Sabbagh, 2006). Importantly, the reality-unknown false photograph task overcomes this problem with earlier developmental studies and is well matched to the reality-unknown false belief task.

5. Nonetheless, some theorists have suggested that language-specific “Logical Form” representations may remain intact in individuals with severely impaired grammatical comprehension and production (e.g., Carruthers 2002; Segal, 1996), so limiting the relevance of data from patients with aphasia for the study of the relation between language and thought. We are not sure what empirically testable predictions arise from this suggestion. But even admitting this possibility we believe the data from patients with severe grammatical impairment do narrow down the possible roles that grammatically structured language may have had in adults’ belief reasoning.

Table 1. Summary of how the interpretation of associations observed between ToM and other cognitive processes during development can be informed by data from adults.

Function in building analogy	Psychological role	Observed relationship in children	Observed relationship in adults	Example
Scaffolding	Emergence	Association	Dissociation	Grammar
Cement	Expression	Association	Association	Executive Function used to resist interference from self-perspective
	Competence	Association	Association	Executive function used to “hold in mind” records of belief and reality