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Deficits in comprehension of speech acts after TBI: The role of theory of mind and executive function

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ABSTRACT

Theory of mind (ToM) is critical to effective communication following traumatic brain injury (TBI) however, whether impairments are specific to social cognition, or reflective of executive demands is unclear. This study examined whether ToM impairments are predicted by executive function difficulties using everyday conversation tasks. Twenty-five individuals with severe-TBI were compared to 25 healthy controls on low- and high-ToM tasks across four conditions: (1) low cognitive load, (2) high flexibility, (3) high working memory (WM) and (4) high inhibition. TBI individuals were impaired on high-ToM tasks in the WM condition. When the WM demands of the task were controlled, the impairments were no longer apparent. TBI individuals were not impaired on high-ToM tasks in the inhibition and flexibility conditions, suggesting these tasks may not have been sufficiently demanding of ToM abilities. The results suggest that ToM impairments in everyday communication may arise due to WM demands, in individuals with TBI.

1. Introduction

A common outcome following traumatic brain injury (TBI) is deficits in social cognition (McDonald, 2013). Social cognition is a broad and loosely defined term that refers to the processes subserving behaviour in response to the behaviour of others and, in particular, to the 'higher cognitive processes' such as social reasoning and social communication that facilitate social behaviours (Adolphs, 1999, 2009).

One important component of social cognition is theory of mind (ToM). ToM is a specific term used to describe the natural human ability to perceive social cues, use these to make inferences about the mental states of other people, and to use these representations to, not only understand, but also predict and judge the utterances and social behaviours of others (Bibby & McDonald, 2005; Brownell & Martino, 1988; Ochsner & Lieberman, 2001; Premack & Woodruff, 1978). A range of tasks have been used in prior research to examine ToM deficits following TBI in adult populations, with results consistently indicating that individuals with TBI perform more poorly on these tasks than individuals without a TBI (e.g., McDonald & Flanagan, 2004; McDonald, Flanagan, Martin, & Saunders, 2004; McDonald, Flanagan, Rollins, & Kinch, 2003; McDonald & Saunders, 2005; Milders, Ietswaart, Crawford, & Currie, 2008; Milders, Ietswaart, Currie, & Crawford, 2006; Muller et al., 2010). Examples of ToM tasks commonly used in these studies include the *Reading the Mind in the Eyes* test (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001), the *Faux Pas Recognition Test* (Stone, Baron-Cohen, & Knight, 1998), the *Cartoon task* (Happé, Brownell, & Winner, 1999), and *The Awareness of Social Inference Test* (TASIT; McDonald, Flanagan, & Rollins, 2011). In general, there are different levels of complexity in ToM judgements. Simple stories or cartoons measuring first-order ToM (judgements about what a person thinks) may not be as susceptible to poor performance as tasks measuring second-order ToM (e.g. judgements about what a person believes about another's beliefs) (Muller et al., 2010; Stone et al., 1998). Other research, however, has demonstrated that both first- and second-order theory of mind abilities are impaired following TBI (Bibby & McDonald, 2005).

ToM directly contributes to communication competence in TBI individuals (McDonald, 2013; McDonald, Gowland, Randall, Fisher, Osbourne-Crowley & Honan, 2014). In particular, it has been linked to problems comprehending non-literal speech such

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as sarcasm, irony, humour, deceit, and hints (Channon & Crawford, 2000; Happé, 1993; McDonald & Flanagan, 2004; Muller et al., 2010; Shamay-Tsoory, Tomer, Berger, Goldsher, & Aharon-Peretz, 2005) and producing language that caters for another's perspective (McDonald et al., 2014). Poor communication, in turn, can have far reaching, detrimental consequences for individuals with TBI such as difficulties with forming and maintaining personal relationships (Wells, Dywan, & Dumas, 2005).

According to neuroimaging research, ToM-related activities appear to be mediated by the medial prefrontal and orbitofrontal regions along with temporoparietal areas (Carrington & Bailey, 2009). Given that the ventromedial and orbital areas of the frontal lobes are highly vulnerable in TBI, it is of no surprise that ToM deficits are common in this population. Interestingly, similar frontal regions of the brain are also known to be implicated in executive function, that is, the "higher-level" cognitive functions involved in the control and regulation of lower-order cognitive processes, inferential reasoning, planning and goal-directed future-oriented behaviour (for review see Alvarez & Emory, 2006; Stuss, 2011a, 2011b).

1.1. ToM and executive functioning: is there a relationship?

Given that tasks that tap ToM and executive function are dependent upon similar brain structures, the question must be addressed as to whether problems with ToM are really a manifestation of broader executive functioning impairments in people with TBI. ToM judgements require working memory, flexibility, so as to see an alternative point of view from one's own and, relatedly, the ability to inhibit one's own perspective in order for this to occur. These are generic executive function skills that are also very vulnerable in TBI. Furthermore, poor inference making, in general, is a common feature of executive function impairment. Thus, it may be that difficulties making mental state inferences are simply an extension of difficulties with more general inference making ability due to deficits in executive function, specifically working memory, flexibility and inhibition. While some studies indicate a relationship between executive function and ToM tasks (Bibby & McDonald, 2005; Channon & Crawford, 2010; Dennis, Agostino, Roncadin, & Levin, 2009; Havet-Thomassin, Allain, Etcharry-Bouyx, & Le Gall, 2006; Henry, Phillips, Crawford, Ietswaart, & Summers, 2006; Milders, Ietswaart, Crawford, & Currie, 2006; Turkstra, 2008) others do not (Bach, Happé, Fleminger, & Powell, 2000; Havet-Thomassin et al., 2006; Muller et al., 2010; Spikman, Timmerman, Milders, Veenstra, & van der Naalt, 2012).

The developmental literature also provides some evidence of the possible link between ToM and executive function. In particular, cross-sectional studies in normally developing children as young as three years old, have demonstrated relationships between ToM tasks and measures of working memory, cognitive flexibility and inhibitory control (e.g., Carlson, Moses, & Breton, 2002; Hughes, 1998). In children with a TBI (aged 7–13 years), Levy and Milgram (2014) recently demonstrated that ToM impairments could be accounted for by performance on tasks of abstract reasoning and working memory. Furthermore, longitudinal studies in normally developing young children (aged 3–6 years) have indicated the existence of a casual pathway whereby the development of executive function ability is predictive of later performance on ToM tasks (Marcovitch et al., 2014).

In adults, one reason for the lack of clarity surrounding the relation between executive function and ToM is that different ToM tasks (e.g., stories versus photographs) make uneven demands on executive processes. Tasks requiring second-order ToM judgements, for example, may be differentially dependent on domains such as WM, cognitive flexibility and inhibition compared to first order inferences. Consistent with this, Bibby and McDonald (2005) found that verbal tasks tapping second-order ToM and non-verbal ToM cartoons were associated with WM (Digit Span) but no association was found with performance on verbal tasks tapping first order ToM, indicating that WM may only partially explain ToM impairments in individuals with TBI. Similar variability in the relationship between performance on executive function and ToM tasks has been noted in studies using alternative populations such as frontotemporal dementia (Lough et al., 2006) and schizophrenia (Pickup, 2008).

An additional problem is that executive function tests themselves are multi-factorial, each having varying reliance upon working memory, cognitive flexibility, inhibition, etc., which may yield different results from one study to the next (Muller et al., 2010). Compounding this problem is that the relation between ToM and executive function is typically examined with correlational evidence, finding an association between two independent measures, executive function on the one hand, ToM on the other. A stronger test of the relationship between executive abilities and ToM, is to compare performance on ToM tasks under higher executive demands to those with less.

This methodology has been used in two studies of non-clinical participants. Bull, Phillips, and Conway (2008) used a dual-task interference methodology in healthy adults. Specifically, participants completed a verbal story task assessing ToM or the *Mind in the Eyes* task while simultaneously completing an "interference" executive function task. The 'stories' task required participants to answer questions about the mental state of a character based on the text, while the *Mind in the Eyes* task required participants to choose a mental state term that best matched a photo of eyes. The results showed that interference affected performance on the verbal 'stories' task, and that these effects were general, i.e., deficits were seen on both questions about mental states and also non-mental physical events, and across all types of executive function. This indicated that general attentional resources were responsible for performance in the verbal dual-task paradigm used in this study. Conversely, high inhibition demands impaired performance on the *Mind in the Eyes* task but not its control equivalent, indicating that inhibitory skills were important and specific to this ToM task. Using a less complex story task than that used by Bull et al. (2008), Maehara and Saito (2011) demonstrated that high WM differentially impaired ToM judgments even when participants were able to read the stories under low WM conditions.

1.2. The current study

The studies by Bull et al. (2008) and Maehara and Saito (2011) suggest that ToM judgments in normal healthy adults may rely upon executive function although clinical participants were not tested. Nor were the materials representative of the kinds of ToM judgments typically made in everyday life. These usually require inferences drawn from real-time language output, facial and body cues and an understanding of the context of the social exchange (McDonald, 2013). It is difficult, for instance, to apply the findings from studies employing static photographs of eyes or cartoons (Johnston, Miles, & McKinlay, 2008), to the types of ToM judgements that might be required in everyday social interactions.

Thus, the following study was designed to determine whether impaired ToM judgements in the context of everyday social interaction is a manifestation of reduced executive skills, specifically, reduced WM, flexibility or inhibition in individuals with TBI. To answer this question, a set of experimental tasks using video vignettes (portraying everyday conversations) were designed with varying executive function demands, including: (1) low cognitive; (2) high WM; (3) high flexibility and (4) high inhibition. In each condition there were sub-tasks that were either low or high in ToM demands. Performance in each condition was compared to a group of adults without brain injury matched for basic demographic characteristics.

On the premise that deficits in ToM following TBI are a reflection of deficits in executive function it was hypothesised that: (1) individuals with TBI would perform similarly to individuals without TBI in high ToM tasks when executive functioning demands are low; (2) individuals with TBI would perform more poorly than individuals without TBI on high ToM tasks when higher demands are placed on executive functioning; (3) group differences on high ToM tasks would be accounted for by the cognitive/executive demands of the task, i.e. group differences on each high ToM task would be explained by variability on the equivalent low ToM task.

2. Method

2.1. Participants

Participants included 25 adults (18 males) with a mean age of 47.52 years (*SD* = 12.09, range: 21–66) and 13.44 mean years of education (*SD* = 3.31, range: 9–22), who were referred to the study from three external brain injury units across metropolitan Sydney on the basis of having met the inclusion criteria and their willingness to participate in research. All participants met the following inclusion criteria: they had sustained a severe TBI resulting in at least one day of in a period of post traumatic amnesia (Russell & Smith, 1961; Teasdale, 1995) were discharged from hospital and living in the community and had English as their primary spoken language. The period of PTA was assessed using the Westmead PTA scale (Marosszeky, Ryan, Shores, Batchelor, & Marosszeky, 1997) or was assessed retrospectively through self-reported period of amnesia. Participants were excluded if they had: uncorrected hearing or vision loss (as determined by an eye or hearing specialist), a current diagnosed drug and/or alcohol addiction, active psychosis or psychiatric condition, dementia or other neurodegenerative disease (as defined by the Diagnostic and Statistical Manual of Mental Disorders (DSM)-IV), aphasia, agnosia, or profound amnesia (informed through self-report or prior clinical assessment). There were no participants in litigation.

The mean PTA length was 69.96 days (*SD* = 53.69, range: 1–189). Testing was completed at enrolment and time post injury at enrolment ranged from 2 to 33 years (*M* = 14.1 years, *SD* = 8.85). Causes of TBI included motor vehicle accidents ($n = 15$), falls ($n = 7$), sporting accidents ($n = 2$), and assault ($n = 1$). Computerised axial tomography (CT) scans indicated that participants' injuries were right hemisphere-focused ($n = 7$), left hemisphere-focused ($n = 4$), or bilateral ($n = 6$). For the remaining participants, scan readings did not specify which hemisphere contained the injury ($n = 3$), or were unavailable ($n = 5$). It should be noted that these scans were conducted for clinical purposes and are unlikely to reflect the true extent of pathology.

A control group of 25 adults without a prior history of head injury were recruited from the general community via advertisements placed online and in local community newspapers. Each control participant was matched to a TBI participant on the basis of being of the same gender, a similar age, and similar educational attainment. In summary, the control group had a mean age of 48.52 years (*SD* = 12.98, range: 21–66) and 14.40 mean years of education (*SD* = 2.12, range: 9–17). The TBI and control groups did not differ significantly with respect to gender distribution, age (mean difference = 2.36; *SD* = 2.84) or years of education (mean difference = 1.92; *SD* = 1.93) (*p*'s = 1.000, .830, and .145, respectively).

2.2. Materials

2.2.1. Background neuropsychological tests

All participants were assessed for (a) premorbid IQ—*Wechsler Test of Adult Reading* (*WTAR*: The Psychological Corporation, 2001), a test requiring participants to read a list of words with irregular pronunciations (estimated IQ based on errors); (b) processing speed—*Trail Making Test (TMT) Part A* (TMT; Reitan, 1992), a test requiring participants to sequentially connect 25 numbers as quickly as possible (time to complete); (c) verbal memory—*Logical Memory I and II* from the Wechsler Memory Scale–Third Edition (WMS-III; Wechsler, 1997b), which requires participants to recall verbally presented stories both immediately and following a delay (scaled scores); (d) facial recognition ability—*Benton Facial Recognition Test* (BFRT; Benton, Sivan, Hamsher, Varney, & Spreen, 1983). The BFRT involves matching a frontal view of a target photograph with an identical photograph, photos of the target taken from different angles, and photos of the target taken under different lighting conditions. The short version of the BFRT was used with scores transformed to a possible total of 54.

2.2.2. Tests of executive functioning

Standard executive functioning tests measuring WM, flexibility and inhibition were administered to help validate the respective high executive function conditions in the experimental paradigms. Working memory was assessed with the *Digit Span* subtest (forward and backward) of the Wechsler Test of Adult Intelligence (WAIS-III; Wechsler, 1997a: scaled score). Flexibility (Johnco, Wuthrich, & Rapee, 2013; Kortte, Horner, & Windham, 2002; Troyer, Moscovitch, Winocur, Alexander, & Stuss, 1998) was assessed with (a) the *Controlled Oral Word Association Test* (COWAT; Benton, Hamsher, & Sivan, 1994) to assess letter fluency (total words) and (b) the *Trail Making Test Part B* (TMT; Reitan, 1992), a task requiring the participant to alternate connect numbers and letters sequentially (time to complete). Inhibition was assessed with the *Hayling Sentence Completion Test* (Burgess & Shallice, 1997). This task requires participants to provide semantically-related or semantically-unrelated (inhibition condition) end words to complete aurally presented sentences (overall profile score, based on time to initiate response and errors made).

2.2.3. Theory of mind (ToM) tests

Standard tests assessing ToM were administered to help validate the ToM tasks included in the experimental paradigms. *The Awareness of Social Inference Test* (TASIT; McDonald et al., 2003) is an ecologically valid (McDonald et al., 2004), and clinically sensitive measure of simple emotion perception and complex social cognition. Participants are required to integrate cues from various sources (e.g., facial expressions, prosody, gesture, and social context) to interpret the emotions, beliefs and intentions (i.e., ToM) of target characters in videotaped conversational interactions. Participants were tested on: (1) Part 1: *The Emotion Evaluation Test*, which comprises 24 short video clips portraying one of six basic emotions (happy, sad, fear, disgust, surprise and anger); (2) Part 2: *Social Inference – Minimal*, a ToM task that is comprised of 15 video clips depicting sincere and sarcastic interactions between two actors; and (3) Part 3: *Social Inference – Enriched*, another ToM task comprised of sixteen vignettes where participants are provided with extra information about the true state of affairs before or after the dialogue of interest. The ability to detect deception (i.e., lies) in social encounters and sarcasm is examined in Part 3. See McDonald (2012) for more detailed information about TASIT.

The *Reading the Mind in the Eyes* test – Revised version (Baron-Cohen et al., 2001) assesses an individual's ability to infer other people's mental states by visually examining black and white photographs of the eye region. The revised version comprises 36 pictures and participants are asked to choose what "mental state" is being portrayed in the photograph from four response options. For example, in the first item, the response options include 'jealous', 'panicked', 'arrogant' or 'hateful'.

2.2.4. Mood questionnaire

The Depression, Anxiety, and Stress Scale-21 (DASS-21; Lovibond & Lovibond, 1995) was administered to assess current mood state. The DASS-21 is a 21-item self-report measure of the negative emotional states of depression, anxiety, and stress. The measure has acceptable levels of internal reliability: $r = .81$ for the Depression subscale; $r = .73$ for the Anxiety subscale, and $r = .81$ for the Stress subscale (Lovibond & Lovibond, 1995).

2.2.5. Experimental design/stimuli

The experimental tasks tested comprehension of conversations depicted in three video vignettes. Four kinds of tasks were created: (1) low cognitive load (i.e., minimal executive function demands) and three tasks with increased executive demands specifically: (2) high WM; (3) high flexibility and (4) high inhibition. Within each of these, there were probes assessing low ToM and high ToM reasoning. Probe questions were similar in format to those used in other ToM tasks (e.g., the Cartoon task and the Faux Pas test; Happé et al., 1999; Milders et al., 2006; Stone et al., 1998). Low ToM probes required participants to make a non-mental inference (e.g. causal, physical or semantic). High ToM probes required the participants to make inferences about the mental states of a character in the vignette. This was designed so that the low ToM scores could be used as a covariate when examining group differences in high ToM scores for each condition. In this way we could effectively control for the cognitive demands (i.e., EF demands including those required to make non-mental inferences) and language demands of the high ToM task. Any between group differences that remained for the high ToM task after controlling for performance on the low ToM task would suggest that there was ToM impairment in TBI individuals that could not be accounted for by the executive demands of the task.

2.2.5.1. Low executive function load condition. The low executive function (i.e. the low cognitive load) condition consisted of a videotaped vignette (displayed on a computer screen) of a woman (Sarah) talking about her experience of being confronted by a protest March. The vignette was periodically stopped to form nine video segments or clips. Participants were advised prior to viewing the clips that they might be asked about information that was not directly given in the vignette and that they should be able to infer their answer from the information that was given. They were also informed that the clips would only be shown once. Following the presentation of each clip, participants answered low and/or high ToM questions in a forced choice format (yes/no/maybe), which appeared on the computer screen. Examples of low and high ToM clips/questions are as follows:

> Low ToM: Sarah reported *"There were people everywhere, they were angry and shouting and holding up banners and signs. Some of the signs had guns and soldiers and stuff like that, you know?"*. Low ToM Question: *"Is the protest about war?"*.
>
> High ToM: Sarah reported *"I tried to catch the attention of the nearest policeman, I was, I was shouting 'Hey! Hey!' and I caught his eye but he didn't respond to me, he just kept saying 'I'm warning you! Get back! Get Back!"*. High ToM question: *"Did the policeman know what Sarah wanted?"*.

Each video segment was between 7.34 and 23.78 s in length (total time = 111.53 s). In total, four low ToM and seven high ToM questions were asked across these segments. Total number correct and total reaction time to low and high ToM questions were recorded.

2.2.5.2. High WM condition. In the high WM condition, participants watched a videotaped vignette of a male newsreader who was reporting on a story about "bikie gang violence". In this condition, whilst the clips were being played, a series of coloured numbers (0, 1, or 2; in green, red, or blue) were displayed on the left hand side of the computer screen. Participants were asked to remember how many times they saw a red "1" or a blue "0" during each clip. They were instructed to answer "1" if they saw one red "1" or one blue "0"; "2" if they saw, for example, one red "1" and one blue "0"; and "3" if they saw, for example, two red "1"s and one blue "0". The question about how many numbers were seen was displayed on the computer screen immediately following the clip and preceded the presentation of the low and high ToM questions.

In other respects the high WM condition was similar to the low cognitive load condition, i.e., the vignette was periodically stopped to form nine video segments or clips. Each segment was between 8.56 and 19.22 s in length (total time = 117.30 s). Examples of low and high ToM clips/questions are as follows:

> Low ToM: *"Other witnesses spoke of local bikie gang members drinking at the pub for several hours before the members of a rival bikie gang arrived, around about midnight."*, Low ToM question: *"Was anyone likely to have been drunk when the incident happened?"*.
>
> High ToM: *"Joe also said that it would be difficult to get bikie gang members to break ranks because of the long hostility between the bikie gang and the police"*. High ToM question: *"Does Joe think bikie gang members will want to help the police solve this case?"*.

In total, there were four low ToM questions and six high ToM questions. The total number correct and total reaction time in both low and high ToM tasks, were recorded.

2.2.5.3. High flexibility condition. In the high flexibility condition, participants watched a vignette of Sarah having a conversation with her friend (Josh) about her protest experience. The flexibility component in this task concerned the participants' ability to focus alternately on one speaker and then the other in order to answer the probes. As before, the videotaped vignette was periodically stopped to form a number of video segments or clips that were between 9.03 and 19.50 s in length (total time = 111.50 s) after which low and/or high ToM questions were asked. Examples of low and high ToM clips/ questions are as follows:

> Low ToM: "[Sarah]: *'And don't you remember that time at that music festival, when I felt faint, we were lining up in this long queue to buy beer?'; [Josh]: 'Yeah, I remember that! I had to come and rescue you!'* ". Low ToM question: *"Was there beer for sale at the music festival?"*.
>
> High ToM: "[Sarah]: *'It just happened so quickly, you know, one minute I'm walking down this quiet street, and the next thing is I'm facing all these police in riot gear! I nearly fainted, I was not very well, it was really scary, you know?'; [Josh]: 'You are such a drama queen! Why do you always go over the top? Was it really that bad?'* ". High ToM question: *"Does Josh think that Sarah is exaggerating her experience?"*.

In total, three low ToM and nine high ToM questions were asked. Total number correct and total reaction time in both low and high ToM tasks, were recorded.

2.2.5.4. High inhibition condition. In the high inhibition condition, participants re-watched the newsreader vignette from the high WM condition. The vignette was stopped at predetermined points before the newsreader had finished a sentence, prompting participants to complete low and high ToM utterances using words that were completely unconnected from the preceding context. Low ToM utterances pertained to semantic or world knowledge. High ToM utterances concerned people's beliefs or attitudes. The length of segments varied between 4.94 and 14.88 s (total time = 79.78 s). Examples of Low and high ToM utterances are as follows:

> Low ToM: *"Good evening and welcome to the late news. First tonight, we've got more details for you about yesterday's bikie gang violence in New South Wales. Police have now issued pictures of the suspects, and appealed to the public for...* ∗inhibit____ [information]".
>
> High ToM: For example, *"Leaders have responded to the news, with the state premier expressing his disgust at the behavior of the bikie gangs and the local mayor describing the incidents as...* ∗inhibit____[terrible]".

Scoring criteria to determine unconnectedness was adapted from the Hayling Sentence Completion task (Burgess & Shallice, 1997). In total, there were four low ToM utterances and five high ToM utterances. Time taken to say the unconnected word (i.e., after the vignette had been stopped) was manually recorded to two decimal places.

2.3. Procedure

Participants were tested by one of three female research assistants trained to administer the test materials and measures. Testing was conducted over one or two sessions depending on participant availability, and level of fatigue. To familiarise participants with the format of the high inhibition condition, the Hayling Sentence Completion test was first completed. Participants were then administered the experimental tasks in the following order: low executive function demand, high WM demand, high flexibility demand, and high inhibition demand. Participants completed two practice items before commencing each task. Participants then completed standardised neuropsychological measures and the DASS questionnaire. A schematic overview of the study's procedure is shown in Fig. 1. Institutional Review Board approval was gained to conduct all aspects of the study.

2.4. Data analyses

Statistical analyses were conducted using IBM SPSS (Version 20). Accuracy scores in each experimental condition were converted to a percentage value prior to analysis. Group differences in neuropsychological test performance and questionnaire scores were examined using two-tailed independent samples *t*-tests.

In order to establish the construct validity of the experimental tasks, we performed correlation and standard regression analyses using the combined groups to examine the relation between (1) conventional ToM tasks and high vs. low ToM (in the low cognitive load condition) and (2) the relevant conventional executive function measure/s and performance on the low cognitive load, high WM, flexibility and inhibition tasks. The assumptions for the regression analyses including linearity, normality, and homoscedasticity of residuals, and absence of multicollinearity and singularly were met. For all analyses, $p < .05$ was considered statistically significant. Rasch dichotomous model item reliability estimates to examine overall item cohesiveness was conducted for each task using WINSTEPS (Version 3.81.0; Linacre, 2006).

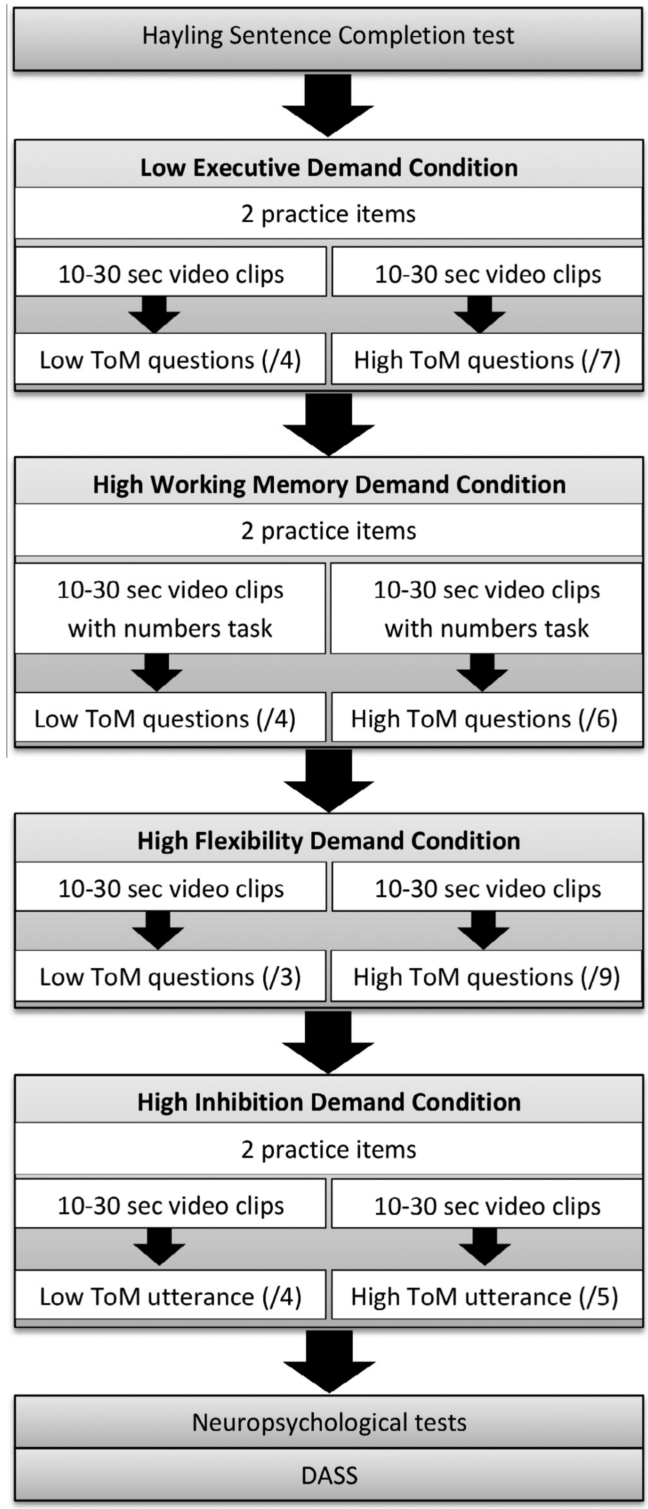

Fig. 1. Schematic overview of experimental procedure and tasks.

The Rasch model is specifically a psychometric model that can be used to analyse categorical data and is independent of test length. Item reliability estimates ranged from .65 (adequate) to .92 (excellent) (see Table 2).

In order to examine group differences in low and high executive (i.e., WM, flexibility, and inhibition) conditions and low and high ToM tasks, two-tailed independent samples *t*-tests and ANCOVA analyses were used. In order to determine whether group differences in ToM were accounted for by the executive demands of the task, we used the low ToM scores for each executive function condition as a covariate when examining group differences in its high ToM counterpart. Square root, logarithmic, and inverse transformations were performed on most variables to correct for skewness, remove outliers, and meet normality assumptions. However, since no overall differences in the level of significance were detected for analyses using either the transformed variables or the untransformed variables, for simplicity, only the results of the analyses for the untransformed variables are reported. Cohen's *d* effect sizes are reported for comparison analyses.

DASS subscale scores (Depression, Anxiety, Stress) and the WTAR were examined as possible covariates for all comparison analyses. Based on the results of a standard regression, relationships were only detected between the DASS subscale scores and the high inhibition tasks (both low and high ToM) [$R = .45$, $F(3,46) = 3.81$, and $p = .016$; $R = .52$, $F(3,46) = 5.76$, $p = .002$, respectively]. Pearson's Correlations also identified significant relationships between the WTAR and the high flexibility high ToM task, $r(48) = .45$, $p = .001$, and the high WM low ToM task, $r(48) = .43$, $p = .001$. DASS subscale and WTAR scores were therefore used as covariates in the respective comparison analyses. However, since no overall differences in results were detected, for simplicity, only the results without the covariates are reported here. Time since injury was not significantly correlated with any variable used in this study.

Table 2
Descriptive statistics of theory of mind task performance in various executive conditions by group with *t*-test comparisons.

Condition	Control (*n* = 25)		TBI (*n* = 25)		*t*-value	*d*	Sig
	M	*SD*	*M*	*SD*			
Low executive							
Low ToM (.87)	81.0	18.09	80.00	23.94	0.17	0.05	.868
High ToM (.73)	90.86	14.21	83.43	12.15	1.99	0.56	.053
High working memory							
Low ToM (.85)	85.00	17.68	73.00	30.55	1.70	0.48	.096
High ToM (.91)	78.00	17.82	65.33	25.42	2.04*	0.58	.047
High inhibition							
Low ToM (.74)	91.00	21.51	68.00	33.49	2.89**	0.82	.006
High ToM (.65)	84.00	24.49	67.20	37.81	1.87	0.53	.068
High flexibility							
Low ToM (.92)	77.33	23.01	74.67	25.96	0.38	0.11	.702
High ToM (.68)	90.67	10.96	85.78	16.20	1.25	0.35	.218

Note: Cohen's *d* is the reported effect size. TBI = traumatic brain injury, ToM = theory of mind. Values provided are the percentage correct in each task. Item reliability estimates are shown in brackets.
* $p < .05$.
** $p < .01$.

3. Results

3.1. Neuropsychological tests and questionnaire comparisons

Descriptive data and comparison statistics for performance in standard neuropsychological tests and questionnaires scores are summarised in Table 1. The TBI group performed significantly worse than the control group on most neuropsychological tests including the WTAR scores, consistent with other research demonstrating such measures are affected by injury severity (Mathias, Bowden, Bigler, & Rosenfeld, 2007; Morris, Wilson, Dunn, & Teasdale, 2005). Significance was approached in the WMS-III Logical Memory I (immediate recall) test ($p = .059$). There was no significance difference between groups detected in the Stress subscale of the DASS questionnaire, but the TBI group was more depressed and anxious.

3.2. Construct validity of experimental paradigms

Standard regression analyses were conducted to examine the ability of standard ToM tasks (i.e., total scores for each of the three TASIT subtests and the Mind-in-the-Eyes test total score) to predict low and high ToM task accuracy scores in the low cognitive load condition. Supporting the validity of our manipulation, the overall regression equation was not significant for the low ToM task [$R = .33$, $F(4,43) = 1.29$, $p = .286$], but was significant for the high

Table 1
Descriptive statistics of standard neuropsychological tests by group with *t*-test comparisons.

Test	Control (*n* = 25)		TBI (*n* = 25)		*t*-value	*d*	Sig
	M	*SD*	*M*	*SD*			
WTAR SS	117.36	8.41	104.92	14.74	3.67	1.04	.001
Hayling SC SS	5.92	1.19	5.04	1.81	2.03	0.57	.048
WMS-III LM I SS#	10.96	3.30	9.04	3.62	1.94	0.55	.059
WMS-III LM II SS#	11.87	2.47	9.56	3.75	2.54	0.73	.015
WAIS-III Digit Span SS	11.88	2.99	9.48	2.65	3.00	0.85	.004
TMT – A (time in s)	31.32	9.34	43.48	25.00	2.28	0.64	.027
TMT – B (time in s)	64.64	15.62	107.88	78.00	2.72	0.77	.009
COWAT (CFL)	45.12	11.64	34.76	11.61	3.15	0.89	.003
Animals	23.04	5.68	17.64	6.00	3.27	0.92	.002
Benton FRT#	46.83	3.77	42.40	6.77	2.82	0.81	.007
Mind-in-the-Eyes#	27.33	4.01	22.04	5.77	3.69	1.06	.001
TASIT#							
Part 1	24.21	1.82	21.24	4.09	3.26	0.94	.002
Part 2	52.63	4.75	46.88	9.00	2.78	0.80	.008
Part 3	54.58	5.01	48.52	8.54	3.01	0.87	.004
DASS							
Depression	3.76	4.98	9.44	8.94	2.78	0.78	.008
Anxiety	2.56	3.63	6.56	8.16	2.24	0.63	.030
Stress	7.44	6.49	11.44	11.41	1.52	0.43	.134

Note: Results of two-tailed *t*-test comparison analyses are shown. # The number control participants for these comparisons were 24. Cohen's *d* is the reported effect size. COWAT = Controlled Oral Word Association Test; DASS = Depression, Anxiety and Stress Scale; FRT = Face Recognition Test; LM = Logical Memory; SS = scaled score; SC = Sentence Completion; TMT = Trail-Making Test; WMS = Wechsler Memory Scale; WTAR = Wechsler Test of Adult Reading. Except where indicated (i.e., SS or time in s), raw scores are provided in the table. Please note that WTAR scores were not controlled for in these analyses.

ToM task [$R = .61$, $F(4,43) = 6.42$, $p < .001$]. Within this regression, the only measure to contribute unique variance was the Lying score from Part 3 of the TASIT, $sr^2 = .06$, $p = .041$. Zero-order correlations between the standard ToM tasks and the high ToM task in this study ranged between $r(47) = .43$ (the Mind-in-the-Eyes test), and $r(47) = .59$ (TASIT Part 3). Zero-order correlations between the standard ToM tasks and our low ToM task ranged from .20 to .31.

To confirm that our high executive demand tasks tapped the particular aspect of executive function as planned, correlations between the relevant executive task and overall performance (summed z-scores of low and high ToM conditions; based on mean scores for the overall sample) was examined. In the high WM condition, a moderate positive correlation was found between Digit Span and accuracy scores, $r(48) = .35$, $p = .013$. In a standard regression analysis, both the TMT B and COWAT combined had a moderate association with flexibility accuracy scores [$R = .42$, $F(2,47) = 5.09$, $p = .010$]. While neither the TMT B or COWAT predicted unique variance in flexibility condition accuracy scores, zero-order correlations between these measures were significant [$r(48) = -.33$, $p = .019$ and $r(48) = .38$, $p = .007$, respectively]. In the high inhibition condition, a strong positive correlation was found between the Hayling Sentence Completion Task and accuracy scores, $r(48) = .68$, $p < .001$.

Finally, the relationship between each standard measure of executive function and accuracy for low versus high ToM in the low cognitive load condition was examined. Accuracy scores on low ToM had non-significant correlations with the Digit Span, $r(48) = -.08$, $p = .564$, TMT B, $r(48) = -.22$, $p = .128$, COWAT, $r(48) = .16$, $p = .282$ and Haylings, $r(48) = .24$, $p = .091$. In the high ToM version of this condition, accuracy had moderate positive correlations with Digit Span, $r(48) = .28$, $p = .050$, COWAT, $r(48) = .34$, $p = .016$ and Haylings, $r(48) = .35$, $p = .014$. There was no significant correlation with TMT B, $r(48) = -.24$, $p = .088$.

To further examine these relationships, we also re-ran the correlations and regressions as within-group correlations and hierarchical regressions, with group controlled for. No overall difference in results were detected, except for a slightly reduced correlation between the high WM condition and the Digit Span task, such that only a trend toward significance was detected [$r(47) = .26$, $p = .069$].

3.3. Experimental paradigm

Percentage correct scores and standard deviations for low and high ToM tasks across the various executive function conditions are shown in Table 2.

3.3.1. Low executive function condition

In order to determine whether people with TBI would be similar to controls on ToM when executive function demands are low (Hypothesis 1), we compared the groups in the low executive condition. No significant differences between the control and TBI participants were found in the low ToM task. The high ToM task, however, did approach significance with a tendency for control participants to perform better than TBI participants ($p = .053$).

3.4. High WM condition

To determine whether people with TBI perform ToM tasks more poorly than controls when executive function demands are high (Hypothesis 2) we compared groups on the high WM subtasks. No significant differences between the control and TBI participants were found for the low ToM task. However, TBI participants performed worse than the control participants in the high ToM task. To determine whether group differences on the high ToM task reflected the particular executive function demands of the task (Hypothesis 3) we used scores on the low ToM task as a covariate to predict scores on the high ToM task. When controlling for low ToM performance, TBI participants no longer performed worse than control participants on the high ToM version [$F(1,47) = 1.81$, $p = .185$, $d = .39$], i.e., poor ToM performance reflected WM demands.

3.4.1. High flexibility condition

In testing our second hypothesis, this time focusing on flexibility, we examined group differences on the high flexibility condition. No significant differences between the control and TBI participants were found for accuracy scores in either low or high ToM tasks. This pattern remained when the low ToM (high flexibility) task was used as a covariate in order to test our third hypothesis [$F(1,47) = 1.39$, $p = .248$, $d = .33$].

3.4.2. High inhibition condition

We tested our second hypothesis once again, this time focusing on the high inhibition condition. TBI participants performed worse than control participants on the low ToM task, but not the high ToM task. The lack of group difference remained when low ToM (high inhibition) was used as a covariate in order to test our third hypothesis [$F(1,47) = 0.47$, $p = .478$, $d = .21$].

4. Discussion

This study aimed to test the premise that ToM difficulties experienced by individuals with TBI can be accounted for by impaired executive processes. To address this, the study used videotaped verbal comprehension tasks with four types of executive functioning demands (low executive demands, high WM, high flexibility, high inhibition). Within each, low vs high ToM reasoning tasks were embedded. By keeping the executive demands constant within each condition we could keep the non-ToM cognitive requirement of the low and high ToM tasks uniform. Performance in each condition was compared to a group of adults without brain injury matched for basic demographic characteristics.

Based on our premise, when executive functioning demands are minimal, we hypothesised that individuals with TBI would have little difficulty with ToM judgements. Our results were equivocal in this regard. Although there was no group difference on the high ToM task, there was a trend ($p = .053$). This suggests that people with TBI may have a small amount of difficulty with ToM reasoning even when executive demands were very low. Interestingly, the fact that Digit Span correlated significantly with high ToM but not low ToM task performance suggested that the ToM question required some skills in common with WM tasks even when executive demands were deliberately kept low.

To further investigate the relationship between executive functioning and ToM, demands in executive functioning were increased in the three subsequent conditions. A varying pattern of results across these was found so the effects of WM, flexibility and inhibition will be discussed separately.

Consistent with our second hypothesis, when increased demands were placed on WM, individuals with TBI performed more poorly than controls on high ToM tasks. However, the crux of the study was to determine whether such poor performance on the ToM task could be specifically accounted for by the executive function demands of the task. When we used the low ToM scores as a covariate (to control for the high WM demands), group differences on the high ToM task were no longer apparent. Taken together, these findings suggest that WM mediated ToM ability in this task. Specifically, there was no evidence of ToM deficits that could not be explained by the working memory and other (non-mental) cognitive demands of the task.

These findings are similar to a prior study by Bibby and McDonald (2005) who found that performance on a WM task (Digit Span) partially mediated poor ToM performance (on verbal second-order belief and non-verbal cartoon ToM tasks). In that study, however, TBI individuals still performed significantly worse than controls when WM and non-mental inferencing was controlled. Our study provided a stronger experimental control for the effects of WM by manipulating WM and ToM demands within design rather than correlating different kinds of tasks. By using this stronger design we demonstrated that WM may have a significant role in ToM abilities following TBI. These results are consistent with Bull et al. (2008) who found that dual processing in non-clinical participants had decremental effects for both ToM and control tasks (cf our High and Low ToM conditions). They also concluded that this was a likely reflection of the high incidental demands of the task, rather than ToM reasoning per se. The TBI individuals in our study were impaired on both WM and ToM abilities as assessed using conventional measures. The introduction of a task that required high WM is likely to have exacerbated their difficulties in making inferences about the mental states of other people in social settings. Thus, they appear better able to deal with high ToM demands when dual processing was low (low executive function, high ToM condition) and high WM demands when ToM was low (high WM, low ToM condition) but they could not manage both.

In the high flexibility condition, no differences between groups were found in either the low or high ToM tasks. Nor were group differences apparent when flexibility demands and non-mental inferencing were controlled for. The present experiment was designed to mimic the type of cognitive flexibility likely to occur in a social context. The specific flexibility component concerned the participant's ability to understand and interpret the semantic and logical content (low ToM) or beliefs and intentions (high ToM) of two alternating speakers. The lack of group differences in either low or high ToM conditions suggests that flexibility was not a problem for people with TBI, but it is possible that our task was insufficiently sensitive to this kind of cognitive capacity. Indeed, in normal conversations such flexibility is required "on-line". There is frequently no time to stop and ponder one person's perspective before having to consider another's, and so on. Our task paused for each question thus providing opportunity for reflection on each person's perspective and may have, therefore, masked any difficulties with speeded flexible thinking. Further delineation of this potential issue will need to be addressed in future research.

A different pattern of results was found for the role of inhibition. In particular, when inhibition demands were high, TBI individuals' performed more poorly than controls on the low but not the high ToM task. Their poor performance on the low ToM measure, in conjunction with the positive relationship between Haylings scores and overall scores on the high inhibition task affirms the fact that the TBI group had difficulties with inhibition. Despite this, the high ToM subtask was not particularly difficult for the participants with TBI whose performance was not significantly different from controls. These results were surprising as they are inconsistent with other research that has reported a relationship between inhibitory processes and pragmatic understanding in both non-clinical (Bull et al., 2008) and TBI participants (Channon & Crawford, 2000). Indeed studies using ToM reasoning tasks in children, concluded that the relationship between ToM and inhibition is stronger than it is for other abilities such as WM, multitasking, and language (Channon & Watts, 2003; Perner & Lang, 1999). A similar relationship has been found in our own work examining language production and ToM in people with TBI (McDonald et al., 2014). The divergence between our results and findings in the literature may be accounted for by the nature of our task. In our efforts to increase inhibition demands we required participants to generate terms that were not consistent with the flow of the narrative. The nature of this response was, thus, qualitatively different to the other conditions which tapped comprehension of both ToM and non-ToM inferences in the narrative. Although, theoretically, comprehension of the narrative should have influenced the ability to *avoid* saying a word that was expected, and despite our design being based on a conventional clinical measure of disinhibition (i.e., the Hayling's sentence completion task), comprehension was not tested directly and this task could have been completed by some strategy other than engaging with the meaning. Inhibition is thought to be important to ToM so as to suppress literal or self-referential interpretations of social cues in order to understand the situation from another's perspective (D'Argembeau et al., 2007; McDonald et al., 2014; Ruby & Decety, 2004). It is possible, nonetheless, that our high inhibition task may not have directly increased the need to inhibit this kind of interpretation. Slightly lower levels of item reliability for the high ToM task in the inhibition condition may have also contributed to the lack of group differences found in this task. Whether these are factors that may be influencing the present results, needs to be examined in future research.

The central focus of the present study was to examine the influence of executive functions on ToM ability. Our controlled experimental design enabled us to exclude, or at least minimise, any potential confounding mediating effect from 'lower-order' cognitive domains or processing systems such as language and short-term memory that may contribute to ToM abilities (Bibby & McDonald, 2005; Muller et al., 2010) as well as our targeted constructs in executive functioning. Never-the-less, it is feasible that other facets of social cognition, in particular "hot" facets such as emotion perception and affective empathy (McDonald, 2013) may have contributed to performance on the high ToM conditions. The videoed vignettes were deliberately created to represent a "conversational tone" and overt emotionality was minimised. Thus, reliance on emotion recognition should have been low. If present, these facets of social cognition might be expected to have a disproportionate role in high ToM reasoning compared to low and might even differ across tasks (news reader versus dialogue between friends). The pattern of our results, however, suggests that there was nothing unique about our high ToM tasks over and above the cognitive and executive function demands.

It is important to also note that social cognition represents a set of learned abilities (Leukel, 1972). Consequently, there is likely to be variation in social cognitive competence in both individuals with TBI and in normal populations (Dress, Kreuz, Link, & Caucci, 2008). Individual differences will also be apparent in terms of the extent of relationship between executive functioning and ToM. This is likely to be more apparent on conversational tasks, such as used in this study which, arguably, demand more skills in self-regulation and metacognition than laboratory-based tasks such as story re-telling or picture description (Byom & Turkstra, 2012). The present study was conducted using English speakers in a relatively restricted sample in metropolitan Sydney. The extent to which the present findings are applicable to other cultures, or people from non-English speaking backgrounds, remains unknown.

Overall, the group with TBI examined in this study demonstrated problems with tasks specifically tapping both ToM and executive function. This sample of TBI participants, as is typical of this population, was heterogeneous with respect to the location of injury and time since injury. None-the-less, regardless of the primary site of the brain injury, the typical pattern of acceleration–deceleration forces that accompany such injuries essentially compromises frontal lobe systems. Specifically, upon impact, soft brain tissue scrapes across the bony floor of the anterior and middle fossa of the skull, and medial frontal surfaces are compressed against the dorsal bone and collide with the cerebral falx resulting in immediate contusions (Bigler, 2007). The resulting injury also causes Wallerian degeneration that disrupts neural activity both within and to the ventrolateral, medial and orbital frontal lobes and the ventromedial temporal lobes (Bigler, 2007; Bigler & Maxwell, 2011; Courville, 1945; Gentry, Godersky, & Thompson, 1988; Hadley et al., 1988). Diffuse axonal injury to the brainstem, corpus callosum and the grey-white matter junctions of the cerebral cortex (Adams et al., 1989; Meythaler, Peduzzi, Eleftheriou, & Novack, 2001; Viano et al., 2005) further disrupt connections between subcortical and frontal systems (Kennedy et al., 2009).

Compromised neuropathology in the frontal lobes, and consequently ToM ability, are therefore likely to be common factors associated with most moderate to severe traumatic brain injuries. This is borne out in a meta-analysis based upon 173–354 adults with acquired brain injury, roughly 50% of whom had TBI. In this, effect sizes for ToM tasks were moderate to large (0.5–0.7) and this was true for the TBI group alone (Martin-Rodriguez & Leon-Carrion, 2010). Clearly, ToM deficits, whether these arise from executive function disorders or uniquely, represent a major area of disability for this population. Furthermore, our participants with TBI were all two years or more post injury. Their difficulties with ToM accord with other researchers who have found such deficits to remain stable over time (Milders et al., 2006).

Several limitations of this study need to be noted. First, the sample size of 25 individuals with TBI, while fairly typical of experimental studies of this kind, was small and thus power was limited. While significant effects consistent with a priori hypotheses were found in this study, it remains possible that alternative effects were not detectable. For example, based on the trend that was apparent in our results, it is possible that our first hypothesis that individuals with TBI would perform similarly to individuals without TBI in high ToM tasks when executive functioning demands are low would not be supported. Second, given that recruitment occurred in a clinic setting, the sample is likely to suffer from ascertainment bias and not be representative of the broader population of adults with TBI as a result. Third, the ecological validity of the tasks included in this study has been assumed based on the fact that they involve comprehension of everyday conversations. The inclusion of a measure of broader social adjustment in this study may have assisted with the establishment of this ecological validity. Such a measure may include, for example, the Sydney Psychosocial Reintegration Scale (SPRS; Tate, Hodgkinson, Veerabangsa, & Maggiotto, 1999) which is specifically designed to measure psychosocial functioning in people with TBI.

Fourth, the order to which the tasks were presented in this study was relatively constrained. Specifically, we administered the low executive function condition first to ensure participants were familiarised with the nature of the task before increasing the difficulty level. Further, we required the inhibition tasks to be administered last because this condition relied on previously viewed content so that non-related utterances could be made by participants. Order effects, thus, cannot be ruled out. As such, we are unable to determine whether our null findings in the inhibition and flexibility conditions were due to exposure to previously presented stimuli. Although the fact that significant effects were detected at various stages throughout the study, suggests that there was no facilitative effect of practice present.

Finally, we were constrained in the design of the videoed vignettes to make it possible to sample low and high ToM reasoning stimuli while also maintaining ecological validity. In order to maintain the "realism" of the videos it was not always possible to have an equal number of questions in each condition or to have video clips that were equal in length. This meant that a direct comparison between the EF conditions was not possible. We were, however, able to use the results that we obtained in our low EF condition (i.e., we found a trend toward significance in our high ToM task) to inform our conclusions. A smaller number of questions in the low ToM tasks (as compared to the high ToM tasks) in particular may have also meant that it was more difficult for us to produce null findings.

Despite these caveats, the findings of this study indicate that executive processes, especially WM, may be important to ToM judgements in everyday communication. Evidence regarding the role of inhibition and flexibility were not convincingly demonstrated. While prior studies have examined the role of executive functioning in ToM, this is the first study to the authors' knowledge, to examine the relationship in a context that requires participants to understand and interpret the meaning of everyday conversation. The findings of this study, therefore, may also have important implications for the rehabilitation of social cognition deficits in individuals with TBI. Programs targeting attentional remediation or adoption of compensatory strategies, which typically foster the internalisation of strategies for effective self-monitoring and self-regulations (Cicerone, Levin, Malec, Stuss, & Whyte, 2006), may play an important role in improving ToM and thus social-communication outcomes following TBI. We expect that future studies adopting similar ecologically valid experimental protocols will further clarify the role that working memory, and indeed other domains of executive functioning, may play in the difficulties that are experienced by those with frontal lobe dysfunction in everyday conversation.

5. Disclosure statement

There are no conflicts of interest to declare.

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References

Adams, J. H., Doyle, D., Ford, I., Gennarelli, T. A., Graham, D. I., & McLellan, D. R. (1989). Diffuse axonal injury in head injury: Definition, diagnosis and grading. *Histopathology, 15*, 49–59.

Adolphs, R. (1999). Social cognition and the human brain. *Trends in Cognitive Sciences, 3*, 469–479.

Adolphs, R. (2009). The social brain: Neural basis of social knowledge. *Annual Review of Psychology, 60*, 693–716.

Alvarez, J. A., & Emory, E. (2006). Executive function and the frontal lobes: A meta-analytic review. *Neuropsychology Review, 16*, 17–42.

Bach, L. J., Happé, F., Fleminger, S., & Powell, J. (2000). Theory of mind: Independence of executive function and the role of the frontal cortex in acquired brain injury. *Cognitive Neuropsychiatry, 5*, 175–192.

Baron-Cohen, S., Wheelwright, S., Hill, J., Raste, Y., & Plumb, I. (2001). The "Reading the Mind in the Eyes" test revised version: A study with normal adults with Asperger syndrome or high-functioning autism. *Journal of Child Psychology and Psychiatry, 42*, 241–251.

Benton, A. L., Hamsher, K. d., & Sivan, A. B. (1994). *Multilingual aphasia examination* (3rd ed.). San Antonio, TX: Psychological Corporation.

Benton, A. L., Sivan, A. B., Hamsher, K., Varney, N. R., & Spreen, O. (1983). *Contribution to neuropsychological assessment*. NY: Oxford University Press.

Bibby, H., & McDonald, S. (2005). Theory of mind after traumatic brain injury. *Neuropsychologia, 43*, 99–114.

Bigler, E. D. (2007). Anterior and middle cranial fossa in traumatic brain injury: Relevant neuroanatomy and neuropathology in the study of neuropsychological outcome. *Neuropsychology, 21*, 515–531.

Bigler, E. D., & Maxwell, W. L. (2011). Neuroimaging and neuropathology of TBI. *NeuroRehabilitation, 28*, 1–12.

Brownell, H., & Martino, G. (1988). Deficits in inference and social cognition: The effects of right hemisphere brain damage on discourse. In M. Breman & C. Chiarello (Eds.), *Right hemisphere language comprehension: Perspectives from*

cognitive neuroscience (pp. 309–328). Mahwah, NJ: Lawrence Erlbaum Associates.
Bull, R., Phillips, L. H., & Conway, C. A. (2008). The role of control functions in mentalizing: Dual-task studies of Theory of Mind and executive function. *Cognition, 107*, 663–672.
Burgess, P. W., & Shallice, T. (1997). *The Hayling and Brixton tests*. Thurston, Suffolk: Thames Valley Test Company.
Byom, L. J., & Turkstra, L. (2012). Effects of social cognitive demand on Theory of Mind in conversations of adults with traumatic brain injury. *International Journal of Language and Communication Disorders, 47*, 310–321.
Carlson, S. M., Moses, L. J., & Breton, C. (2002). How specific is the relation between executive function and theory of mind? Contributions of inhibitory control and working memory. *Infant and Child Development, 11*, 73–92.
Carrington, S. J., & Bailey, A. J. (2009). Are there theory of mind regions in the brain? A review of the neuroimaging literature. *Human Brain Mapping, 30*, 2313–2335.
Channon, S., & Crawford, S. (2000). The effects of anterior lesions on performance on a story comprehension test: Left anterior impairment on a theory of mind-type task. *Neuropsychologia, 38*, 1006–1017.
Channon, S., & Crawford, S. (2010). Mentalising and social problem-solving after brain injury. *Neuropsychological Rehabilitation, 20*, 739–759.
Channon, S., & Watts, M. (2003). Pragmatic language interpretation after closed head injury: Relationship to executive functioning. *Cognitive Neuropsychiatry, 8*, 243–260.
Cicerone, K., Levin, H., Malec, J., Stuss, D., & Whyte, J. (2006). Cognitive Rehabilitation interventions for executive function: Moving from bench to bedside in patients with traumatic brain injury. *Journal of Cognitive Neuroscience, 18*, 1212–1222.
Courville, C. B. (1945). *Pathology of the nervous system* (2nd ed.). Mountain View: CA California Pacific Press.
D'Argembeau, A., Ruby, P., Collette, F., Degueldre, C., Balteau, E., Luxen, A., et al. (2007). Distinct regions of the medial prefrontal cortex are associated with self-referential processing and perspective taking. *Journal of Cognitive Neuroscience, 19*, 935–944.
Dennis, M., Agostino, A., Roncadin, C., & Levin, H. S. (2009). Theory of mind depends on domain-general executive functions of working memory and cognitive inhibition in children with traumatic brain injury. *Journal of Clinical and Experimental Neuropsychology, 31*, 835–847.
Dress, M. L., Kreuz, R. J., Link, K. E., & Caucci, G. M. (2008). Regional variation in the use of sarcasm. *Journal of Language and Social Psychology, 27*, 71–85.
Gentry, L. R., Godersky, J. C., & Thompson, B. (1988). MR imaging of head trauma: Review of the distribution and radiopathologic features of traumatic lesions. *American Journal of Roentgenology, 150*, 663–672.
Hadley, D. M., Teasdale, G. M., Jenkins, A., Condon, B., MacPherson, P., Patterson, J., et al. (1988). Magnetic resonance imaging in acute head injury. [Comparative Study Research Support, Non-U.S. Gov't]. *Clinical Radiology, 39*, 131–139.
Happé, F., Brownell, H., & Winner, E. (1999). Acquired 'theory of mind' impairments following stroke. *Cognition, 70*, 211–240.
Happé, F. G. E. (1993). Communicative competence and theory of mind in autism: A test of relevance theory. *Cognition, 48*, 101–119.
Havet-Thomassin, V., Allain, P., Etcharry-Bouyx, F., & Le Gall, D. (2006). What about theory of mind after severe brain injury? *Brain Injury, 20*, 83–91.
Henry, J. D., Phillips, L. H., Crawford, J. R., Ietswaart, M., & Summers, F. (2006). Theory of mind following traumatic brain injury: The role of emotion recognition and executive dysfunction. *Neuropsychologia, 44*, 1623–1628.
Hughes, C. (1998). Executive function in preschoolers: Links with theory of mind and verbal ability. *British Journal of Developmental Psychology, 16*, 233–253.
Johnco, C., Wuthrich, V. M., & Rapee, R. M. (2013). The role of cognitive flexibility in cognitive restructuring skill acquisition among older adults. *Journal of Anxiety Disorders, 27*, 576–584.
Johnston, L., Miles, L., & McKinlay, A. (2008). A critical review of the Eyes Test as a measure of social-cognitive impairment. *Australian Journal of Psychology, 60*, 135–141.
Kennedy, M. R. T., Wozniak, J. R., Muetzel, R. L., Mueller, B. A., Chiou, H.-H., Pantekoek, K., et al. (2009). White matter and neurocognitive changes in adults with chronic traumatic brain injury. *Journal of the International Neuropsychological Society, 15*, 130–136.
Kortte, K. B., Horner, M. D., & Windham, W. K. (2002). The trail making test, Part B: Cognitive flexibility or ability to maintain set? *Applied Neuropsychology, 9*, 106–109.
Leukel, F. (1972). *Introduction to physiological psychology*. St Louis: C.V Mosby Co.
Levy, N. K., & Milgram, N. (2014). Cognitive contributions to theory of mind ability in children with a traumatic head injury. *Child Neuropsychology* (available online ahead of print).
Linacre, J. M. (2006). *A user's guide to WINSTEPS MINISTEP Rasch-model computer programs*. Chicago, IL: Winsteps.com.
Lough, S., Kipps, C. M., Treise, C., Watson, P., Blair, J. R., & Hodges, J. R. (2006). Social reasoning, emotion and empathy in frontotemporal dementia. *Neuropsychologia, 44*, 950–958.
Lovibond, P. F., & Lovibond, S. H. (1995). *Manual for the depression anxiety stress scales. Sydney, Australia: Psychology foundation of Australia. Sydney*. Sydney, Australia: Psychology Foundation of Australia.
Maehara, Y., & Saito, S. (2011). I see into your mind too well: Working memory adjusts the probability judgment of others' mental states. *Acta Psychologica, 138*, 367–376.
Marcovitch, S., O'Brien, M., Calkins, S. D., Leerkes, E. M., Weaver, J. M., & Levine, D. W. (2014). A longitudinal assessment of the relation between executive function and theory of mind at 3, 4, and 5 years. *Cognitive Development, 33*, 40–55.
Marosszeky, N. E. V., Ryan, L., Shores, E. A., Batchelor, J., & Marosszeky, J. E. (1997). *The PTA protocol: Guidelines for using the Westmead Post-Traumatic Amnesia (PTA) scale*. Sydney: Wild & Wooley.
Martin-Rodriguez, J. F., & Leon-Carrion, J. (2010). Theory of mind deficits in patients with acquired brain injury: A quantitative review. *Neuropsychologia, 48*, 1181–1191.
Mathias, J. S., Bowden, S. C., Bigler, E. D., & Rosenfeld, J. V. (2007). Is performance on the Wechsler test of adult reading affected by traumatic brain injury? *British Journal of Clinical Psychology, 46*, 457–466.
McDonald, S. (2012). New frontiers in neuropsychological assessment: Assessing social perception using a standardised instrument, the awareness of social inference test. *Australian Psychologist, 47*, 39–48.
McDonald, S. (2013). Impairments in social cognition following severe traumatic brain injury. *Journal of the International Neuropsychological Society, 19*, 231–246.
McDonald, S., & Flanagan, S. (2004). Social perception deficits after traumatic brain injury: Interaction between emotion recognition, mentalizing ability, and social communication. *Neuropsychology, 18*, 572–579.
McDonald, S., Flanagan, S., Martin, I., & Saunders, C. (2004). The ecological validity of TASIT: A test of social perception. *Neuropsychological Rehabilitation, 14*, 285–302.
McDonald, S., Flanagan, S., & Rollins, J. (2011). *The awareness of social inference test (revised)*. Sydney, Australia: Pearson Assessment.
McDonald, S., Flanagan, S., Rollins, J., & Kinch, J. (2003). TASIT: A new clinical tool for assessing social perception after traumatic brain injury. *Journal of Head Trauma Rehabilitation, 18*, 219–238.
McDonald, S., Gowland, A., Randall, R. K., Fisher, A., Osborne-Crowley, K., & Honan, C. (2014). Cognitive factors underpinning poor expressive communication skills after traumatic brain injury: Theory of Mind or poor executive function? *Neuropsychology, 28*, 801–811.
McDonald, S., & Saunders, J. C. (2005). Differential impairment in recognition of emotion across different media in people with severe traumatic brain injury. *Journal of the International Neuropsychological Society, 11*, 392–399.
Meythaler, J. M., Peduzzi, J. D., Eleftheriou, E., & Novack, T. A. (2001). Current concepts: Diffuse axonal injury-associated traumatic brain injury. *Archives of Physical Medicine & Rehabilitation, 82*, 1461–1471.
Milders, M., Ietswaart, M., Crawford, J. R., & Currie, D. (2006). Impairments in theory of mind shortly after traumatic brain injury and at 1-year follow-up. *Neuropsychology, 20*, 400–408.
Milders, M., Ietswaart, M., Crawford, J. R., & Currie, D. (2008). Social behavior following traumatic brain injury and its association with emotion recognition, understanding of intentions, and cognitive flexibility. *Journal of the International Neuropsychological Society, 14*, 318–326.
Milders, M., Ietswaart, M., Currie, D., & Crawford, J. R. (2006). Impairments in theory of mind shortly after traumatic brain injury and ar 1-year follow-up. *Neuropsychology, 20*, 400–408.
Morris, P. G., Wilson, J. T., Dunn, L. T., & Teasdale, G. M. (2005). Premorbid intelligence and brain injury. *British Journal of Clinical Psychology, 44*, 209–214.
Muller, F., Simion, A., Reviriego, E., Galera, C., Mazaux, J.-M., Barat, M., et al. (2010). Exploring theory of mind after severe traumatic brain injury. *Cortex, 46*, 1088–1099.
Ochsner, K. N., & Lieberman, M. D. (2001). The emergence of social cognitive neuroscience. *American Psychologist, 56*, 717–734.
Perner, J., & Lang, B. (1999). Development of theory of mind and executive control. *Trends in Cognitive Sciences, 3*, 337–344.
Pickup, G. J. (2008). Relationship between theory of mind and executive function in schizophrenia: A systematic review. *Psychopathology, 41*, 206–213.
Premack, D., & Woodruff, G. (1978). Does the chimpanzee have a theory of mind? *Behavioral and Brain Sciences, 1*, 515–526.
Reitan, R. M. (1992). *Trail making test*. Tucson, AZ: Reitan Neuropsychological Laboratories.
Ruby, P., & Decety, J. (2004). How would you feel versus how do you think she would feel? A neuroimaging study of perspective-taking with social emotions. *Journal of Cognitive Neuroscience, 16*, 988–999.
Russell, W., & Smith, A. (1961). A post-traumatic amnesia in head injury. *Archives of Neurology, 5*, 16–29.
Shamay-Tsoory, S. G., Tomer, R., Berger, B. D., Goldsher, D., & Aharon-Peretz, J. (2005). Impaired "affective theory of mind" is associated with right ventromedial prefrontal damage. *Cognitive and Behavioral Neurology, 18*, 55–67.
Spikman, J. M., Timmerman, M. E., Milders, M. V., Veenstra, W. S., & van der Naalt, J. (2012). Social cognition impairments in relation to general cognitive deficits, injury severity, and prefrontal lesions in traumatic brain injury patients. *Journal of Neurotrauma, 29*, 101–111.
Stone, V. E., Baron-Cohen, S., & Knight, R. T. (1998). Frontal lobe contributions to theory of mind. *Journal of Cognitive Neuroscience, 10*, 640–656.
Stuss, D. T. (2011a). Functions of the frontal lobes: Relation to executive functions. *Journal of the International Neuropsychological Society, 17*, 759–765.
Stuss, D. T. (2011b). Traumatic brain injury: Relation to executive dysfunction and the frontal lobes. *Current Opinion in Neurology, 24*, 584–589.
Tate, R., Hodgkinson, A., Veerabangsa, A., & Maggiotto, S. (1999). Measuring psychosocial recovery after traumatic brain injury: Psychometric properties of a new scale. *The Journal of Head Trauma Rehabilitation, 14*, 543–557.

Teasdale, G. M. (1995). Head injury. *Journal of Neurology, Neurosurgery and Psychiatry, 58*, 526–539.

The Psychological Corporation (2001). *Wechsler test of adult reading*. San Antonio, TX: Harcourt Assessment.

Troyer, A. K., Moscovitch, M., Winocur, G., Alexander, M. P., & Stuss, D. (1998). Clustering and switching on verbal fluency: The effects of focal frontal- and temporal-lobe lesions. *Neuropsychologia, 36*, 499–504.

Turkstra, L. S. (2008). Conversation-based assessment of social cognition in adults with traumatic brain injury. *Brain Injury, 22*, 397–409.

Viano, D. C., Casson, I. R., Pellman, E. J., Zhang, E. J., King, A. I., & Yang, K. H. (2005). Concussion in professional football: Brain responses by finite element analysis: Part 9. *Neurosurgery, 57*, 891–916.

Wechsler, D. (1997a). *Wechsler adult intelligence scale – Third edition (WAIS-III)*. San Antonio, TX: Psychological Corporation.

Wechsler, D. (1997b). *Wechsler Memory Scale* (3rd ed.). New York: Psychological Corporation.

Wells, R., Dywan, J., & Dumas, J. (2005). Life satisfaction and distress in family caregivers as related to specific behavioural changes after traumatic brain injury. *Brain Injury, 19*, 1105–1115.