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# Representational and executive selection resources in 'theory of mind': Evidence from compromised belief-desire reasoning in old age

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## Abstract

Effective belief-desire reasoning requires both specialized representational capacities—the capacity to represent the mental states as such—as well as executive selection processes for accurate performance on tasks requiring the prediction and explanation of the actions of social agents. Compromised belief-desire reasoning in a given population may reflect failures in either or both of these systems. We report evidence supporting this two-process model from belief-desire reasoning tasks conducted with younger and older adult populations. When task inferential complexity is held constant, neither group showed specific difficulty with reasoning about mental state content as compared with non-mental state content. However, manipulations that systematically increase executive performance demands within belief-desire reasoning caused systematic decreases in task performance in both older and younger adult groups. Moreover, the effect of increasing executive demands was disproportionately greater in the older group. Regression analysis indicated that measures of processing speed and inhibition contributed most to explaining variance in accuracy and response times in the belief-desire reasoning tasks. These results are consistent with the idea that compromised belief-desire reasoning in old age is likely the result of age-related decline in executive selection skills that supplement core mental state representational abilities, rather than as a result of failures in the representational system itself.


*Keywords:* Belief-desire reasoning; Theory of mind; Executive function; Cognitive aging

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## 1. Introduction

Our capacity to understand the actions, reactions and interactions of other social beings, termed 'theory of mind', has been studied extensively over the last 20 years, most prolifically from a developmental perspective. Recently, the capacities underwriting social cognition have begun to receive serious attention more broadly in cognitive neuroscience, including the documentation of possible brain areas supporting 'theory of mind' via neuroimaging (see Gallagher, & Frith, 2003; Saxe, Carey, & Kanwisher, 2004 for recent reviews) and neuropsychological case studies of acquired and developmental brain lesions (e.g. Baron-Cohen, Leslie, & Frith, 1985; Fine, Lumden, & Blair, 2001; Frith, Morton Leslie, 1991; Rowe, Bullock, Polkey, & Morris, 2001; Channon, & Crawford, 2000; Apperly, Samson, Chiavarino, & Humphreys, 2004). Remarkably, despite more than 20 years of cognitive developmental research on 'theory of mind', the first simple models of successful belief-desire reasoning have only recently been proposed (Friedman, & Leslie, 2004a, 2004b; 2005; Leslie, & Pollizi, 1998; Leslie, Friedman, & German, 2004; Leslie, German, & Pollizi, 2005).

In the current paper, we outline briefly the assumptions of a recent model of belief-desire reasoning, and test predictions of this model in young and older adults. The model has been developed to account for results from behavioral belief-desire reasoning tasks largely undertaken with young children as participants, in which children are required to predict or explain the actions that social agents take in terms of their underlying mental states. For example, children might be required to predict where a story character might look for some desired object *x*, given that she believes it is in location *y*.

Inference tasks such as this might seem trivially simple from an adult point of view, but for young children, under certain conditions, they can prove quite challenging. For example, in one prominent task children watch a character, Sally, hide a marble in one location before leaving the scene, whereupon the marble is switched to another location in her absence. In predicting Sally's search on returning to the room children younger than 4 years of age often fail to take into account her false belief, and predict search at the location containing the object—an error that is overcome by the time that typically developing children reach age five (Baron-Cohen, et al., 1985; Wellman, et al. 2001). Thus, one major contributor to the ease or difficulty of belief-desire reasoning is whether the content of the belief to be attributed is true (easier) or false (more difficult), and this fact has proved to be one key finding that theories of the development of belief-desire reasoning have attempted to explain (Bloom, & German, 2000).

There is considerable debate about the nature of the mechanisms that support 'theory of mind' skills. However, theories in cognitive development have generally agreed that effective belief-desire reasoning requires at least two kinds of process. First, there must be representational resources that capture mental state knowledge itself. Second, there must be processes that allow this knowledge to be deployed in actual prediction and explanation tasks. Different theorists place more or less emphasis on the relative importance of each kind of process in explaining the developmental data (Leslie et al., 2004, 2005; Scholl, & Leslie, 1999, 2001; Wellman et al., 2001).

### 1.1. Elements of effective belief-desire reasoning

According to the framework adopted here, 'theory of mind' capacities are in part based on a representational system that allows mental state concepts such as belief and desire to be represented as such. This representational system is provided by a specialized reliably developing modular neuro-cognitive mechanism that supports the early capacity to attend to and then learn about mental states (Baron-Cohen, 1995; German, & Leslie, 2000, 2001, 2004; Leslie, 1994b, 2000; Leslie, et al., 2004; Roth, & Leslie, 1998; Scholl, & Leslie, 1999). Reasoning over the representations provided by this basic representational system also requires a species of executive function. These supplementary processes serve to select particular mental state contents to be attributed to social agents in a given belief-desire reasoning problem.

The idea is that in a given situation, perceptual descriptions of a social agent's behavior act as inputs to the specialized representational system which provides a number of candidate mental state attributions. The executive selection process then decides among these candidate mental state contents. For example, in the false belief task, the system might provide two possible contents for Sally's belief: first, that she believes the marble is in location 1 (where she left it) or second, that she believes it is in location 2 (where it currently is). A further assumption of this model of belief desire-reasoning is that the selection process has a default content. Because people's beliefs are most often true, the selection process will always attach most initial weight to the true-belief content: the content consistent with the state of the world as it appears to the attributer of the belief (e.g. the participant).

On this theory, the standard false belief task is difficult because the selection process is required to overcome the default 'true belief' attribution. By hypothesis, executive inhibitory processes are required to manage this selection, in effect reducing the activation level of the true belief content to a point below that of the false belief content (which is the correct content to attribute given the situation). The proposal that inhibitory processes are involved in belief-desire reasoning has support from several converging sources.

First, inhibitory executive function is limited in the preschool period and beyond (Gerstadt, Hong, & Diamond, 1994; Diamond, Kirkham, & Amso, 2002), and performance on belief-desire reasoning problems is strongly correlated with measures of executive inhibitory function (Carlson, Moses, & Hix, 1998; Carlson, Moses, & Breton, 2002; Carlson, & Moses, 2001; Russell, Mauthner, Sharpe, & Tidswell, 1991). Second, false belief performance in young children is affected by manipulations of the relative salience of the 'true belief' vs. 'false belief' (correct) content. For example, when attention is drawn to the initial location of the object in a false belief problem, children perform significantly better (Leslie et al., 2005; Siegal, & Beattie, 1991; Surian, & Leslie, 1999; Yazdi, German, Defeyter, & Siegal, in press).

Effective belief-desire reasoning thus depends critically on an intact representational system for belief and desire knowledge that comes online in the typical case in the first years of life (Leslie, 1987; 1994a) and also on mechanisms of executive selection that develop only gradually over the preschool years. Therefore while successful performance requires both cognitive systems to be intact, compromised performance might result from inefficiencies in either system, or both. With colleagues, we have argued elsewhere that inefficient belief-desire reasoning that is seen in young children (e.g. failures in the false belief task) can be plausibly accounted for in terms of the gradual development of pre-frontal cortex supported executive selection systems, as demonstrated via the strategy of varying the difficulty of the selection demands in belief-desire reasoning problems described above (German, & Leslie, 2000, 2004; Leslie et al., 2004; 2005; Yazdi et al., in press)[1].

In other populations with known social cognition problems, however, failures with the specialized belief-desire representational system itself have been implicated. This hypothesis has been advanced for the case of the Autism Spectrum Disorders (Baron-Cohen, 1995; Frith, et al., 1991; Leslie, & Roth, 1993; Leslie, & Thaiss, 1992).

### *1.2. Theory of mind and cognitive aging*

In the current paper we investigate recent claims of compromised belief-desire reasoning associated with cognitive aging (Maylor et al., 2002) with respect to the question of decline in frontal executive systems.

Individuals undergoing cognitive aging are an ideal population to test the notion that belief-desire reasoning requires executive selection processes because such individuals have been shown to suffer from decline in a range of executive capacities including aspects of inhibitory function (Hasher, & Zacks, 1988; Kramer, Humphrey, Larish, Logan, & Strayer, 1994), as well as processing speed (Salthouse, 1996) as age increases. These declines have been captured under the 'frontal' hypothesis of aging (Lowe, & Rabbitt, 1997; Raz, 2000). Moreover, whereas for preschool children, the claim that belief-desire reasoning failure might result from a failure to have yet acquired relevant specialized representational knowledge about mental states (Wellman et al., 2001) is at least plausible, it seems considerably less so for elderly adults[2].

Prior studies of 'theory of mind' in old age have provided mixed results. An initial study by Happé, Brownell and Winner (1998) used tasks requiring inferences from short stories and reported a sparing of mental state inferences compared to control tasks; their older group (mean age 73 years) outperformed a younger group (mean age 21 years) in the mental state inference condition. However, this advantage was not replicated by Maylor et al. (2002), who actually found an age related decline in the ability to successfully answer simple theory of mind inferences, as compared to control tasks. Moreover, the decline in mental state based inferences was shown to persist even in tasks with reduced memory demands, and taking into account measures of processing speed and executive

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[1] Most debate in the cognitive developmental literature has surrounded this claim. Alternatives to the current characterization suggest that it is changes in the core conceptual capacity itself that explains improved performance at false belief over the preschool years rather than any combination of executive or other 'performance' factors (Wellman et al., 2001). Since the current study does not provide direct evidence on this question, we defer its treatment until the Discussion.

[2] Note that this is not to deny that normal aging or aging with associated dementia might result in some loss of semantic memory with the result that conceptual knowledge becomes fractionated or lost. This fractionation of semantic memory might plausibly extend to conceptual knowledge about mental states as has been argued for individuals with frontal variant fronto-temporal dementia (Gregory et al., 2002; Lough, Gregory, & Hodges, 2001).

function (see also, Sullivan, & Ruffman, 2004). Maylor et al. (2002) concluded that the declining theory of mind abilities observed in their study were consistent with both neuroimaging and neuropsychological evidence of a frontal locus for aspects of processing in theory of mind tasks (Frith, & Frith, 1999; Saxe et al., 2004; Rowe et al., 2001) and the notion of frontal decline associated with aging (Lowe, & Rabbitt, 1997), but expressed puzzlement at the lack of association with their measures of executive function (the WCST), and the persistence of the problem after executive and speed of processing measures were accounted for (Maylor et al., 2002, p 481).

We note that one possible reason for the failure to find an executive association, noted above, might be an underestimation of the fractionation that could exist within executive frontal processes (Burgess, Alderman, Evans, Emslie, & Wilson, 1998; Goldman-Rakic, 1996; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000; Shallice, & Burgess, 1991). Developmental evidence has suggested that the relationship between executive function and mental state reasoning may be quite specific to tasks within the executive function spectrum that draw on certain inhibitory components (e.g. response conflict rather than delay, Carlson et al., 2002). Thus, finding or not finding an association might depend critically on the selected measures of executive function chosen.

In the current study, we tested a central prediction of the two part processing model of belief-desire reasoning—that executive selection is required as part of belief-desire reasoning—in a group of elderly participants (mean age = 78) and a group of younger adult control participants (mean age = 20), using two basic strategies. Firstly, we created matched minimally different inference tasks that either required a calculation based on the mental states of a social agent, or a calculation based on a physical system that had access to equivalent information. Critically, we improved on prior inference tasks used to assess ‘theory of mind’ vs. ‘control’ inferences, both with elderly participants (Happé et al., 1998; Maylor et al., 2002) and in early functional imaging studies (Fletcher, Happé, Frith, Baker, Dolan and Frackowiak, 1995; Gallagher, Happé, Brunswick, Fletcher, Frith and Frith, 2000), by designing true minimal pair story content.

Minimal pair designs aim to manipulate content between two conditions via the smallest possible change being made. Examples from cognitive development that have elucidated understanding of the acquisition of ‘theory of mind’ skills include the comparison between the false belief task and the false photograph task (Zaitchik, 1990), in which task structure remains constant and content is minimally altered. This pair of tasks was used to demonstrate the domain specific nature of the limitation showed in reasoning about representational content in children with autism spectrum disorders, who perform at ceiling with public representations such as photographs and maps, while performing poorly on problems involving belief (Charman, & Baron-Cohen, 1995; Leslie, & Thaiss, 1992). Another key example of a minimal pair design that has had great impact involves the addition of a single word to the standard false belief action prediction problem; if children, instead of being asked where Sally will look, are asked where she will look first, performance dramatically improves (Siegal, & Beattie, 1991; Surian, & Leslie, 1999; Yazdi et al., in press). To date, minimal pair designs such as these have not been utilized in the study of mental state reasoning in elderly populations; inspection of the stories used in the mental state vs. control conditions reveals many potential differences in content, structure, and complexity of the inferences. In the current manuscript, we attempted to more closely match the structure of the mental state and control problems such that a close minimal pair was formed.

In one battery of reasoning tasks, representational content was varied within a task structure held constant in terms of the number and complexity of the inferences required. In 'mental state' tasks a scenario was described and a social agent was introduced. A judgment was then required about the action that agent would take, given the scenario. In the control versions of the tasks, the same scenarios were used but the inference was required about whether a mechanical device (e.g. an alarm system) with access to equivalent information would be triggered or not. Critically, the amount of information required to make each inference was held constant. Because mental state stories involved an additional entity (the social agent), this feature was matched in the control inference by the inclusion of an additional variable that could affect the outcome (e.g. whether a power supply was functioning or not). An example of a minimal pair of inference tasks used in the experimental battery appears in Table 1.

The second strategy was to manipulate executive selection requirements of a basic belief-desire reasoning problem. In each case, the participant was required to predict the action that would follow from a particular belief-desire pair. The tasks differed according to factors empirically known to affect the ease or difficulty of the executive selection problem, based on studies conducted with preschool children. One factor, briefly discussed

Table 1
Two examples of story content for inference stories used in the mental state vs. control inference battery

In a national park there is a high prevalence of fires in the dry summer season.

Temperature sensors have been placed in the park to detect fires before they spread

When the temperature reaches a certain level the sensors cause an alarm to sound and firemen are dispatched

Covers over the sensors prevent them being triggered by direct sunlight

| *Mental state inference task* | *Non mental state control inference task* |
|---|---|
| A sensor in the north of the park is missing a cover | There is no fire in the park forest today |
| The ranger knows/does not know the cover is missing | A sensor is missing its cover/ all sensor covers are intact |
| *Will the ranger override the alarm or let it got through?* | *Will the alarm go off or will it remain status quo?* |

In the mental state stories the inference required keeping track of what information the social agent had about the preceding sequence of events. The question asked about the agent's action given their knowledge of that sequence. For example, in this example story the agent either knew or did not know about a condition affecting the output of the device. This extra step in the mental state inferences stories was matched in the control stories via the mechanical device itself either having some function intact (allowing a certain response) or having that function disabled (such that a response was impossible).

before, was that the tasks varied in terms of the truth or falsehood of the belief (TB vs. FB tasks). As noted, false belief problems are harder for preschool children than are true belief problems.

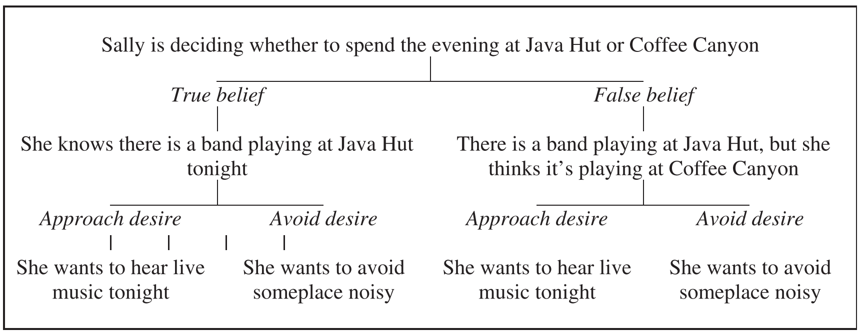
The second factor manipulated in this task battery was whether the actor had a desire to ‘approach’ or ‘avoid’ a target object. While children from age four typically solve false belief tasks where the character has the desire of approaching the object (e.g. Sally wants her marble, but thinks it is in the box) results show that this success does not extend to the case where Sally wishes to avoid something about the location of which she has a mistaken belief (Cassidy, 1998; Leslie, & Pollizi, 1998; Leslie et al., 2005). Children do not reliably solve avoid desire false belief problems until age six (Friedman, & Leslie, 2004a, b). Indeed, from the preschool data across tasks that vary the truth and falsehood of the protagonist’s belief, and whether the character has the desire to approach or avoid the object, there is a predictable developmental trajectory: TB approach > TB avoid > FB approach > FB avoid (Cassidy, 1998; Friedman, & Leslie, 2004; Leslie, & Pollizi, 1998; Leslie, et al., 2005). An example of a story in each of its four versions appears in Table 2.

We predicted that if belief-desire reasoning problems arise as a result of failures to meet the executive selection demands, our elderly participants would show a disproportionate increasing cost in accuracy and/or response time in solving the belief-desire reasoning tasks as executive performance demands increase in the order derived from the developmental trajectory.

Finally, in order to directly assess the hypothesis that executive selection capacities are related to belief-desire reasoning, a number of measures of cognitive function with no mental state content were included. These were chosen to provide a focused test of the idea that executive selection in belief-desire reasoning might draw on inhibitory processes (Friedman, & Leslie, 2004a,b; Leslie, 2000; Leslie et al., in press, 2004) and thus a variety of ‘response competition’ inhibition tasks were included. These comprised interference conditions of the Stroop task, the Hayling sentence completion task (Burgess, & Shallice, 1996), and the interference condition of the ‘day–night’ task (Gerstadt et al., 1994).

In addition, given claims that working memory might be one of the executive systems engaged by mental state reasoning (Gordon, & Olsen, 1998; Davis, & Pratt, 1995), we

Table 2
Structure of four belief-desire reasoning tasks varying the content of the character’s belief (true vs. false) and whether or not the character wanted to approach or avoid the target item



assessed working memory via the backwards digit span task. Following Maylor et al. (2002) we also assessed 'fluid' processing speed and matched our participants in terms of 'crystallized' and 'pre-morbid' intelligence.

## 2. Methods

### 2.1. Participants

The participants in this study were 27 young adults (18 females, 9 males; mean age 20 years, range 18–26), recruited through an Introductory to Psychology Course at University of California, Santa Barbara, and received course credit for participation in the study and 20 elderly adults (19 females, 1 male; mean age 78, range 62–90), recruited through independent living retirement communities in the vicinity of Santa Barbara, CA, USA who were paid for their participation.

The mean number of years of education, and measures of crystallized verbal IQ (Mill Hill vocabulary test; Raven, Raven, & Court, 1988), pre-morbid verbal IQ (Wechsler Test of Adult Reading, Weschler, 1981) were taken from all participants and appear in Table 3.

### 2.2. Tasks and materials

#### 2.2.1. General cognitive assessment tasks

As noted above, a battery of tests used to assess general aspects of cognitive function were administered to each participant. These tests include proxy measures of crystallized intelligence (Mill Hill vocabulary test) and pre-morbid verbal IQ (Weschler test of adult reading).

In addition to these general tasks, we measured memory span (via the forward digit span task), working memory (via the backward digit span), a measure capturing 'fluid' speed of processing (the digit symbol substitution test, following Maylor et al., 2002), and as a result of the hypothesis that inhibitory processing might be a key cognitive function related to belief-desire reasoning, we included a battery of tasks that stress cognitive inhibition with response conflict (Carlson et al., 2002), including the color stroop

Table 3
Mean age (in years), mean years of education, mean estimated crystallized verbal IQ (Mill Hill vocabulary test), and mean estimated pre-morbid verbal IQ (WTAR) for participants in each group

| Measure | Younger adults | | Older adults | |
|---|---|---|---|---|
| | *M* | SD | *M* | SD |
| Age* | 19.51 | (1.51) | 78.22 | (8.27) |
| Years of Education | 12.78 | (0.93) | 13.20 | (1.64) |
| Crystallized Verbal ability[a] | 16.41 | (4.55) | 17.12 | (5.38) |
| Pre-morbid Verbal ability[b] | 40.67 | (5.48) | 38.40 | (8.67) |

*$t_{(20)} = 31.36$, $p < 0.01$ (degrees of freedom adjusted to account for inequality of variances).

[a] Mill Hill vocabulary test (Raven et al., 1988); maximum score = 33.

[b] Weschler test of adult reading (Weschler, 1981); maximum score = 50.

(baseline, interference and 'negative priming' conditions), the 'day–night' task (Gerstadt, et al., 1994), and the Hayling sentence completion task (Burgess, & Shallice, 1996).

The Stroop Task was administered in three conditions—baseline (naming ink color of blocks of Xs), interference (naming ink color of mismatching color words), and negative priming (naming ink color where distracter word for trial $n-1$ becomes target ink color of trial $n$). For each condition, total time in seconds to complete the list and number of errors was recorded.

The day–night response competition task consisted of 14 cards, seven with a picture of a sun and seven with a picture of a moon and stars. The cards were shuffled and flipped over one at a time, and the participant was instructed to say the opposite of what the card depicted. For instance, if a card has a picture of a sun, the correct response is 'night'; and, if the card has a picture of a moon and stars, the correct response is 'day'. Total time in seconds to make it through the 14 cards and number of errors was recorded for each participant.

The final measure of inhibitory processing was obtained with Hayling's Sentence Completion Test (Burgess, & Shallice, 1996), in which the participant must complete a sentence stem with a word that is unconnected to the content of the stem. Total time in seconds to complete 15 sentences was recorded, as well as the total number of errors made in the unconnected sentence completion condition (e.g. where a related word is used as the completion).

### 2.2.2. *Theory of mind tasks*

Each participant received a series of belief-desire reasoning problems, and a series of problems with no mental state content.

One set of tasks involved 'theory of mind' and control reasoning tasks that employed the matched inference structures—comprising story pairs that differed in only two key sentences. The content was identical, save for the last episode in which either a social agent ('theory of mind' story) or a mechanical device (control story) was described as having witnessed the preceding events. Participants were asked to make a judgment about the action of the social agent or the output of the mechanical device.

Participants received either the mental state or control version of a given story problem, and received a total of two tasks with each content type. Note that while some stories required reasoning from a situation where the social agent was ignorant (equivalent to 'false belief' scenarios) others required reasoning from knowledge ('true belief'). This feature was matched for the control stories, where the mechanical system was either compromised in some way (and therefore had lack of access to information or a response) or was intact (and had full information or capacity to respond). The inference stories were designed such that participants were required to assess each step of the inference chain, and make a decision about the social agent (based on the belief he/she would form) or the output of the machine (based on the events and functionality of the machine). An example story content in its two versions appears in Table 1.

A second set of tasks all required the participants to reason about mental states (e.g. predict an action that resulted from a belief and desire). However, the tasks differed in the extent to which they required the deployment of executive performance demands. The tasks involved either true or false beliefs (TB vs. FB), and either the character had the desire to approach the object (approach desire: +) or avoid it (avoid desire: −). An example of a story in each of its four versions appears in Table 2. Participants received three examples of each story type, for a total of 12 stories.

### 2.3. Procedure

All participants were tested individually. The young participants were tested in a quiet laboratory setting at the University, and the elderly participants were tested in a quiet room at their retirement community. The first task administered to participants was the Mill Hill vocabulary test, which was given as a paper and pencil task. Participants were then presented with a booklet containing the two 'theory of mind' problems and the two matched 'control' problems. They were informed that the booklet contained some simple short stories with a story on one page followed by a question on the next page. They were instructed to follow along in the booklet as the stories were read out loud to them. When they felt that they understood what was going on in the story, they were to turn the page to the question.

Once they turned the page, the experimenter then asked the question for that story and recorded the participant's oral response. Participants were instructed that, if necessary, they were allowed to refer back to the story before they answered the question. The experimenter recorded the number of times the participant referred to the story before answering the prediction question, the number of control question corrections, and the response time (s) the participant took to answer each prediction question.

When the booklet was completed, the participants were given the Weschler test of adult reading followed by the baseline, interference, and negative priming conditions of the Stroop task, the coding portion of the digit symbol substitution test, the day–night response competition task and then the Hayling's sentence completion test.

Participants were then given the second booklet of theory of mind stories, this one containing the 12 belief-desire reasoning problems that varied according to true/false belief and approach/avoid desire (three each). They were reminded of the instructions, and the same procedure stated above was followed. Participants were again instructed to follow along in their booklet as the stories were read out loud, and to turn the page to the question when they were ready for the questions. Once they turned the page, the experimenter asked the prediction question and recorded the participant's oral response. As with the first booklet of stories, participants were informed that they were allowed to refer back to the story, if necessary, before they answered the question. The experimenter recorded the response time (s) using a handheld stopwatch.

Finally, the participants were given the memory tasks—forward digit span followed by backward digit span. They were thanked for their time, paid and debriefed.

## 3. Results

### 3.1. Memory, speed of processing and inhibition

Mean performance on the various cognitive tasks (speed of processing, memory tasks, and the battery of inhibitory tasks), for each participant group appears in Table 4.

Table 4
Mean scores on measures of cognitive function including speed, memory and working memory and inhibitory processing in younger and older adults (standard deviations in parentheses)

| Measure | Young adults | Older adults | $t$ | $p$ |
|---|---|---|---|---|
| | Mean (SD) | Mean (SD) | | |
| *Speed of processing* | | | | |
| Digit symbol substitution | 86.88 (8.89) | 36.20 (13.06) | −14.62 | ** |
| *Memory* | | | | |
| Digit span | 6.56 (1.05) | 5.80 (1.44) | −2.09 | * |
| Backwards digit span | 5.11 (1.48) | 3.50 (0.89) | −4.65 | ** |
| *Inhibition* | | | | |
| (i) Stroop | | | | |
| Baseline time (s) | 9.67 (1.67) | 22.76 (12.43) | 2.12 | * |
| Baseline errors | 0.11 (0.32) | 0.47 (0.70) | 4.56 | ** |
| Interference time (s) | 14.97 (2.92) | 45.08 (27.67) | 3.01 | ** |
| Interference errors | 0.41 (0.57) | 4.63 (6.10) | 4.72 | ** |
| Negative priming time (s) | 15.31 (3.14) | 40.16 (17.58) | 2.37 | ** |
| Negative priming errors | 0.74 (1.29) | 3.42 (4.81) | 6.10 | * |
| (ii) Day–night task | | | | |
| Time (s) | 22.85 (6.86) | 23.79 (8.17) | 1.87 | N.S. |
| Errors | 0.56 (0.75) | 1.35 (1.79) | 0.43 | N.S. |
| (iii) Hayling sentence completion | | | | |
| Time (s) | 18.37 (24.95) | 47.63 (22.84) | 3.85 | ** |
| Errors | 2.81 (3.04) | 7.84 (5.09) | 4.05 | ** |

Note: *$p<.05$, **$p<.01$, two-tailed.

Inspection of this table indicate that as might be expected, the older adults performed more poorly across the entire range of cognitive assessments, with the exception of performance on the day–night interference task.

### 3.2. Isolating conceptual competence: 'Mental state' vs. 'control' inference tasks

Participants scored one point for a correct response on each task, and thus scores for each task type 'mental state' and 'control', ranged from 0–2. There were no effects of story type, order of presentation, or whether the inference was based on either 'knowing' or 'not knowing' (in the case of social agents) or on 'full function' vs. 'lack of function' (in the case of mechanical systems). Nor were there any effects of problem order or story content. Mean performance and mean response times for each group and according to story type appear in Table 5.

Inspection of this table suggests that accuracy across both mental state and control tasks is affected by age, with older participants performing more poorly than the young adults. The effect of content (mental state vs. control) on accuracy appears modest. An analysis of variance (ANOVA) with two levels of task (theory of mind vs. control) as the within subjects variable and age group as the between subjects variable confirmed these impressions. There was a significant effect of age, $F(1,45)=8.43$, $p<0.01$. The strength of the relationship between age and performance on these tasks, as assessed by $\eta^2$, was moderate with age accounting for 15.8% of the variance in performance. The main effect of task (mental state vs.

Table 5
Mean scores and mean response times across 'theory of mind' inference tasks in younger and older participants (SDs in parentheses)

| Measure | Young adults Mean (SD) | Older adults Mean (SD) |
|---|---|---|
| *Mentalizing vs. non-mentalizing* | | |
| (i) Accuracy (max = 2) | | |
| Mental state inference | 1.59 (0.57) | 1.30 (0.80) |
| Control inference | 1.63 (0.63) | 1.10 (0.79) |
| (ii) Response time (s) | | |
| Mental state inference | 4.21 (5.23) | 13.68 (19.80) |
| Control inference | 9.66 (8.65) | 18.75 (17.28) |
| *Performance across belief-desire reasoning tasks* | | |
| (i) Accuracy (max = 3) | | |
| TB + | 2.93 (0.27) | 2.65 (0.67) |
| TB − | 3.00 (0.00) | 2.55 (0.66) |
| FB + | 2.70 (0.61) | 1.50 (0.83) |
| FB − | 2.44 (0.75) | 1.35 (0.88) |
| (ii) Response time (s) | | |
| TB + | 0.70 (0.24) | 3.09 (2.35) |
| TB − | 0.80 (0.47) | 3.75 (3.37) |
| FB + | 1.19 (0.82) | 4.80 (3.49) |
| FB − | 1.20 (0.90) | 6.07 (4.86) |

TB +, true belief approach desire; TB −, true belief avoidance desire; FB +, false belief approach desire; FB −, false belief avoidance desire.

control inferences) was not significant, $\Lambda = 0.99$, $F(1,45) = 0.31$, $p > 0.05$, and there was no interaction between task and age, $\Lambda = 0.99$, $F(1,45) = 0.66$, $p > 0.05$[3].

In summary, this pattern of results suggests that if closely matched task structures are employed, there is no evidence that theory of mind inferences are performed more poorly than inference tasks with non-mental state content. Indeed, mental state inferences were performed equally accurately and significantly more quickly than were inferences about physical-mechanical systems. The effect of increasing age on this pattern was to reduce accuracy and increase response time, but there is no hint of any disproportionate impairment on the capacity to handle mental state inferences (as compared with control inferences) in the older group, as would be expected if they had any specific problem with theory of mind.

### *3.3. Isolating 'executive selection': belief-desire reasoning problems*

Scores for the four belief-desire reasoning problems (TB +, TB −, FB +, FB −) ranged from 0–3. Mean accuracy and mean response time for each group, arranged by task type

[3] Similar analysis was conducted for the response time dataset, which revealed an almost identical pattern of results, except that the main effect of task was significant for the response time measure, $\Lambda = 0.85$, $F(1,45) = 7.89$, $p < 0.01$, suggesting that latencies were longer for the control inference stories about mechanical systems than they were for the mental state inferences.

also appears in Table 5. Inspection of Table 5 suggests that performance across all belief-desire reasoning tasks declines with age, and appears to decline as predicted performance difficulty increases. A repeated measures analysis of variance (ANOVA) with four levels of task (TB approach desire [TB+], TB avoidance desire [TB−], FB approach desire [FB+], and FB avoidance desire [FB−]) as a within subjects variable, and age group as a between subjects variable confirmed that there was a significant main effect of age on accuracy, $F(1,45)=42.67$, $p<0.01$. The strength of the relationship between age and performance on these tasks, as assessed by $\eta^2$, was strong with age accounting for 48.7% of the variance in task performance.

There was also a main effect of task type, $\Lambda=0.33$, $F(3,43)=29.30$, $p<0.01$, as well as an interaction between task type and age, $\Lambda=0.63$, $F(3,43)=8.13$, $p<0.01$. Analysis of response time data revealed the same pattern of results. See Fig. 1 for a plot of this interaction, which reveals an increased effect of task difficulty in the older group as compared with the younger group[4].

In summary, these results support the idea that executive selection processes are implicated in belief-desire reasoning. The task difficulty metric identified on the basis of tasks administered to preschool and young school age children was shown to hold for both measures of accuracy and response time in both young and older adults. Interestingly, inspecting Fig. 1, it can be seen that the costs of each factor in our difficulty manipulation (true vs. false; approach vs. avoid), are for the majority of measures different, with a greater cost accruing for the true vs. false belief factor. This result is consistent with developmental findings suggesting that the selection processing involved in the attribution of false belief is greater than that involved in attributing avoid desire (Leslie et al., 2005).

Moreover, as well as showing a general cost in both accuracy and response time, as compared with the younger group, the older adults were disproportionately affected by the increases in selection difficulty across the four tasks, with the TB+ task resulting in the smallest age deficit, and the FB- task resulting in the largest.

### *3.4. Relationships between belief-desire reasoning and measures of cognitive function*

Table 4 shows correlations between background variables (chronological age, years of education, crystallized IQ, pre-morbid verbal IQ), and both accuracy and response times for the four belief-desire reasoning tasks.

Inspection of Table 6 reveals that the only background variable that correlated with performance on all belief-desire reasoning tasks was chronological age. The TB avoid task was also significantly correlated with the verbal IQ measures. Performance on all four of the tasks was significantly correlated with speed of processing. Performance on all tasks except the TB approach task was also significantly correlated with working memory.

[4] Simple linear ordered contrast analysis confirmed the predicted order of difficulty of the tasks from easiest to most difficult reasoning tasks (TB+ > TB− > FB+ > FB−) $F(1,45)=80.89$, $p<0.01$. Separate contrast analyses were conducted for the elderly, $F(1,19)=71.10$, $p<0.01$, and for the young adults, $F(1,26)=13.71$, $p<0.01$, showing the predicted order of difficulty contrast was significant for both the young and elderly adult groups. The same analysis was conducted for the response time dataset, which revealed an identical pattern of results.

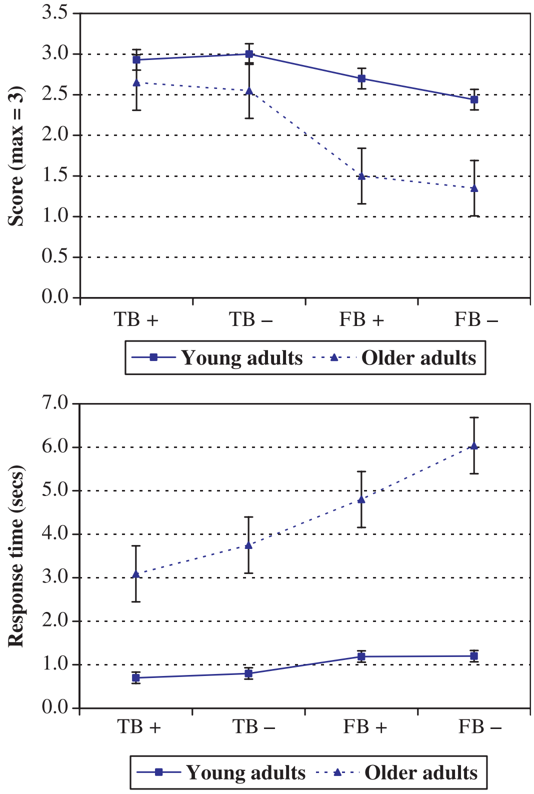



Fig. 1. Plots of belief-desire reasoning in each of the four tasks (true belief approach desire [TB+], true belief avoid desire [TB−], false belief approach desire [FB+], and false belief avoid desire [FB−]), as a function of age, for both accuracy (top panel), and response time (bottom panel).

However, memory span was only significantly correlated with performance on the TB avoid and FB approach tasks.

Correlations between chronological age, the composite inhibitory processing measure, speed of processing, memory span, working memory, and accuracy on the four belief-desire reasoning tasks appears in Table 7a, while correlations between the same measures and response time for the belief-desire reasoning tasks appear in Table 7b.

Overall, performance on the four belief-desire reasoning tasks, as indexed both by accuracy of inferences and response time was strongly correlated with measures of three cognitive abilities. These abilities were (i) speed of processing (as indexed by digit symbol substitution, (ii) inhibitory processing (as indexed by a composite of Stroop [interference and negative priming conditions] and the Hayling's sentence completion task), and (iii) working memory (as indexed by the backwards digit span).

Because these measures of general cognitive function were themselves strongly inter-correlated (Table 7a), a series of hierarchical regression analyses were conducted to determine the predictors of accuracy and response time for each of the four belief-desire

Table 6
Correlations between participants' chronological age, years of education, crystallized verbal IQ, premorbid verbal IQ, and (a) accuracy of performance on belief-desire reasoning tasks and (b) response time performance on belief-desire reasoning tasks

| Measure | Education | CVA[a] | PVA[b] | TB+ | TB− | FB+ | FB− |
|---|---|---|---|---|---|---|---|
| (a) Correlations with ToM accuracy | | | | | | | |
| Age | 0.19 | 0.14 | −0.15 | −0.26 | −0.50** | −0.61** | −0.55** |
| Education | | 0.18 | 0.08 | 0.02 | 0.02 | −0.05 | −0.00 |
| CVIQ | | | 0.66** | 0.21 | 0.32* | 0.28 | 0.13 |
| P-VIQ | | | | 0.09 | 0.33* | 0.28 | 0.22 |
| (b) Correlations with ToM response time | | | | | | | |
| Age | | | | 0.63** | 0.56** | 0.63** | −0.64** |
| Education | | | | 0.07 | 0.09 | 0.08 | 0.10 |
| CVIQ | | | | −0.11 | −0.09 | −0.12 | −0.17 |
| P-VIQ | | | | −0.00 | −0.13 | −0.09 | −0.26 |

Note: $*p<0.05$, $**p<0.01$, two-tailed. TB+, true belief approach desire; TB−, true belief avoidance desire; FB+, false belief approach desire; FB−, false belief avoidance desire.
[a] CVA, crystallized verbal ability as measured by Mill Hill vocabulary test (Raven et al., 1988).
[b] P-VIQ, pre-morbid verbal ability as measured by Weschler test of adult reading (Weschler, 1981).

reasoning tasks. The three cognitive abilities were entered into sets of regressions in an order determined on the basis of the strength of the relationship between these variables and age, as established by the previous analyses: speed of processing; inhibitory processing; and then working memory.

For the accuracy scores, the most reliable predictor of performance across tasks was speed of processing, which accounted for between 30 and 42% of variance across the four inference tasks. For just one task (TB avoid) the addition of the inhibitory measure at step 2 accounted for an additional proportion of variance (37%). Working memory, at step

Table 7a
Correlations between chronological age, memory span, working memory, speed of processing, measure of inhibition, and accuracy of performance on the four belief-desire reasoning tasks

| Measure | MS[a] | WM[b] | Speed[c] | Inhibition[d] | TB+ | TB− | FB+ | FB− |
|---|---|---|---|---|---|---|---|---|
| Age | −0.36* | −0.54** | −0.92** | 0.59 ** | −0.25 | −0.50** | −0.61** | −0.55** |
| MS | | 0.54** | 0.36* | −0.44** | 0.07 | 0.35* | 0.35* | 0.16 |
| WM | | | 0.58** | −0.47** | 0.14 | 0.39** | 0.49** | 0.39** |
| Speed | | | | −0.66** | 0.47** | 0.62** | 0.58** | 0.60** |
| Inhibition | | | | | −0.41** | −0.74** | −0.42** | −0.45** |
| TB+ | | | | | | 0.42** | 0.32* | 0.45** |
| TB− | | | | | | | 0.56** | 0.29* |
| FB+ | | | | | | | | 0.47** |

Note: $*p<0.05$, $**p<0.01$. TB+, true belief approach desire; TB−, true belief avoidance desire; FB+, false belief approach desire; FB−, false belief avoidance desire.
[a] MS, Memory span as measured by forward digit span.
[b] WM, Working memory as measured by backward digit span.
[c] Digit symbol substitution test (Weschler, 1981).
[d] Inhibition composite score (stroop interference errors, stroop negative priming errors, hayling sentence completion errors).

Table 7b
Correlations between chronological age, memory span, working memory, speed of processing, measure of inhibition and response time performance on the four belief-desire reasoning tasks

| Measure | TB+ | TB− | FB+ | FB− |
|---|---|---|---|---|
| Age | 0.63** | 0.56** | 0.63** | 0.64** |
| MS | −0.36** | −0.37** | −0.37** | −0.45** |
| WM | −0.36* | −0.38** | −0.41** | −0.47** |
| Speed | −0.70** | −0.57** | −0.70** | −0.65** |
| Inhibition | 0.58** | 0.27 | 0.55** | 0.73** |
| TB+ | | 0.69** | 0.80** | 0.61** |
| TB− | | | 0.64** | 0.63** |
| FB+ | | | | 0.67** |

Note: *$p<0.05$, **$p<0.01$. TB+, true belief approach desire; TB−, true belief avoidance desire; FB+, false belief approach desire; FB−, false belief avoidance desire. MS, memory span as measured by forward digit span. WM, working memory as measured by backward digit span. Digit symbol substitution test (Weschler, 1981). Inhibition composite score (stroop interference errors, stroop negative priming errors, hayling sentence completion errors).

three, did not account for any additional variance for any task once speed of processing and inhibition were already in the model.

For the response time measure of the theory of mind inference, speed of processing explained a large proportion of variance for all tasks when entered in step 1 of the regression ($R^2$ ranging from 28 to 56%), and accounted for most unique variance for three of the four tasks (27% for TB approach; 31% for TB avoid and 33% FB approach). The addition of inhibition at step 2 significantly accounted for additional variance for three of the four tasks (6% for TB approach, 10% for TB avoid and 15% for FB avoid). Interestingly, for the FB avoid task, while speed of processing explained 40% of variance when added in step 1, it dropped short of significance as a predictor once the score on the inhibitory battery was entered (explaining 54% of the variance)—the inhibitory composite was the only significant predictor in the model for this task. Working memory, added at step 3, did not explain any additional variance for any of the four tasks.

In summary, the association and regression analysis provides evidence that the mental state reasoning performance decline seen in the older adult group in this study is strongly associated with declining processing speed in this group. In addition, especially for the response time measures, inhibitory executive function also appears to play a role. These results therefore support the notion of a role for executive selection processes as part of belief-desire reasoning, and suggest that it is decline in these cognitive functions that drives inefficiencies in belief-desire reasoning in old age.

## 4. Discussion

Belief-desire reasoning, according to the framework adopted here, requires specialized representational resources to capture the actions of social agents in terms of the underlying mental states, as well as executive selection processes controlling the deployment of these representational resources to solve problems requiring attribution of beliefs and desires to predict and explain those actions (Leslie et al., 2004). In the current study, we investigated predictions of this basic model by assessing belief-desire reasoning capacities in old age, a period in which the efficiency of cognitive executive processes is thought to be in decline (Lowe, & Rabbitt, 1997).

The results of this investigation clarified a number of issues with respect to the belief-desire reasoning capabilities of older adults. Two strategies were employed to isolate whether any belief-desire reasoning problem in this population resulted from compromised functioning of core mental state representational capacities on the one hand, or compromised executive selection processes on the other.

### *4.1. Mental state vs. non-mental state content*

To isolate a possible problem with mental state representational content, we employed a battery of tasks that were matched in terms of the inferential demands they placed on participants. Identical stories were employed in each condition that differed only in the information presented in the final part of the story. Either a social agent or a mechanical device was introduced at that time and the participants were required to predict behavior in each case. This is a greater degree of control over task structure than has been deployed in most prior studies of this kind, with the exception of the use of the false photograph task (Leslie, & Thaiss, 1992; Saxe, & Kanwisher, 2003; Zaitchik, 1990).

Using this strategy, there was no evidence for spared or enhanced function in reasoning involving mental state content as compared with control content (pace Happé et al., 1998). Moreover, we found no difficulty with inference tasks that had mental state content compared with those with control content (pace Maylor et al., 2002; Sullivan, & Ruffman, 2004). Interestingly, when response time was assessed on these batteries, the mental state stories, despite equivalent steps in the inference requirements, were solved somewhat faster by both groups of participants. This result was unexpected, but may reflect the familiarity that individuals have in considering and reasoning about people and their actions. Critically, the extent of the advantage was the same for both our population groups, and thus the results provide no evidence for selective sparing or impairment of ‘theory of mind’ in the elderly, as claimed by prior investigators. Alternatively, the additional time might even reflect the control tasks being processed more comfortably than the mental state inference tasks, but result in participants searching for some trick before answering, not unlike a ‘target absent’ trial in visual search. Critically, and unlike the case of the manipulation of executive selection demands undertaken in the other battery, the response time measures are not also reflected in accuracy differences.[5]

Mental state content itself does not appear to place particular demands on older adult participants if the task structure is otherwise closely matched to the assessments used for non-mental state content. Prior investigations of mental state reasoning involving comparison of mental state vs. no mental state content may have taken insufficient precautions in matching inference structure between experimental and control materials, and therefore confounded mental state content with inference complexity.

[5] We are grateful to an anonymous reviewer for pointing out this possible explanation for this result.

### *4.2. Manipulation of executive selection within belief-desire reasoning*

The second strategy used here was to isolate the executive selection demands on belief-desire reasoning tasks, while keeping constant the requirement that mental state representational resources be deployed. We achieved this via the use of four tasks with a known difficulty metric, established via extensive study in the cognitive developmental literature (Cassidy, 1998; Friedman, & Leslie, 2004a,b; Leslie et al., 2005; Leslie, & Pollizi, 1998).

The results from this task battery showed that increases in executive selection demands resulted in systematically poorer performance (assessed either in terms of accuracy or response time) in both older and younger adults. Contrast analysis demonstrated a significant predicted linear trend in each case and for each age group as the tasks increased in difficulty. This finding demonstrates a remarkable degree of continuity across age groups in performance factors thought to affect belief-desire reasoning. As well as reflecting the overall order of difficulty for the four tasks, the results also replicated the developmental finding that meeting the requirements of attributing a false belief (rather than a true one) appears to place greater demands than attributing action based on an avoid desire (rather than an approach; Leslie et al., 2005).

Moreover, consistent with the idea that executive selection processes might decline in later adulthood, increases in selection processing demands had a disproportionate effect on the reasoning performance of the older age group. Regression analysis demonstrated that among the cognitive functions that were associated with belief-desire reasoning performance, including processing speed (as measured by digit-symbol substitution), working memory (as measured by backward digit span), and response conflict based inhibitory processes (as measured by Stroop and Hayling sentence completion), processing speed accounted for the majority of variance in accuracy of performance, with inhibitory processing also playing a significant role.

In terms of response time measures, the role of inhibitory processes was even greater. This latter finding thus provides the first direct, albeit tentative support, for a specific role for inhibitory processing in the solution of these belief-desire tasks, across two populations distinct from preschool and school age children. The results are thus are consistent with 'selection via inhibition' models that have been proposed to account for the developmental evidence accrued with these tasks (Friedman, & Leslie, 2004a,b; Leslie, & Pollizi, 1998; Leslie et al., 2004; 2005), and the empirical work demonstrating relationships between mental state reasoning and measures of inhibition in preschoolers (Carlson et al., 1998, 2002).

Why might 'speed of processing' have contributed so much to explaining variance in the regression models of task performance? There are several possible reasons. First, and possibly least interestingly, it should be pointed out that the match between tasks that have been identified and named by cognitive psychologists and cognitive neuropsychologists as measuring a particular cognitive capacity, and the underlying executive processing mechanisms that exist is at best a fragile one (Burgess, 2000). While 'speed of processing' appears important in completing the digit-symbol substitutions that are required in that task, there are clearly a host of more narrowly definable cognitive capacities that come into play.

Not only are 'frontal' executive skills highly fractionated, with tasks assessing executive function often dissociable from one another (Burgess et al., 1998), as noted in the introduction, but in addition, the underlying models of the nature of this fractionation are myriad. As yet, the precise nature of different executive systems that might exist, and their interrelations are poorly understood. One possible organization consists in their being multiple different executive processes (Miyake et al., 2000) that are all available for use by mechanisms dedicated to different domains. Another possibility is that there are domain-dedicated executive functions.

On the assumption that speed of processing is implicated in these belief-desire reasoning tasks, then this might appear to reflect the importance of temporal factors in the processing that underwrites the belief-desire tasks employed here. Friedman, & Leslie (2004b) provide evidence that adult reasoners may solve belief-desire reasoning problems via different information processing procedures than do young children. Briefly, Friedman, & Leslie (2004a,b) test between two different models of belief-desire reasoning initially proposed by Leslie, & Pollizi (1998). These two models make different predictions about performance on false belief avoid tasks that have been modified to include two equally correct answers. A full discussion of these models is outside the scope of the present article, but critically, while young children show evidence of solving such tasks via processing belief and desire information in parallel (Friedman, & Leslie, 2004a; see also Leslie et al., 2004; 2005), adult reasoners show a different pattern of performance, consistent with the idea that serial processing of belief and desire information is involved (Friedman, & Leslie, 2004b). Recent evidence suggests that the shift from parallel processing model might occur at around age 10 years (Hehman, Truxaw, Wertz, Niehaus, Roarty and German, 2005, April). If these speculations are correct, then a possible explanation for the importance of processing speed might be generated. Pending further evidence on these interesting questions, we refrain from further comment.

### *4.3. Representational and executive selection resources as a framework for 'theory of mind'*

The cognitive development literature has debated extensively the question of whether improvement in belief-desire reasoning with cognitive development is driven by maturation of executive selection capacities against the background of a stable core representational system for mental state concepts (German, & Leslie, 2000; 2004; Leslie, 2000; Leslie et al., 2005; Yazdi et al., in press) or instead is best explained in terms of changes in the core conceptual capacity itself, as claimed by a number of scholars of cognitive development (Wellman et al., 2001).

Though not speaking directly to this developmental question, the demonstration that the same task difficulty manipulations that strongly affect young children's belief-desire reasoning performance have a consistent effect on reasoning in the same content domain across the lifespan lends credibility to the idea that models of executive selection processes in successful belief-desire reasoning will be a valuable contribution to our understanding of the origin and development of social cognition.

As argued in the introduction, the two-component framework for belief-desire reasoning that informs the current study (e.g. core representational system plus executive selection process) admits the possibility of compromised function in *either* component of the system to explain any given example of inefficient task performance. A number of findings in cognitive development, in cognitive neuropsychological research on developmental disorders and acquired lesions, as well as recent functional imaging work in cognitive neuroscience is consistent with this approach.

For example, despite identified executive function problems in Autism spectrum disorders (ASD; see e.g. Ozonoff, Pennington, & Rogers, 1991; Ozonoff, Strayer, McMahon, & Filloux, 1994), it is likely that this population manifests a dysfunction in the core representational system for mental state conceptual competence. Such a core representational problem might manifest as a result of direct disruption to mechanisms that produce mental state representations (Leslie, 1987, 1994b, 2000; Leslie, & Roth, 1993) and/or as a result of disrupted input to such mechanisms on account of social-attention problems earlier in the processing stream (Adophs, Sears, & Piven, 2001; Baron-Cohen, 1995; Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998).

The strongest evidence for this proposal is that individuals with ASD can solve tasks that place identical executive selection pressure as typical belief-desire reasoning tasks (e.g. the false photo task, Zaitchik, 1990), but that requires no mental state representational content (Charman, & Baron-Cohen, 1995; Griffith, Pennington, Wehner, & Rogers, 1999; Leslie, & Thaiss, 1992; see also Russell, Saltmarsh, & Hill, 1999). Moreover, while typically developing children gain purchase on the selection difficulties inherent in false belief tasks when they are modified to reduce inhibitory demands (Leslie et al., 2005; Siegal, & Beattie, 1991; Surian, & Leslie, 1999; Yazdi et al., in press), similar manipulations do not help the individual with ASD (Roth, & Leslie, 1998).

Further examples of the advantage of this approach come from single case studies where problems with reasoning about mental state content does not appear to be driven by executive selection failure. Fine et al. (2001), report a single case of an individual with early left amygdala damage who performs poorly on a battery of mental state reasoning tasks, alongside normal-range performance on an executive function battery, and Lough et al. (2001) report a similar pattern of performance in a 47-year-old patient with frontal variant frontotemporal dementia (Gregory, Lough, Stone, Erzinclioglu, Martin and Baron-Cohen, 2002). Finally, Apperly, Samsom, Chiavarino, & Humphreys (2004) show that reducing executive selection difficulty in belief-desire reasoning problems eases the impairment shown by a group of patients with frontal damage, suggesting executive selection problems might account for these patients social-cognitive problems. A group of temporal-parietal patients tested in the same study did not benefit from the reduced task demands reasoning (Samsom, Apperly, Chiavarino, & Humphreys, 2004), raising the possibility that temporal-parietal regions of the brain area may play a role in handling the representational rather than the executive selection requirements of belief-desire reasoning.

Approaching belief-desire reasoning from the current perspective may also shed light on the increasing number of ‘theory of mind’ neuro-imaging results (Gallagher, & Frith, 2003; Saxe et al., 2004 for recent reviews). The two process model makes explicit the need to focus attention on the question of whether given areas are activated because they are involved in the core representational system for mental state concepts, or in the executive selection processing required for some belief-desire reasoning tasks (or both). Minimal pair designs (e.g. false photograph vs. false belief; Leslie, & Thaiss, 1992), allow us to consider representational resources in two tasks with (assumed) similar executive selection demands. Consistent with the position outlined above on the basis of neuropsychological patient data, temporal-parietal and posterior superior temporal sulcus (STS) activations seen in response to false belief task content when activation resulting from photograph task content is controlled for (Saxe, & Kanwisher, 2003), might reflect the involvement of this region in core mental state representational processes rather than those that handle executive selection demands (Frith, & Frith, 2003).

Medial frontal activations, also widely seen in response to mental state reasoning tasks, might reflect executive selection processes that are specific to belief-desire reasoning (Gallagher, & Frith, 2003; German, Niehaus, Roarty, Giesbrecht, & Miller, 2004), or alternatively, selection processes that cut across content domains (Ferstl, & von Cramon, 2002). This question will be illuminated by studies that attempt to correlate executive selection difficulty (such as the metric utilized in the current study), with activations in a variety of brain areas sensitive to 'theory of mind' content (Roarty, German, Guerin, & Miller, 2005).

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