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Brief article

Executive function is necessary for perspective selection, not Level-1 visual perspective calculation: Evidence from a dual-task study of adults

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ABSTRACT

Previous research suggests that perspective-taking and other "theory of mind" processes may be cognitively demanding for adult participants, and may be disrupted by concurrent performance of a secondary task. In the current study, a Level-1 visual perspective task was administered to 32 adults using a dual-task paradigm in which the secondary task tapped executive function. Results suggested that the secondary task did not affect the calculation of perspective, but did affect the selection of the relevant (Self or Other) perspective for a given trial. This is the first direct evidence of a cognitively efficient process for "theory of mind" in adults that operates independently of executive function. The contrast between this and previous findings points to a distinction between simple perspective-taking and the more complex and cognitively demanding abilities more typically examined in studies of "theory of mind". It is suggested that these findings may provide a parsimonious explanation of the success of infants on 'indirect' measures of perspective-taking that do not explicitly require selection of the relevant perspective.

1. Introduction

The ability to take the perspective of others is fundamental to social interaction, where it is frequently necessary to take account of what other people see, know, think and want. Under the label "theory of mind" (ToM), perspective-taking has been intensively studied by developmental psychologists (Carpendale & Lewis, 2006) and has recently become of increasing interest to cognitive psychologists and cognitive neuroscientists (see Mason & Macrae, 2008). Studies of children frequently find that ToM is dependent on scarce cognitive resources for executive function (EF) (see Hughes & Ensor ,2007; for a recent review), and a growing body of evidence suggests that this is also true in adults (Apperly, Samson, & Humphreys, 2009). The current work examined whether there might be exceptions to this general pattern, by studying ToM abilities in adults that develop particularly early in children.

Most tests of ToM generate a perspective difference between the participant and the agent whose behaviour or mental state must be judged. False belief tasks are the most widely-studied task of this type (e.g., Wellman, Cross, & Watson, 2001). In a typical task a target protagonist sees an object hidden in location A, but fails to see when it is moved to location B. From around 4 years children tend to make accurate predictions about what the agent thinks (he thinks the object is in location A) or where he will search for his object (location A). Even more complex 2nd order false belief tasks, which require judging what one agent thinks another agent thinks, are passed by most 7–8-year olds (Perner & Wimmer, 1985). Under normal conditions adults do not make errors on such tasks.

In order to study adults, one way around this problem of ceiling effects is to have adults undertake ToM judgements concurrently with a secondary task designed to

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tax cognitive resources that may be necessary for those judgments. McKinnon and Moscovitch (2007) used a working memory task that required monitoring an auditory stream of tones and judging whether the current tone was the same as the last-but-one tone. Performing this task disproportionately impaired simultaneous performance on a story-based ToM task that required judgements about a character's thoughts and feelings (Happé, 1994) compared with a non-ToM control condition. Bull, Phillips, and Conway (2008) used three different executive tasks that loaded most heavily on three different executive functions: inhibition, switching and updating. All three of these tasks impaired simultaneous performance on Happé's (1994) story-based ToM task, but they also impaired simultaneous performance of non-ToM control trials, suggesting that the effects were not specific to judgements about characters' thoughts and feelings. In contrast, performance on the "mind in the eyes task" (where participants judged emotional states from pictures of the eyes; Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001) was specifically disrupted by concurrent performance of the inhibition task. Altogether, these studies suggest that ToM in adults may depend upon the availability of cognitive resources for EF. Moreover, this evidence converges with findings from studies of patients who have impaired cognitive function as a result of brain injury (e.g., Apperly, Samson, & Humphreys, 2005). These have shown that patients with impaired EF abilities show impaired performance on a range of ToM tasks (e.g., Happé, Malhi, & Checkley, 2001; Samson, Apperly, Kathirgamanathan, & Humphreys, 2005; Stone, Baron-Cohen, & Knight, 1998; though see Bird, Castelli, Malik, Frith, & Husain, 2004).

There are two main limitations to our current understanding of the role of EF in ToM in adults. Firstly, most studies of adults have examined relatively complex ToM abilities – such as tests of false belief reasoning (Wellman et al., 2001; Wimmer & Perner, 1983) – that develop relatively late in children. It is not clear that similar conclusions about the role of EF extend to early-developing ToM abilities. Since infants and young children have fewer executive resources at their disposal we might expect a smaller role for EF in whatever ToM abilities are present at these ages. Moreover, it is important for theories of the cognitive basis of ToM to know whether such efficient ToM processes might remain available to adults, alongside more sophisticated ToM abilities that are known to be cognitively demanding. Thus, in the current study we tested adults on a visual perspective-taking task similar to those passed by children aged 14 months (Sodian, Thoermer, & Metz, 2007), and examined whether performance was disrupted by simultaneous performance of a second task that taxed EF.

Secondly, previous studies have not typically distinguished between sub-processes that contribute to ToM. In one suggestion for possible sub-processes, Leslie and colleagues have long proposed a distinction between processes involved in the *calculation* of what someone sees, knows or thinks, and processes involved in the *selection* of such information in order to make a judgement (e.g., Leslie, German, & Polizzi, 2005; Leslie & Thaiss, 1992). Based on their interpretation of data from typical and atypical development, Leslie and colleagues propose that ToM calculation is a modular process, which is fast, automatic and cognitively efficient, whereas selection of ToM information requires effortful deployment of executive resources. Our aim in the current study was to subject this conjecture about the processing characteristics of ToM calculation versus selection to direct empirical test for the first time.

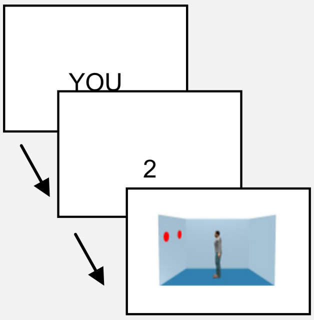
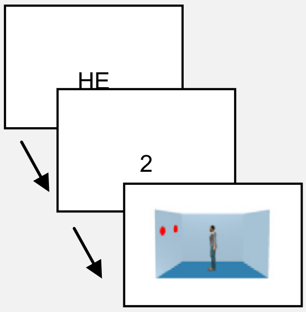
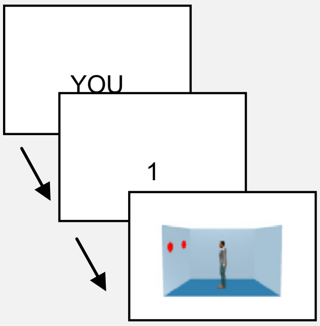
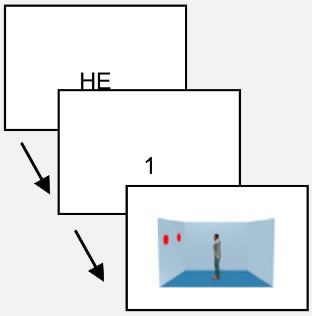
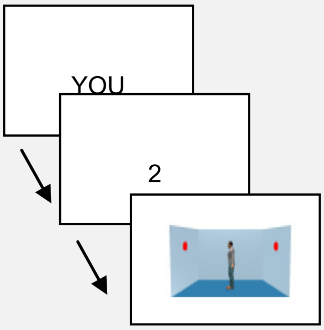
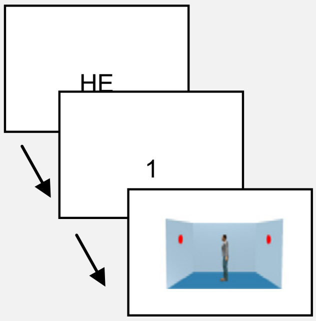
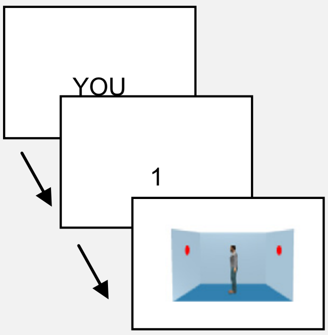
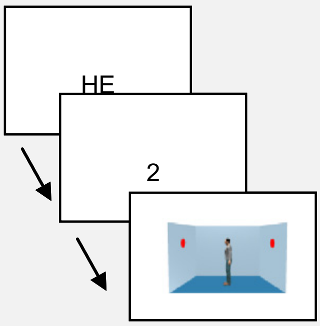
1.1. Direct and indirect measures of perspective-taking

There is growing empirical evidence suggesting that at least some ToM processing may be achieved in a way that is much more cognitively efficient than most studies have suggested. Studies of infants, who have rather limited resources for effortful cognitive control, indicate an early-developing ability to track what an agent can or cannot see (Level-1 visual perspective-taking; Flavell, Everett, Croft, & Flavell, 1981; Moll & Tomasello, 2006) and that this may extend to at least a simple understanding of "knowledge" and "belief" (e.g., Onishi & Baillargeon, 2005; Sodian et al., 2007). Notably, the earliest such abilities are apparent on tasks that use indirect measures such as eye gaze, rather than those that require an explicit judgement about what someone thinks, knows or sees. It has been conjectured that such indirect measures might somehow obviate the need for perspective selection, making it possible to observe that infants have in fact calculated another person's perspective (Baillargeon, Scott, & He, 2010).

Recent findings from older children and adults converge with this suggestion that perspective calculation may, at least in some circumstances, be a cognitively efficient process, and also with the suggestion that the effects of perspective calculation may be observed on indirect measures (Samson, Apperly, Braithwaite, Andrews, & Bodley Scott, in press; Surtees & Apperly, submitted for publication). We describe this task in detail as it is central to the current study. Samson et al. (in press) presented adults with a novel Level-1 visual perspective-taking task. Like more traditional tasks used with young children, this required participants to judge what could be seen by another person whose physical location meant that s/he may not see the same set of objects as the participant. Unlike tasks used with young children participants made a large number of judgements, and in addition to accuracy data, response times were recorded. Participants judged either the number of dots that they could see on the walls of a cartoon room (Self-perspective condition), or the number that could be seen by an avatar standing in the room (Other-perspective condition). At the beginning of each trial participants were told whose perspective to judge. On Consistent trials the avatar could see all of the dots, whereas on Inconsistent trials s/he saw fewer dots than the participant (see Table 1).

When participants made direct judgements about the avatar's perspective (Other-perspective condition) they were slower and more error-prone when their own perspective was inconsistent with the avatar's. This fits with regular reports of "egocentric" bias in explicit perspective-taking, which is thought to originate from the need

Table 1
Example event sequences for the different conditions of the visual perspective-taking task.

Perspective consistency	Perspective: Self	Perspective: Other	Correct response
Consistent			"Yes"
Consistent			"No"
Inconsistent			"Yes"
Inconsistent			"No"

to set aside Self perspective while judging the perspective of another (Epley, Keysar, van Boven, & Gilovich, 2004). The difficulty for our current objectives is that such direct judgements about perspectives clearly require both perspective calculation and selection of this perspective in preference to one's own. On its own, the Other-perspective condition does not allow these processes to be examined independently.

Importantly, however, in the Self-perspective condition an analogous "altercentric" effect was also observed, with slower and more error-prone responses when the avatar's irrelevant perspective was inconsistent with the participant's Self-perspective. This is important because it indicates that participants calculated the avatar's perspective even though they knew that it was irrelevant. The effect remained in a further experiment in which participants only ever judged their Self-perspective, indicating that participants calculated the avatar's perspective even though they were never asked to do so. Critically, however, similar effects were not observed when the avatar was replaced with a non-social control stimulus (a featureless grey bar of similar dimensions), suggesting that the effect was due to perspective-taking, and was not an artefact of processing a complex picture where the dots on the walls of the room were separated by a salient stimulus. We suggest that these "altercentric" effects provide an indirect test of perspective calculation: Judging one's Self-perspective is clearly not a direct test of the ability to adopt the avatar's perspective and clearly does not require selection of the avatar's perspective, but the existence of altercentric interference indicates that the avatar's perspective has, nevertheless, been calculated. The advantage of this over direct tests of perspective-taking (as in the Other-perspective condition) is that it is possible to examine perspective calculation without any confounding effects of a necessity for selecting the other person's perspective over one's own perspective.

In summary, Samson et al.'s (in press) findings suggest that when participants view the avatar in the room they have their own perspective and, in addition, they calculate the perspective of the avatar in a relatively automatic manner. They must then select one of these perspectives in order to follow the task instruction to judge either Self or Other perspective. Samson et al.'s findings suggest that this process of selection is slower and more error-prone when the perspectives are inconsistent than when they are consistent.

However, even though calculation of the avatar's perspective appears relatively automatic, the role of general executive resources in perspective calculation has yet to be determined. Likewise, even though perspective selection shows a demonstrable cost when Self and Other perspectives are inconsistent, it remains to be determined what role, if any, executive resources have in this process of selection. Importantly, whereas the division of labour between perspective calculation and selection has been much discussed in previous work, Samson et al.'s paradigm allows it to be tested directly for the first time, by examining what happens when participants make Self and Other judgements at the same time as a secondary task that taxes executive function.

1.2. Predictions

Concurrent performance of an executive function task might result in a variety of effects or combinations of effects on the perspective-taking task that would not inform our hypotheses about perspective calculation and selection. However, our task analysis leads to two distinctive predictions that would hold even if other effects were also apparent.

1.2.1. Selection

It has previously been proposed that perspective selection requires executive function (e.g., Leslie & Thaiss, 1992; Leslie et al., 2005). The above task analysis suggests that, when the perspective task is performed without a concurrent task, both Self and Other trials require perspective selection, with these demands being highest when Self and Other perspectives are inconsistent. It follows that concurrent performance of an executive task might increase the processing costs for all trials, but would disproportionately affect Inconsistent trials. Put another way, the distinctive finding would be that dual tasking disproportionately increases *both* the egocentric and altercentric interference effects, in comparison with when the task is performed alone.

1.2.2. Calculation

Recall that when the perspective task is performed without a concurrent task, on Self trials, the avatar's perspective does in fact seem to be calculated even though it is not required for these trials. It is this unnecessary calculation that makes Self judgements more demanding when the irrelevant avatar's perspective happens to be inconsistent (the altercentric effect). If EF is required for this unnecessary calculation of the avatar's perspective then it follows that concurrent performance of an executive task should disrupt this calculation. Consequently, the avatar's perspective would no longer be available to interfere with Self judgements and so Self judgements should no longer be more demanding when the avatar's perspective happens to be inconsistent. Put another way, the distinctive finding would be that dual tasking *reduces* the altercentric interference effect in comparison with the effect observed when the task is performed alone. This contrasts with the prediction for egocentric interference (observed on Other-perspective trials), which on any account should either remain the same during dual tasking compared with when the task is performed alone, or otherwise be increased. These predictions are summarised in Table 2.

2. Methods

2.1. Participants

Thirty-two students (five males; two left-handed; mean age 20.9, range 18–36) participated in the study for course credits.

2.2. Apparatus

The visual perspective task was presented on a 15-in. Samsung SyncMaster 793s monitor and a standard keyboard with a 2.40 GHz Pentium-based PC running DMDX (Forster & Forster, 2003). The secondary task was presented on a Toshiba Satellite Pro laptop, using EPrime 1.1 (Schneider, Eschmann, & Zuccolotto, 2002) and an external speaker.

2.3. Design

2.3.1. Visual perspective task

The visual perspective-taking task used the stimuli and procedure of Samson et al. (in press, Experiment 1). The stimuli consisted of a picture showing a lateral view into a room with the left, back and right walls visible and with red dots displayed on one or two walls. A centrally positioned human avatar faced either the left or right wall. On 50% of trials the avatar's position meant that s/he saw the same dots as the participants (Consistent condition). On 50% of trials the avatar's position meant that s/he could

Table 2
Summary of predictions for the effects of concurrent performance of an executive function task on Self-perspective and Other-perspective judgements if executive function is necessary for perspective calculation or perspective selection.

	Role of executive function	
	Calculation	Selection
Self judgements	Decreased altercentric interference	Increased altercentric interference
Other judgements	Increased processing cost for all other judgements[a]	Increased egocentric interference

[a] This prediction is not discussed in the text because it could arise for a variety of other reasons, such as an entirely general effect of dual task performance.

not see some of the dots that were visible to the participants (Inconsistent condition). Participants were first presented with a cue for 750 ms telling them which perspective to judge ("YOU" versus "S/HE"), then another cue for 750 ms telling them an amount of dots to verify (between 0 and 3), followed by the picture of the room. When the picture appeared, participants judged if the number of dots seen by Self or Other matched the number cue. The correct answer was "Yes" on 50% of trials. The picture was displayed until participants responded (or a maximum of 2000 ms). Participants responded with their right hand using a computer mouse (left and right buttons for "yes" and "no", respectively). The main task consisted of four equivalent blocks of 52 trials.

2.3.2. Executive task

The executive task was based on Luria's tapping task (1966). Participants heard auditory stimuli through a speaker (one or two tones) and responded with incongruent key presses (e.g., one press to two tones).[1] The task makes several demands on EF, including inhibiting the response that is congruent with the stimulus. Trials were presented in a pseudo-random order with no more than three trials of the same type in a row. In the dual-task condition participants performed the task continuously throughout each block of the visual perspective task. Because the executive task and the visual perspective task had different durations their phase shifted throughout each block, with the result that the maximal processing cost induced during a trial of the executive task was equally likely to occur at any given point of the visual perspective task.

2.4. Procedure

Participants completed 26 practice trials of the visual perspective task, followed by five practice trials on the executive task and a further 100 trials on the executive task as a baseline measure. Participants then completed 75 practice trials of the visual perspective task simultaneously with the executive task. The four experimental blocks of the visual perspective task were then completed, half in the alone task condition and half in the dual-task condition. The order of the blocks and task condition were counter-balanced.

3. Results

3.1. Visual perspective

Processing costs were calculated for each participant by condition (processing cost = mean correct response time/proportion of correct responses).[2] Following Samson et al. (in press) we only analysed data from trials where the correct answer was "yes". Prior to analysis, response times more than 2.5 SD from the mean, and response omissions due to the timeout procedure, were eliminated as outliers.

We conducted a repeated-measures ANOVA with Consistency (Consistent, Inconsistent), Perspective (Self, Other) and task condition (Dual, Alone) as repeated measures. This revealed a main effect of Consistency (Inconsistent > Consistent; $F_{(1,\ 28)} = 90.39$, $p \leqslant 0.01$, $\eta_p^2 = 0.76$) and task condition (Dual > Alone; $F_{(1,\ 28)} = 115.72$, $p \leqslant 0.01$, $\eta_p^2 = 0.81$), but no effect of Perspective ($F_{(1,\ 28)} = 0.43$, $p = 0.52$, $\eta_p^2 = 0.02$). The only significant interaction was between Consistency and task condition ($F_{(1,\ 28)} = 13.47$, $p \leqslant 0.01$, $\eta_p^2 = 0.33$).

The interaction between Consistency and task condition was examined further. In both Alone and Dual conditions there was an effect of Consistency (Alone, $F_{(1,\ 28)} = 57.44$, $p \leqslant 0.01$, $\eta_p^2 = 0.67$; Dual, $F_{(1,\ 28)} = 59.25$, $p \leqslant 0.01$, $\eta_p^2 = 0.68$), but numerically the difference between processing costs for Consistent and Inconsistent trials was larger in the dual condition (Alone = 132.34 ms; Dual = 268.27 ms). There was an effect of task condition for both Consistent and Inconsistent trials (Consistent, $F_{(1,\ 28)} = 50.25$, $p \leqslant 0.01$, $\eta_p^2 = 0.64$; Inconsistent, $F_{(1,\ 28)} = 72.99$, $p \leqslant 0.01$, $\eta_p^2 = 0.72$), but the difference between processing costs between Alone and Dual conditions was greater for the Inconsistent trials, which make higher demands on perspective selection (Consistent = 155.44 ms; Inconsistent = 306.32 ms) (see Fig. 1).

In sum, concurrent performance of an executive task in the Dual condition increased both egocentric and altercentric interference, and did so to a similar extent in each case.

3.2. Executive task

Participants performed less well on the executive task when performed concurrently with the visual perspective task than when performed alone (response time: $F_{(2,\ 60)} = 62.58$, $p \leqslant 0.01$, $\eta_p^2 = 0.68$; proportion correct: $F_{(2,\ 54)} = 49.83$, $p \leqslant 0.01$, $\eta_p^2 = 0.65$). This confirms that there were

[1] A pilot study showed that performance was worse in the incongruent condition compared to a congruent condition.

[2] The same patterns of results were shown by separate response time and error analyses.

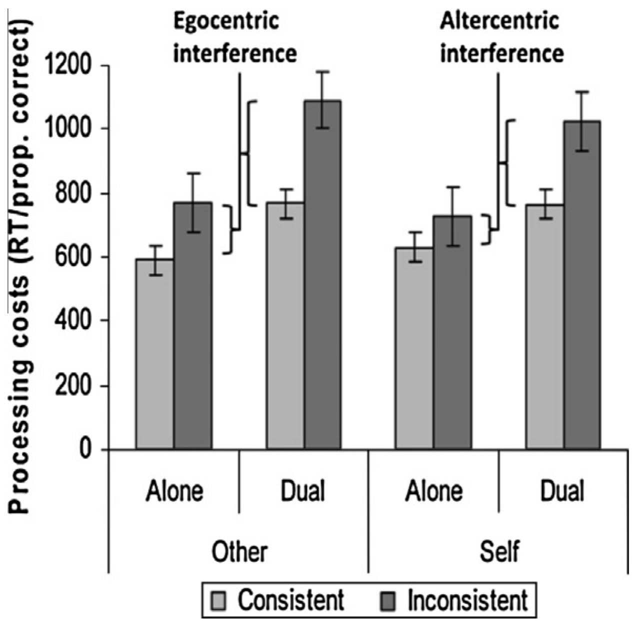


Fig. 1. Processing costs (and standard error) for each task condition. Curved brackets indicate the relative size of the difference between Consistent and Inconsistent trials, which for the Other-perspective condition corresponds to Egocentric interference and in the Self-perspective condition corresponds to Altercentric interference.

common processes between the two tasks. In principle, the common processes might not only involve EF but also motor planning and motor execution processes linked to the motor response required by both tasks. However, on the visual perspective-taking task the Consistent and Inconsistent trials required a similar motor response yet the effect of Condition (Dual or Alone) interacted with the effect of Consistency. This finding suggests that over and above any general interference on planning and executing a motor response, there was a specific effect on processes involved in dealing with inconsistency between Self and Other perspectives, which we attribute to the EF demands of the secondary task.

The current design did not allow us to look at the effects of Consistency and Perspective on EF task performance. Different trials of the visual perspective task were mixed within a block and were of similar but not identical duration to trials of the EF task. As already mentioned, this meant that the maximal processing cost for each EF trial was equally likely to fall at any given point in the visual perspective task. However, this also meant that there was no reliable way of identifying which trial or part of a trial of the visual perspective-taking task overlapped with a given trial of the EF task, or indeed whether the overlap included the end of one visual perspective-taking trial and the start of another. This means that we cannot directly investigate whether the pattern of dual-tasking effects observed in the visual perspective-taking task are due to strategic trade-offs between the two tasks. However, we do not believe such a trade-off is a likely explanation for our findings. For a trade-off to explain away our critical findings it would have to be that the disproportionate negative effect of dual tasking on the Inconsistent trials of the visual perspective-taking task was offset by disproportionately good performance on the EF task while undertaking Inconsistent trials. This seems highly unlikely to be the case, since we already know from the Alone condition that Inconsistent trials of the visual perspective-taking task incur higher processing costs than Consistent trials, so Inconsistent trials should, if anything, be expected to disrupt EF performance more, not less, than Consistent trials.

4. Discussion

Performing an executive task concurrently with the visual perspective-taking task increased overall processing costs, but disproportionately increased the cost due to perspective inconsistency. This was the case for both Self and Other-perspective judgements, resulting in increased altercentric and egocentric effects respectively. Relative to our predictions, the results suggest that executive processes are involved in selection between perspectives, which is more demanding when these perspectives are inconsistent. Moreover, they suggest that the executive processes taxed by the secondary task are *only* involved in perspective selection, and not in the process of calculating the avatar's perspective. This follows from the observation that the executive task did not reduce the effect of perspective consistency on Self perspective judgements (indeed, this altercentric interference was increased). The latter effect suggests that participants continued to perform an irrelevant calculation of the avatar's perspective on Self trials in spite of simultaneously performing the executive task. These findings are consistent with Samson et al.'s (in press) conclusion that adult participants calculate the avatar's perspective in a relatively automatic manner. Importantly, they are the first evidence that perspective calculation is a cognitively efficient process that makes relatively few demands on EF and so is not disrupted by concurrent performance of an executive task.

The suggestion that visual perspectives may be calculated in an efficient manner contrasts with the majority of studies on ToM in children and adults that suggest that ToM is cognitively effortful and heavily reliant on EF (see Apperly et al., 2009 for a recent review). Although this suggestion might seem surprising, it fits with analogous evidence that infants may succeed on ToM problems in some circumstances, even though they lack the executive resources often presumed necessary for ToM (see e.g., Baillargeon et al., 2010). An explanation for these contrasting patterns might lie partly in the fact that studies suggesting that ToM is cognitively effortful invariably confound perspective calculation and selection. Leslie and colleagues (e.g., Leslie & Thaiss, 1992; Leslie et al., 2005) have proposed that the ability to ascribe mental states depends on a cognitively efficient process for perspective calculation plus a cognitively effortful executive process for selecting between different outputs of this process. This implies that participants lacking resources for perspective selection may be capable of perspective calculation, and this calculated perspective might have observable cognitive effects, even before it is "selected" for some particular purposes, such as explicit judgements.

For example, it has been conjectured that calculation without selection might be sufficient to explain the success of infants on ToM tasks that use indirect measures such as looking time (e.g., Baillargeon et al., 2010; Leslie, 2005), even though such success is insufficient to guarantee correct answers to direct questions about the very same ToM judgement (e.g., Clements & Perner, 1994; Ruffman, Garnham, Import, & Connolly, 2001). However, because it is far from clear that infants should not need *both* calculation and selection in order to succeed on ToM tasks that use indirect measures, the idea that calculation is cognitively efficient whereas selection is cognitively effortful has remained conjecture. The current study provides direct support for this hypothesis because the Self-perspective condition demonstrates effects of calculation of the avatar's perspective in circumstances where participants clearly are not selecting this perspective, and shows that perspective calculation is not disrupted by concurrent performance of an executive task. Altogether then, our results suggest that adults might share with infants a cognitively efficient process for perspective calculation. In addition to this, adults are capable of the perspective selection that is required for direct perspective judgements, but this is cognitively effortful, and may be disrupted by the concurrent performance of other demanding tasks.

However, although we think that a distinction between perspective calculation and perspective selection may partly explain the difference between cognitively efficient and cognitively costly ToM processes, we believe there are good reasons for doubting that this is the full explanation because it is implausible that perspective calculation could always be efficient. It is notable that the current data and those from studies of infants only concern the calculation of very simple perspectives. As Apperly and Butterfill (2009) have argued, in many circumstances, ToM calculations require participants to draw on complex background knowledge, represent complex propositional contents, and make complex abductive inferences to the best explanation. All of these requirements are likely to contribute to the observation that ToM is frequently rather cognitively demanding. In the "two-systems" account proposed by Apperly and Butterfill (2009) this means that when ToM calculations manage to be cognitively efficient it may be because they are performed by a cognitive mechanism that is exclusively restricted to processing relatively simple ToM problems. Clearly, an important avenue for further work is to test whether cognitively efficient capacities for ToM calculations are indeed limited to relatively simple problems, and to understand how these abilities might be related, in development and in on-line processing, to the more effortful abilities that are necessary for other kinds of ToM problem.

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