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Impairments in 'theory of mind' shortly after traumatic brain injury and at one-year follow-up.

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Abstract

Most studies into acquired "theory of mind" (ToM) deficits assessed patients once, long after the onset of brain injury. As a result, the time course of acquired ToM impairments is largely unknown. The present study examined whether ToM impairments following traumatic brain injury (TBI) recover, remain stable or worsen over time. Because of the alleged association between ToM and social communication, ToM impairments may deteriorate due to changes in patients' social environment following injury. ToM ability and executive functioning were assessed shortly after injury and at one-year follow-up. Compared to orthopaedic controls, the TBI group was impaired on ToM and executive functioning tasks at both assessments. Furthermore, the ToM impairments in the TBI group remained stable over time.
(118 words)

Keywords: traumatic brain injury, theory of mind, executive function, recovery, follow-up

Introduction

The ability to recognise and make inferences about other people's intentions and beliefs is often referred to as theory-of-mind (ToM) and this ability is regarded as crucial for effective social communication (Channon & Crawford, 2000; Happé, Malhi, & Checkley, 2001). While most early research into ToM deficits focussed on developmental disorders, such as autism and Asperger's syndrome (e.g. Baron-Cohen, Leslie, & Frith, 1986; Leekam & Perner, 1991), there is increasing interest in acquired deficits in ToM following brain damage in adult patients.

Impaired performance in ToM tests has been reported in patients with acquired brain damage due to various aetiologies, including stroke (Channon & Crawford, 2000; Happé, Brownell, & Winner, 1999; Samson, Apperly, Chiavarino, & Humphreys, 2004; Siegal, Carrington, & Radel, 1996; Stone, Baron-Cohen, & Knight, 1998; Stuss, Gallup, & Alexander, 2001; Surian & Siegal, 2001, frontotemporal dementia (Gregory, Lough, Stone, Erzinclioglu, et al., 2002; Snowden, Gibbons, Blackshaw, Doubleday, et al., 2003) , neurosurgical lesions (Happé et al., 2001; Rowe, Bullock, Polkey, & Morris, 2001; Stone, Baron-Cohen, Calder, Keane, & Young, 2003), tumours (Channon & Crawford, 2000; Stuss et al., 2001) or herpes simplex encephalitis (Stone et al., 2003). Relatively few studies have assessed ToM abilities in adult patients with traumatic brain injury (TBI) even though social communication, which is commonly associated with ToM, is frequently disturbed following TBI (Cicerone & Tanenbaum, 1997; Kendall & Terry, 1996; Levin, 1995; Tate & Broe, 1999). Some of the studies on acquired ToM impairments mentioned above did include patients with lesions resulting from TBI, amongst patients with other aetiologies (Channon & Crawford, 2000; Stone et al., 1998; Stuss et al., 2001),

but findings from the patients with TBI were not reported separately. In an earlier study, we found impaired performance on a ToM task in patients with moderate to severe TBI (Milders, Fuchs, & Crawford, 2003). More recently, McDonald and Flanagan (2004), Bibby and McDonald (2005) and Channon, Pellijeff and Rule (2005) also reported impaired performance on ToM tasks in patients with severe TBI. These studies indicate that ToM impairments can be found following TBI, or at least following severe TBI.

A limitation of previous studies into ToM impairments following TBI, and in fact of most studies of acquired ToM impairments, was that ToM ability was assessed only once, which for many patients was several years following injury. As a consequence, little is known about the time course of acquired ToM impairments. If impairments in ToM are a direct result of brain damage and behave similarly to most neuropsychological deficits, ToM impairments should be found early after injury and remain fairly stable over time or possibly show signs of recovery, in step with recovery in other cognitive functions. However, it is also conceivable that ToM impairments become more severe over time. ToM impairments may be different from other cognitive deficits because of the hypothesized association between ToM and social communication. Therefore, changes in patients' social environment following injury that result in fewer social interactions and reduced social communication might affect ToM ability and ToM deficits occurring shortly after injury may further deteriorate as a result of the patients' impoverished social environment. In the developmental literature there is a similar debate on the direction of the relationship between ToM and social communication. While some researchers suggest that ToM is a necessary precursor for social communication, others argue that experience with social communication is a condition for ToM (see Martin and McDonald, 2003 for an

overview). At the moment the possibility that ToM impairments increase over time in patients with acquired brain damage cannot be ruled out due to the lack of longitudinal data, but increased severity of ToM impairments with chronicity has been observed in patients with schizophrenia (Brüne, 2005).

In the study reported here we investigated the relationship between ToM performance, executive functioning and chronicity in patients with TBI in a longitudinal design. The reason to include executive functioning was that there is a long-standing debate in the neuropsychological and development literature whether ToM is a distinct function or whether it is part of those processes involved in flexible and goal-directed behaviour, often referred to as executive functioning. Developmental studies have demonstrated a link between the development of ToM and executive function abilities (Perner & Lang, 1999; Carlson, Mandell, & Williams, 2004), suggesting a relationship between these two functions, although the causal direction of this relationship is still unclear. Studies in adults with brain injury showed conflicting results regarding the link between ToM and executive functions. Some studies found associations between impairments in ToM and executive functioning, raising the possibility of shared processes (Channon & Crawford, 2000; Snowden et al., 2003), but other studies reported dissociations between ToM and executive functioning impairments (Bach, Happé, Fleminger, & Powell, 2000; Rowe et al., 2001), suggesting independent processes.

In the current study, ToM and executive function performance was assessed shortly after patients had sustained their first TBI and again one year later. Performance of the TBI group was compared to that of patients with traumatic orthopaedic injuries. Orthopaedic controls were chosen in order to control for the potential impact of trauma and hospitalisation on test performance. The main

questions were: 1. Can ToM impairments already be identified early after TBI; 2. Are changes in ToM performance over a one-year interval suggestive of recovery or deterioration; 3. Are impairments in ToM performance associated with impaired executive functioning, shortly after injury and at one-year follow-up; and 4. Is severity of TBI related to severity of the ToM impairments, as ToM impairments have so far mainly been reported in patients with severe TBI.

Method

Participants

Participants were 70 adults, 36 with TBI and 34 with orthopaedic injuries, who were recruited from the Department of Neurosurgery and the Orthopaedic Trauma Unit at Aberdeen Royal Infirmary. The patients with TBI were recruited consecutively while orthopaedic patients were recruited to match the patients with TBI for gender, age and years of education. Exclusion criteria were a neurological or psychiatric history, dementia or a history of alcohol or drug dependency. An extra exclusion criterion for the orthopaedic patients was brain injury. Two patients with TBI were excluded because they had suffered previous brain injuries. All participants were screened for language comprehension deficits using the Complex Ideation subtest of the Boston Diagnostic Aphasia Examination (Goodglass & Kaplan, 1983). One patient with TBI scored below cut-off at the time of the first assessment and was excluded from further analysis.

The TBI group that entered the study consisted of 28 males and 5 females. The overrepresentation of males in the TBI group is typical for this form of brain injury.

The control group consisted of 30 males and 4 females. The TBI and control groups were matched for age (TBI: M = 37.5, SD = 16.1 years; control: M = 35.6, SD = 13.1 years) and years of education (TBI: M = 13.1, SD = 2.1; control: M = 13.5, SD = 2.2). In addition, the two groups were comparable in that all patients had sustained traumatic injuries, which either included head injuries or were restricted to orthopaedic injuries. The mean of the lowest Glasgow Coma Scale (GCS) score, as assessed during the acute phase, was 10 (range 3-15). Mean duration of post-traumatic amnesia (PTA) in the TBI group was 12.5 days (range 1- 90 days). Length of PTA was assessed in the acute phase by daily examination of the patient's memory for events of preceding days. If no acute assessments were available, length of PTA was estimated retrospectively in the subacute or chronic phase from the patient's recall of the time immediately following injury. Following a conventional classification (Teasdale & Jennett, 1974) of mild injury (GCS 13-15 or PTA < 24 hours), moderate injury (GCS 9-12 or PTA 1-7 days) and severe injury (GCS < 9 or PTA>7 days), 9 patients were classed as mild, 14 as moderate and 10 as severe TBI.

The average interval between injury and first assessment was 2.1 (SD = 1.8) months in the TBI group and 1.2 (SD = 1.0) months in the orthopaedic group; this difference was significant, $t(64)=2.62$, $p<.05$. All participants gave informed consent to participate in the study, which had been approved by the Grampian Research Ethics Committee.

Material

Digit Symbol. The Digit Symbol task is a subtest of the Wechsler Adult Intelligence Scale (WAIS-III; Wechsler, Wycherley, Benjamin, Crawford, &

Mockler, 1998). The Digit Symbol task is a measure of mental speed and is known to be very sensitive to the effects of brain injury. The test form consists of a sample line of digits numbered 1 to 9 with a simple nonsense symbol printed below each digit. Patients are presented with a sheet containing the digits 1 to 9 in random order and the task is to write the associated symbol next to the correct digit. The Digit Symbol score is the number of correct symbols produced within 90 seconds.

Executive functioning. Participants completed two measures of executive functioning, a non-verbal test, the Brixton Spatial Anticipation task (Burgess & Shallice, 1997), and a verbal test, the Alternating Fluency test (Downes, Sharp, Costall, Sagar, & Howe, 1993). These tasks assess primarily cognitive selection and flexibility. We assumed these elements of executive functioning to be particularly relevant for patients' ability to take other people's perceptive as assessed in the ToM tasks. Furthermore, previous studies that either found associations (Channon & Crawford, 2000; Snowden et al., 2003) or dissociations (Bach et al., 2000; Rowe et al., 2001) between ToM and executive functioning impairments used similar tasks of executive functioning.

The Brixton Spatial Anticipation task consists of 56 pages each containing two rows of five circle outlines. One of the circles is filled and the position of this filled circle varies across successive pages following predefined rules. The participants' task is to detect these rules and to predict the position of the filled circle on the next page. The test requires 55 responses and the number of errors is recorded. The Alternating Fluency test is a verbal fluency test in which the task is to generate names of items from alternating categories. The test consists of three subtasks: 1. words beginning with T and countries; 2. words beginning with D and colours; 3. words beginning with

C and occupations. Participants received one point for each correct exemplar produced within 60 seconds. Correct scores from the three subtasks were summed into in single total Alternating Fluency score.

ToM measures. Two tests were used to measure ToM ability, the Faux Pas test (Stone et al., 1998) and the Cartoon test (Happé et al., 1999). Both tasks have been used before in brain-damaged adults and represent a verbal and non-verbal test, respectively.

Faux Pas Test. This test consists of 20 very short stories, 10 describe a social faux pas, and 10 contain no faux pas. A sheet on which a story is printed was placed in front of the participant and the experimenter read the story out aloud. After a story had been read, participants answered a number of questions while keeping the printed story in front of them. Following stories that contained a faux pas, five questions were asked that assessed participants' detection of the social faux pas (two questions that form a detection score) and understanding of the intentions and beliefs of the characters in the story (three questions form a clarification score), a sixth question probed the participants' general comprehension of the story (control question). Following stories without faux pas, one question was asked that assessed detection of the absence of a faux pas (rejection score) and a second question tested general comprehension of the story (control question). Participants received one point for each correct response. There were separate scores for the 10 faux pas stories and the 10 stories without faux pas. Stories with and without faux pas were presented in random order.

Cartoon test. This test consists of 12 cartoons taken from magazines that display humorous situations. In six cartoons the joke is based on the false belief or

ignorance of a character in the cartoon. These mental cartoons would probe ToM ability. In the remaining six cartoons the joke is based on a physical anomaly. Participants were presented with one cartoon at a time and asked to explain why the cartoon is funny. Mental and physical cartoons were presented in random order. The responses were recorded and scored in accordance with guidelines from Happé et al. (1999). An answer received three points if it provided a complete and explicit explanation, two points if the explanation was incomplete or implicit and one point if relevant parts of the cartoon were mentioned, without further explanation. Incorrect or irrelevant answers received no points. Scores for mental items and physical items were summed into separate subscores.

Procedure

All participants were tested individually either at their home, the School of Psychology or on the ward. Patients were tested twice on all the neuropsychological and ToM tasks mentioned above, first shortly after they had sustained their injury (TBI or orthopaedic injury) and again about one year after this first assessment.

Results

Initial assessment

Neuropsychological tests. Performance of the two groups at the first assessment on the neuropsychological tests is displayed in Table 1. Estimated effect sizes are reported in the form of partial eta squared values (η_p^2). The TBI group had

significantly lower scores than the control group on the Digit Symbol test, $F(1, 62) = 8.49$, $p<.01$, $\eta_p^2=.12$, and on the Alternating Fluency test, $F(1, 62)= 18.19$, $p<.001$, $\eta_p^2=.23$, but on the Brixton test, the group difference was not significant (see Table 1).

[Table 1 about here please]

ToM tests. Faux Pas test. Responses on the Faux Pas test were scored by two independent raters and inter-rater reliability was .97. Mean performance of each group on the five scores from the Faux Pas test are displayed in Table 1. The stories containing a faux pas produced three scores: detection (maximum score = 20), clarification (maximum score = 30) and control (maximum score = 10). The stories without faux pas produced a rejection score (correct response that no faux pas had occurred) and a control score (for both maximum score = 10). Because the Faux Pas subscores had different scales, the scores of the TBI and control groups were compared in separate between-group comparisons, while the alpha level was adjusted for multiple comparisons: .05/5=.01. The TBI group scored significantly poorer than the controls on clarification, $F(1, 65)= 7.45$, $p<.01$, $\eta_p^2=.10$, and rejection of non-faux pas, $F(1, 65)= 7.26$, $p<.01$, $\eta_p^2=.10$, but group differences on the remaining scores were not significant at the adjusted alpha level. The patients with TBI made more errors than controls in interpreting the intentions and feelings of the characters in the faux pas stories, as reflected in their impaired clarification score, and the patients with TBI were poorer in correctly rejecting the presence of a faux pas in the items without faux pas.

Cartoon test. Responses on the Cartoon test were scored by the same raters who had scored the Faux Pas test and inter-rater reliability was .87. The Cartoon test

produced separate scores for mental and physical cartoons (maximum score = 18 for each category). Mean mental and physical scores for the TBI and control groups are shown in Table 1 and were compared in a 2 (category: mental, physical) x 2 (group: TBI, control) repeated measures ANOVA. This analysis revealed main effects of group, $F(1, 64)=27.33$, $p<.001$, $\eta_p^2=.29$, and category, $F(1,64)=8.25$, $p<.01$, $\eta_p^2=.11$, but no interaction, $p=.68$, $\eta_p^2 =.003$. The patients with TBI scored significantly poorer than the control patients on both the mental and the physical items and within each group the number of correct responses was higher for the mental items than for the physical items.

Kolmogorov-Smirnov tests indicated that scores on the ToM tests, with the exception of Faux Pas clarification, were not normally distributed, ps$<.04$. However, it is known that ANOVAs are robust to deviations from normality and re-analysis of those scores that were not normally distributed with non-parametric Mann-Whitney tests produced results very similar to those from the ANOVAs reported above.

To examine whether the two ToM tasks could be measuring a common ability, e.g. understanding beliefs and intentions in others, correlations were calculated within each group between those measures from the Faux Pas and Cartoon tasks that differentiated between patients and controls, i.e. Faux Pas clarification, Faux Pas rejection, mental cartoons and physical cartoons. The alpha level was adjusted for the number of comparisons in each group: .05/4 = .0125. Non-parametric Spearman rank correlations were calculated to reduce the impact of outliers and because of the skewed distribution of most scores on the ToM tasks. Within the TBI group, mental cartoons, $r_s =.66$, $p<.001$, and physical cartoon, $r_s =.63$, $p<.001$, both correlated with Faux Pas clarification, but neither correlated with Faux Pas rejection (see Table 2). Within the control group, mental cartoons, $r_s =.61$, $p<.001$, and physical cartoons, r_s

=.44, $p<.01$, correlated with Faux Pas clarification scores and mental cartoons correlated with Faux Pas rejection, r_s =.45, $p<.01$.

Executive functioning and ToM performance. Spearman rank correlations were calculated between those ToM measures that proved impaired in the TBI group (Faux Pas clarification, Faux Pas rejection, mental cartoons and physical cartoons) and Alternating Fluency (see Table 2). Within the TBI group Alternating Fluency scores correlated significantly with Faux Pas clarification, r_s =.54, $p<.01$, mental cartoons, r_s =.71, $p<.001$, and physical cartoons, r_s =.77, $p<.001$. Within the control group, Alternating Fluency did not correlate with any of the ToM measures, which was probably due to the overall high performance and restricted variance in this group. Associations with performance on the Brixton task were not considered, as this task did not discriminate between the TBI and control groups at initial assessment.

[Table 2 about here please]

Follow-up

Out of the original sample of 67 participants who were tested shortly following injury, 61 participants, 30 patients with TBI (5 female, 25 male) and 31 controls (4 female, 27 male), returned for follow-up and were retested on the same tasks. The groups retested at follow-up were matched for age (TBI: M = 37.3, SD = 16.3 years; control: M = 36.1, SD = 13.2 years) and years of education (TBI: M = 13.1, SD = 2.1; control: M = 13.7, SD = 2.2). The average interval between first assessment and follow-up was 11.8 (SD =1.9) months for the TBI group and 11.4 (SD

=1.8) months for the controls. This difference was not significant. Of those patients who returned for follow-up, none scored below cut-off on the Complex Ideational subtest of the Boston Diagnostic Aphasia Examination. The main interest at follow-up was to establish whether ToM performance of the TBI group had changed compared to the first assessment. We did expect performance in the control group to remain largely unchanged, except perhaps for improvements caused by retest-effects. Therefore, to demonstrate recovery in the TBI group, an improvement in performance in this group would have to exceed any improvement in the control group.

Neuropsychological tests. Mean initial assessment and follow-up scores on executive function tests and Digit Symbol task from those participants who were retested are displayed in Table 3. As our interest was in changes in performance, scores shortly after injury and at follow-up were compared between the TBI and control groups in separate repeated measures ANOVAs.

Digit Symbol scores were compared in a 2 (time of assessment: initial, follow-up) x 2 (group) ANOVA. This analysis revealed main effects of time of assessment, $F(1,57)= 55.84$, $p<.001$, $\eta_p^2=.49$, and group, $F(1,57)= 8.24$, $p<.01$ $\eta_p^2=.12$, but no interaction, $p=.80$, $\eta_p^2=.001$. Both groups had improved their performance at follow-up and the extent of the improvement was equivalent in the two groups. Similar results were found for the Alternating Fluency test which showed main effects of time of assessment, $F(1,57)= 30.58$, $p<.001$, $\eta_p^2=.35$, and group, $F(1, 57)= 18.67$, $p<.001$, $\eta_p^2=.24$, but no interaction, $p=.74$, $\eta_p^2=.002$. Comparison of the Brixton scores at first and second assessment revealed a main effect of group, $F(1,58)= 6.73$, $p<.015$, $\eta_p^2=.10$, but no group x time interaction, $p=.64$, $\eta_p^2=.004$, while the main effect of time of assessment just failed to reach significance, $p=.022$, $\eta_p^2=.09$, at the adjusted

alpha level (.05/3=.016). In the sample that was tested on both occasions on the Brixton test, the TBI group performed significantly poorer than the control group at follow-up, $t(58)=2.59$, $p<.015$, $\eta_p^2=.10$, but the group difference at initial assessment was marginally significant, $t(58)=1.99$, $p=.05$, $\eta_p^2=.06$. Across all three neuropsychological tests the pattern of results was similar in that performance in both groups improved to the same extent from initial assessment to follow-up.

[Table 3 about here please]

ToM tests. Faux Pas test. Faux Pas scores at initial and follow-up assessment (see Table 3) were compared between the two groups in separate repeated measures ANOVAs, while the alpha level was adjusted for multiple comparisons: .05/5=.01. Comparing the Faux Pas detection scores in a 2 (time of assessment: initial, follow-up) x 2 (group) ANOVA revealed a main effect of time of assessment, $F(1,59)= 11.54$, $p<.01$, $\eta_p^2=.16$, but no group effect and no interaction between time and group, $ps>.10$, $\eta_p^2<.04$. A similar comparison of the Faux Pas clarification scores showed main effects of time, $F(1,59)= 17.58$, $p<.001$, $\eta_p^2=.23$, and group, $F(1,59)= 8.42$, $p<.01$, $\eta_p^2=.12$, but no interaction, $p=.63$, $\eta_p^2=.004$. The TBI group performed poorer than the control group, although both groups had improved from initial assessment to follow-up. Rejection of non-Faux Pas showed an effect of group, $F(1,59)= 8.02$, $p<.01$, $\eta_p^2=.12$, but no main effect of time of assessment and no interaction effect, $ps>.08$, $\eta_p^2<.05$. Group differences on the Faux Pas control and non-Faux Pas control questions at follow-up were compared with one-sample tests because of ceiling effects in the control group. Comparison of the TBI groups' performance at follow-up on

these control questions against the score of the control group (10) revealed no group differences that were significant at the adjusted alpha-level.

Cartoon Test. Comparing initial and follow-up scores on the physical cartoons in a 2 x 2 ANOVA showed significant main effects of time, $F(1,58)= 15.32$, $p<.001$, $\eta_p^2=.21$, and group, $F(1,58)= 21.92$, $p<.001$, $\eta_p^2=.27$, but no interaction, $p=.11$, $\eta_p^2=.04$. A similar comparison of the initial and follow-up scores of the mental cartoons revealed main effects of time, $F(1, 59) = 26.86$, $p<.001$, $\eta_p^2=.31$, and group, $F(1,59) = 17.56$, $p<.001$, $\eta_p^2=.23$, as well as a group x time interaction that was just significant at the 5% level, $F(1, 59)= 4.09$, $p=.048$, $\eta_p^2=.06$; the improvement from initial assessment to follow-up was relatively larger in the TBI group than in the control group. The general pattern for the ToM measures was similar to that found for the other neuropsychological tests in that performance in both groups improved from first to second assessment and the extent of improvement was equivalent in the two groups. One exception was the mental cartoon score, for which the improvement was marginally stronger in the TBI than in the control group.

Of the associations between ToM tasks that had been identified at initial assessment within the TBI group, the correlation between Faux Pas clarification and mental cartoons remained significant at follow-up, Spearman's $r_s =.51$, $p<.01$ (see Table 4), but the correlation with physical cartoons failed to reach significance at the adjusted alpha level (.5/4=.0125). Within the control group, none of the correlations between Faux Pas and Cartoon task scores were significant at follow-up.

[Table 4 about here please]

Executive functioning and ToM performance. Associations between executive function and ToM performance were compared in the same way as at initial assessment (see Table 4). Within the TBI group, Alternating Fluency correlated with mental and physical cartoons, r_s >.49, *p*s<.01. Performance on the Brixton task correlated with Faux Pas clarification, r_s = -.84, *p*<.001, but not with the cartoon task. Within the control group, there were no significant correlations between Alternating Fluency or Brixton scores and any of the ToM measures.

Relationship between ToM performance and severity of head injury

Severity of TBI was not associated with severity of the ToM impairments. Spearman rank order correlations between the lowest GCS score and the impaired ToM measures (Faux Pas clarification, rejection of non-Faux Pas, mental cartoons and physical cartoons) at initial assessment revealed no significant associations at the adjusted alpha level of .0125, r_s <.38, *p*s>.03. Similar results were obtained with length of PTA as index of injury severity, r_s <-.38, *p*s>.03. At follow-up, Spearman rank order correlations again revealed no significant associations between severity of TBI, as estimated from GCS and PTA, and ToM performance, r_s <.-41, *p*s>.02.

Although TBI severity was not associated with ToM scores at initial assessment or at follow-up, it was possible that injury severity could predict the extent of improvement from first to second assessment. To examine this possibility we carried out hierarchical regression analyses with the TBI group's scores on a ToM measure at follow-up as the dependent variable. Performance on the same measure at first assessment was entered as the first predictor variable followed by GCS score, as an indicator of TBI severity, as the second predictor. Four separate regression

analyses showed that scores from the first assessment on Faux Pas clarification, rejection of non-Faux Pas, mental cartoon and physical cartoons all contributed towards predicting follow-up scores on these same measures, R^2>=.22, *p*s<=.01. However, GCS scores did not contribute to the prediction of follow-up scores over and above what was already predicted by first assessment scores; the change in R^2 from adding GCS in these analyses ranged between .004 to .033, *p*s>.19. Repeating these analyses with length of PTA instead of GCS as second predictor produced very similar results. The change in R^2 from adding PTA ranged between .009 and .022, *p*s>.30. Severity of TBI was not associated with the extent of change in ToM performance over the one-year interval.

Discussion

A consecutive series of patients with TBI showed impairments on verbal and non-verbal measures of ToM and on tests of executive functioning compared to an orthopaedic control group, shortly after sustaining their first TBI and one year later. Although performance of the TBI group on most measures improved from initial assessment to follow-up, performance of the control group improved to the same extent. Retest-effects were expected to affect performance in both groups, and to be considered indicative of recovery, improvement in test performance in the TBI group had to exceed improvement in the control group over the same time interval. Apart from a marginal effect on the mental cartoons, ToM performance in the TBI group showed no sign of recovery over a one-year interval as their improvement in test performance did not exceed what was expected from repeated testing. This finding is

in line with Bibby and McDonald's (2005) conclusion from their cross-sectional study that the time since TBI had little influence on ToM performance.

TBI severity, as indicated by lowest GCS score or length of PTA, did not predict impairments in ToM performance or the extent of change in ToM performance over a one-year interval. This result indicates that impairments in ToM ability were not restricted to patients with severe TBI. A limitation of the PTA measure was that PTA duration was not consistently assessed during the acute phase within the TBI sample. Despite the different methods used to estimate length of PTA, during acute phase and retrospectively, the results obtained for this indicator of TBI severity did not differ from those obtained for GCS. Overall, the severity of brain injury in the current consecutive sample of patients with TBI was less severe than in previous studies on ToM impairments following TBI, which selected only patients with severe TBI (Bibby & McDonald, 2005; Channon et al., 2005; McDonald & Flanagan, 2004; Milders et al., 2003). Our results, therefore, show that impairments on ToM tasks can also occur following less severe TBI.

Executive function performance, specifically cognitive selection and flexibility, was associated with ToM impairments in the TBI group both at initial assessment and at follow-up, which confirms earlier reports of associations between ToM and executive function impairments, including selection and flexibility, in adult patients (Channon & Crawford, 2000; Snowden, et al., 2003). These previous studies concluded that ToM represents one aspect of executive functioning. The results of the current study do not allow conclusions about the direction of the relationship between ToM and executive functioning, but the results are in line with suggestions that ToM and executive functioning involve common processes (Perner & Lang, 1999). However, there are also reports of dissociations between impairments in ToM

performance and executive functioning that suggest separate processes (Bach et al., 2000; Rowe et al., 2001). One explanation for functions that show dissociations as well as associations, is that the neural substrates of those functions are separate but in close spatial proximity. In line with this interpretation is the fact that Rowe et al. (2001) reported independent impairments in ToM and executive functioning in patients with highly localised surgical lesions. Reports of associations between impairments, on the other hand, come from group studies in patients with more diffuse or widespread damage, such as stroke, neurodegenerative disease or TBI (Channon & Crawford, 2000; Snowden, et al., 2003).

In normal development there is a link between development of language skills and ToM. Language impairments in children have been shown to affect their performance on ToM tasks (Miller , 2004), although other studies found no deficits in ToM performance in children with specific language impairment (Ziatas, Durkin, & Pratt, 1998). How likely is it that language impairments in the patients with TBI were responsible for their ToM impairments? Because of the possible link between language impairments and ToM, we screened all participants for gross language comprehension deficits. Since this screening test was probably insensitive to more subtle language impairments, we used a non-verbal as well as a verbal ToM task. Our results show that the TBI group performed at least as poorly on the non-verbal Cartoon test as on the verbal Faux Pas test. Furthermore, the TBI group was not significantly impaired on control questions of the Faux Pas test, which assess basic understanding of the stories. Therefore, it seems unlikely that impairments in language comprehension were the reason for poor ToM performance in the TBI group.

Although memory performance was not formally assessed, it does not seem plausible that memory impairments were an important factor in the ToM impairments. The procedures of both ToM tasks ensured that memory demands were minimal; the text of the Faux Pas stories and the cartoons remained available to the patient throughout each trial. Furthermore, Bibby and McDonald (2005) showed than ToM impairments in their TBI sample could not be explained by memory impairments. The patients with TBI did show impairments in processing speed, as revealed by their performance on the Digit Symbol test, but as neither ToM task was timed reduced speed of information processing probably had little effect on the patients' performance on these tasks. Other impairments in attention, in particular focussed or sustained attention, in the TBI group could have affected performance on any of the tasks, including the ToM tasks. During assessment participants were monitored for signs of loss of concentration and if necessary assessment was carried out over multiple sessions.

The impairments of the TBI group on the Faux Pas task were restricted to ToM related subscores, Faux Pas clarification and rejection of non-Faux Pas. Poor clarification scores suggest difficulties in understanding or explaining the intentions and feelings of the characters in the Faux Pas stories. The patients with TBI were also poorer than controls at correctly rejecting non-Faux Pas stories as containing a faux pas. This may reflect uncertainty with identifying a faux pas, which made the patients with TBI more inclined than controls to incorrectly report the presence of a faux pas. Such a bias among the patients with TBI to respond that a faux pas had occurred could also account for their high detection scores on those items that did contain a faux pas.

On the Cartoon Test, the impairments were not restricted to ToM related items as the TBI group was equally impaired on mental items and physical items, even though only the former would require understanding of beliefs and intentions. Bibby and McDonald (2005) also reported impairments on both ToM and non-ToM cartoons in their sample of patients with TBI and similar results were described by Snowden et al. (2003) in patients with Huntington's disease or fronto-temporal dementia. In contrast, Happé et al. (1999) reported more severe impairments on mental than on physical cartoons in stroke patients with localised frontal lesions. The fact that the patients with TBI were impaired on both mental and physical cartoons may reflect an impairment that is not specific to understanding beliefs and intentions in others. One possibility is loss of humour appreciation. Indications for such impairments in patients with TBI have been reported by Braun, Lussier, Baribeau and Ethier (1989) and Docking, Murdoch and Jordan (2000). An impairment in humour appreciation could interfere with the ability to explain why the cartoons were funny, regardless of whether the jokes were based on false beliefs or on physical anomalies. An impairment in drawing inferences beyond the literal meaning of the information provided could also affect the interpretation of both mental and physical cartoons. There are several indications that patients with TBI have difficulties understanding deception or the non-literal meaning of speech, as in sarcasm, (Channon et al., 2005; Dennis, Barnes, Wilkinson, & Humphreys, 1998; Martin & McDonald, 2003; McDonald, 1999) or in reasoning and problem-solving (Lezak, 1995). Such difficulties could have affected performance on both categories of items of the Cartoon test.

A control group of orthopaedic patients was used to control for the potential influence of the stress and anxiety caused by trauma and hospitalisation. Although the

orthopaedic patients had not sustained brain injuries, we cannot exclude the possibility that they performed below the level expected from healthy controls. Performance below the normal healthy level in the orthopaedic control group would have implications for the conclusion that their improvement in test performance reflected retest-effects only, as this assumed unimpaired performance at initial assessment. However, comparisons with published results on the same tasks show that the control group's performance was comparable to that of healthy controls. On the Faux Pas test the orthopaedic controls obtained 89% of the maximum possible score at the first assessment, while the healthy control group in our earlier study (Milders et al., 2003) obtained 90% of the maximum score. On the Cartoon test, the control group obtained 88% and 84% of the maximum score on mental and physical items, respectively, at first assessment. The healthy controls reported in Happé et al. (1999; 2001) obtained 85% on mental cartoon and 71% on the physical cartoons, and the healthy controls in Snowden et al.'s (2003) study obtained around 70% of the maximum score on both mental and physical items. This slight advantage of the orthopaedic controls over these healthy controls may reflect age differences, since most healthy controls in Happé et al. (1999, 2001) and Snowden et al. (2003) were older than the orthopaedic controls in the current study. Although informal, these comparisons with previous studies give no reason to suspect impairments in ToM ability in the orthopaedic control group. Therefore, it seems unlikely that comparison with a healthy control group would have led the different conclusions regarding the ToM impairments in the TBI group.

Our results showed impairments in ToM measures within two months following TBI, while previous studies into acquired ToM impairments tested patients many months or even years following the onset of brain injury. Over a one-year

interval, ToM performance, as well as performance on other cognitive tests, had improved but not recovered in the TBI group. ToM impairments in the TBI group were fairly stable over time and showed no signs of further deterioration. This pattern of impaired performance shortly after injury without deterioration over time suggests that the ToM impairments were a direct result of the brain damage (Prigatano, 1992) and that the early ToM impairments were not further affected by any changes in the patients' social environment during the one-year interval. It is worth pointing out that the ToM tasks used in the current study may underestimate the extent of ToM impairments occurring in day-to-day social functioning. That is because the current ToM tasks had unlimited presentation times and required no speeded responses, whereas daily life often demands quick decisions and responses which could be particularly problematic for patients with impairments in processing speed. To investigate the impact of processing speed on ToM impairments, future studies may include speeded ToM tasks.

With ToM impairments arising early after TBI and probably being a direct consequence of the brain injury, it is possible that ToM impairments can play a role in causing changes in social behaviour following TBI, which are often characterised by insensitivity for other people's feelings and intentions (Kendall & Terry, 1996). In line with this possibility, we found that poorer performance on the Faux Pas task was associated with more behavioural problems in another sample of patients with TBI (Milders et al., 2003). However, Turkstra, Dixon, & Baker (2004) found no impairments in social knowledge and beliefs in adolescents with TBI despite deficits in ToM. Clearly more work is required to clarify the relation between acquired ToM impairment and behavioural changes following TBI and follow-up over longer intervals may be needed to confirm the absence of recovery or deterioration with

chronicity. If it is confirmed that ToM impairments following brain injury show little spontaneous recovery, programs aimed at training ToM ability, such as those developed for people with schizophrenia (Sarfati, Passerieux, & Hardy-Baylé, 2000) or autism (Ozonoff & Miller, 1995), may also be useful for adult patients with acquired brain injuries

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Table 1.

Mean test scores of TBI and control patients at the initial assessment.

	TBI	Controls			
	M (SD)	*M* (SD)	*t*	*p*	η_p^2
Digit Symbol	56.06 (17.95)	68.58 (16.39)	2.91	.005*	.12
Alternating Fluency (total)	28.81 (11.04)	38.88 (7.64)	4.26	<.001*	.23
Brixton (errors)	17.36 (5.94)	14.79 (6.22)	1.73	.09	.04
Faux Pas test					
Detection	17.18 (3.49)	18.12 (2.54)	1.25	.22	.02
Clarification	20.00 (5.65)	23.12 (3.48)	2.71	.009*	.10
Control Faux Pas	9.67 (0.65)	9.97 (0.17)	2.62	.013	.10
Rejection non-Faux Pas	9.27 (1.05)	9.82 (0.52)	2.67	.010*	.10
Control non-Faux Pas	9.82 (0.39)	9.85 (0.36)	0.38	.71	.02
Cartoon test					
Mental items	12.39 (3.93)	15.85 (1.76)	4.63	<.001*	.25
Physical items	11.41 (3.85)	15.18 (2.08)	4.90	<.001*	.28

*significant at adjusted alpha level.

Table 2.

Spearman rank order correlations between impaired ToM test scores and Alternating Fluency within TBI group (A) and control group (B) at initial assessment.

A. TBI	Faux Pas Clarification	Rejection non-FP	Mental cartoons	Physical cartoons
Rejection non-FP	.019			
Mental cartoons	.66**	-.04		
Physical cartoons	.63**	-.007	.82**	
Alt. Fluency	.54**	-.11	.71**	.77**

B. Controls	Faux Pas Clarification	Rejection non-FP	Mental cartoons	Physical cartoons
Rejection non-FP	.26			
Mental cartoons	.62**	.45*		
Physical cartoons	.44*	-.05	.29	
Alt. Fluency	.22	.17	.26	.23

* $p<.0125$, ** $p<.005$

Table 3.

Mean test scores of TBI and control patients who were tested on both assessments: shortly after injury and at one-year follow-up.

	Initial		Follow-up	
	TBI	Controls	TBI	Controls
	M (SD)	*M* (SD)	*M* (SD)	*M* (SD)
Digit Symbol	56.48 (18.40)	68.90 (16.11)	65.48 (16.97)	77.30 (15.68)
Alternating Fluency	29.45 (11.13)	39.03 (7.47)	34.48 (10.46)	44.70 (8.79)
Brixton (no. errors)	17.83 (5.69)	14.68 (6.50)	16.45 (6.89)	12.61 (4.36)
Faux Pas test				
Detection	17.17 (3.66)	18.00 (2.63)	18.37 (2.29)	19.26 (1.41)
Clarification	19.90 (5.81)	23.32 (3.52)	22.70 (6.16)	25.55 (3.14)
Control Faux Pas	9.63 (0.67)	9.97 (0.18)	9.60 (1.00)	10 (0)
Rejection non-Faux Pas	9.23 (1.10)	9.81 (0.54)	9.53 (0.94)	9.90 (0.30)
Control non-Faux Pas	9.83 (0.38)	9.84 (0.37)	9.70 (0.70)	10 (0)
Cartoon test				
Mental items	12.50 (4.12)	15.94 (1.81)	14.63 (3.18)	16.87 (1.84)
Physical items	11.62 (3.80)	15.16 (2.16)	13.24 (2.92)	15.84 (1.93)

Table 4.

Spearman rank order correlations between impaired ToM test scores, Alternating Fluency and Brixton task within TBI group (A) and control group (B) at follow-up.

A. TBI	Faux Pas Clarif.	Rejection non-FP	Mental cartoons	Physical cartoons	Alt. Fluency
Rejection non-FP	.13				
Mental cartoons	.51**	.24			
Physical cartoons	.39	.35	.60**		
Alt. Fluency	.34	.12	.50*	.61**	
Brixton	-.84**	-.10	-.35	-.26	-.33

B. Controls	Faux Pas Clarif.	Rejection non-FP	Mental cartoons	Physical cartoons	Alt. Fluency
Rejection non-FP	-.18				
Mental cartoons	.22	-.12			
Physical cartoons	.03	-.38	.33		
Alt. Fluency	.24	-.40	.31	-.13	
Brixton	-.13	.11	-.26	-.005	-.10

* $p<.0125$, ** $p<.005$