ELSEVIER

Neuropsychologia xxx (2007) xxx–xxx

NEUROPSYCHOLOGIA

www.elsevier.com/locate/neuropsychologia

Longitudinal aspects of emotion recognition in patients with traumatic brain injury

Magdalena Ietswaart [a,*], Maarten Milders [b], John R. Crawford [b], David Currie [c], Clare L. Scott [b]

[a] *School of Psychology and Sport Sciences, University of Northumbria, Northumberland Building, Newcastle-upon-Tyne NE1 8ST, UK*
[b] *School of Psychology, University of Aberdeen, UK*
[c] *Department of Neurosurgery, Grampian University Hospital Trust, Aberdeen, UK*

Received 30 August 2006; received in revised form 25 June 2007; accepted 4 August 2007

Abstract

Changes in emotional and social behaviour are relatively common following traumatic brain injury (TBI). Impairments in recognising the emotional state of others may underlie some of the problems in social relationships that these patients experience. The few previous studies examining emotion recognition in TBI typically assessed patients once, long after the onset of brain injury, making it difficult to distinguish the direct effect of brain injury from the effects of environmental changes. This study examined 30 patients with TBI shortly after brain injury and 32 orthopaedic control patients on their recognition of emotions expressed in the face and the voice using discrimination and labelling tasks. These patients were followed up 1 year later to examine the longitudinal development of emotion recognition deficits. TBI patients were found to be impaired on emotion recognition compared to the control patients both early after injury and 1 year later. The fact that impairments in emotion recognition were evident early after TBI and no evidence of recovery over time was found, suggests a direct effect of brain injury.

Keywords: Brain damage; Affect; Facial expression; Vocal prosody; Recovery

1. Introduction

There has been a recent increase in the number of studies examining emotion recognition in different patients groups, however emotion recognition in patients with traumatic brain injury (TBI) is of particular interest because of the possible link with changes in emotional and social behaviour. Changes in emotional and social behaviour are relatively common following TBI (Kendall & Terry, 1996; Prigatano, 1992). Impairment in recognising the emotional state of others may underlie some of the problems in social relationships that these patients experience. Below, the evidence from the relatively few studies examining emotion recognition in TBI is summarised, followed by an outline of some of the pending issues that are of interest in relation to the question whether emotion recognition deficits may underlie some behavioural changes following TBI.

Evidence that changes in emotional and social behaviour may be associated with impairments in recognising emotions comes from work in patients with behavioural changes following focal frontal lesions. Hornak, Rolls, and Wade (1996) demonstrated that impaired recognition of expressions was associated with subjective reports of emotional change in patients with damage to the ventral frontal lobes. Case studies of patients with behavioural disturbances following damage to the orbitofrontal cortex have shown impaired recognition of facial expressions (Blair & Cipolotti, 2000). In patients with schizophrenia Hooker and Park (2002) found a significant correlation between emotion recognition and social functioning. With regards to TBI, Pettersen (1991) noted that head injured children and adolescents who were impaired at recognising facial expressions were also rated by their parents as showing less socially appropriate behaviour.

* Corresponding author.
E-mail address: magdalena.ietswaart@unn.ac.uk (M. Ietswaart).

0028-3932/$ – see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.neuropsychologia.2007.08.002

Studies of neurological patients and neuroimaging studies have indicated a distributed network associated with emotion recognition, involving the frontal cortex and regions within the temporal lobes (Adolphs, 2002; Sprengelmeyer, Rausch, Eysel, & Przuntek, 1998), and a role for white matter tracts (Adolphs, Damasio, Tranel, & Damasio, 1996). The brain regions most vulnerable to TBI typically include the frontal and temporal lobe (e.g. Levin, Williams, Eisenberg, High, & Guinto, 1992) with associated diffuse axonal damage (e.g. Adams et al., 1989).

There is indeed a steadily emerging record documenting TBI patients' inability to recognise emotions in others (Braun, Lussier, Baribeau, & Ethier, 1989; Croker & McDonald, 2005; Green, Turner, & Thompson, 2004; Hopkins, Dywan, & Segalowitz, 2002; Jackson & Moffat, 1987; McDonald & Saunders, 2005; Milders, Fuchs, & Crawford, 2003; Pettersen, 1991; Spell & Frank, 2000). The majority of these studies made use of photographs of facial expression and generally showed that chronic TBI patients were poorer at recognising facial expressions than healthy controls. Some of these studies reported reduced ability to recognise negative emotions (Hopkins et al., 2002; Jackson & Moffat, 1987) or facial expressions of fear in particular (Braun et al., 1989). However such findings may reflect the general pattern of task difficulty as facial expression of fear are also recognised most poorly by healthy participants (Biehl et al., 1997; Ekman & Friesen, 1976). Hopkins et al. (2002) complemented their findings with evidence of reduced electrodermal responses to negative emotions in patients with TBI.

Several studies examined recognition of emotions expressed in channels other than facial expressions in patients with TBI. Jackson and Moffat (1987) found impairments in TBI patients in the recognition of body postures related to social behaviour, such as "welcoming" or "indifferent" using displays of stick figures. Braun et al. (1989) also used descriptions of emotional scenes, while Pettersen (1991) used line drawings of emotional scenes and emotional vignettes, all showing impaired emotion recognition in TBI patients.

Three studies examined emotion recognition through both visual and auditory channels in TBI patients but the results were ambiguous. Milders et al. (2003) examined patients with severe TBI on emotion recognition both in voices and faces and found impairments on both tasks. No comparison between performances on the two modalities was made. Spell and Frank (2000) found a mixed relationship between recognising emotions in facial or vocal expressions, depending on whether the stimuli were expressed by a child, an adolescent or an older person. TBI patients were more impaired at recognising emotional expressions in the voice than the face when presented with child and young adult stimuli, but the reverse pattern was shown when presented with stimuli of older adults (Spell & Frank, 2000). McDonald and Saunders (2005) presented information through the separate visual and auditory channels as well as through integrated audiovisual displays and found that their sample of TBI patients was unimpaired on recognising emotions through the visual route, i.e. faces. However, the TBI patients were impaired on recognising emotions on the basis of auditory information alone or audiovisual displays. Therefore, it is so far unclear whether there is a relationship between impairments in recognising emotion in the voice or the face in patients with TBI. Association between impairment in both modalities would be of interest as this would indicate a generic emotion recognition deficit.

A limitation of previous studies examining emotion recognition in TBI patients – and in fact of many studies of acquired emotion recognition deficits – was that emotion recognition was assessed only once. The above studies examined chronic brain injury patients, which for most patients was several years following injury, with the exception of Green et al. (2004) who studied severe TBI patients shortly after injury. As a result, little is know about the time course of emotion recognition abilities following TBI, and one consequence of this is that it is more difficult to attribute emotion recognition deficits directly to the effect of brain damage. If impairments in emotion recognition are a direct result of the brain damage, impairments should be found early after injury and remain fairly stable over time or perhaps show signs of recovery, in step with recovery in other cognitive functions. However, it is also conceivable that emotion recognition deteriorates over time. Emotion recognition impairments may partly be an indirect consequence of TBI. For example, the anxiety and depression experienced by many chronic TBI patients could affect emotion recognition. Changes in patients' social environment following injury that result in fewer social interactions might also affect the ability to recognise expressions. Consequently, emotion recognition deficits occurring shortly after injury might deteriorate further over time. At present the possibility that impairments in expression recognition increase over time in patients with TBI cannot be ruled out due to the lack of longitudinal data. In other patients groups, such as in schizophrenia, there are reports of deterioration in recognition of emotional expressions with chronicity (Kington, Jones, Watt, Hopkin, & Williams, 2000; Mueser et al., 1996). Assessment of emotion recognition shortly after TBI *and* during the chronic phase would clarify whether the deficit is a primary or secondary consequence of brain damage.

In summary, for emotion recognition to be a possible candidate deficit underlying social and behavioural change one would expect that: (1) emotion recognition deficits are a direct effect of the injury, rather that an indirect effect of patients' changes in social environment or their emotional reactions to the consequence of the injury. Direct effect can be suspected if deficits are present early after injury and remain fairly stable over time. (2) Emotion recognition deficits should not be explained by general perceptual deficits, but be related to the emotional content. (3) Emotion recognition deficits should be associated with injury severity, because injury severity is one of best predictors of social outcome (Tate & Broe, 1999). Most studies so far included only patients with severe TBI, therefore, it is difficult to examine the relation between severity and emotion recognition deficits.

The current study focussed on the relation between emotion recognition and chronicity in TBI. Emotion recognition was assessed in TBI patients shortly after they had sustained their first TBI and 1 year later, examining whether emotion recognition deficits in TBI are present early after injury and remain fairly stable over time. Emotion recognition of both facial and

Please cite this article in press as: Ietswaart, M., et al., Longitudinal aspects of emotion recognition in patients with traumatic brain injury, Neuropsychologia (2007), doi:10.1016/j.neuropsychologia.2007.08.002

vocal expressions was explored to examine the relation between impaired performance and emotional content. Impaired emotion recognition in both face and voice would indicate a generic emotion recognition deficit. Emotion recognition in both modalities was assessed at different task levels. At a basic non-verbal level patients were asked to match expressions of the same emotional content. Furthermore, the ability to name the emotional expression in face or voice was examined in labelling tasks. Impairments in both matching and naming would indicate general perceptual emotion recognition deficit rather that difficulty putting a label to the emotion. A further more sensitive task was included labelling subtle facial expressions presented in images achieved by computer assisted morphing of different expressions. This task would detect more subtle recognition impairments that may not be evident when labelling prototypical facial expressions. No equivalent morphed task was available for expressions in the voice. Control tasks with non-emotional content were assessed in both modalities to ascertain that emotion recognition deficits were not resulting from general perceptual deficits. Through consecutive recruitment it was aimed to include a representative sample of TBI patients with injuries ranging from mild to severe. Performance of the TBI group was compared with that of orthopaedic patients, who had sustained traumatic orthopaedic injuries, and who were tested at the same time intervals as the TBI patients. Orthopaedic controls were chosen in order to control for the potential impact of trauma and hospitalisation on test performance. The main questions of this study were: (1) whether emotion recognition impairments can already be identified early after TBI; (2) whether changes in emotion recognition performance over a 1-year interval, if present, are suggestive of recovery or deterioration.

2. Method

2.1. Participants

In total 71 patients, 37 with TBI and 34 with orthopaedic injuries were recruited from the Departments of Neurosurgery and Orthopaedic Surgery at Aberdeen Royal Infirmary. The patients with TBI were recruited consecutively while orthopaedic patients were recruited to match the TBI patients for gender, age and years of education. Through consecutive recruitment this study aimed to include a representative sample of patients with TBI. Patients in the TBI group were included in the study on the basis of the following inclusion criteria: (1) a clinical diagnosis of TBI during hospitalisation; (2) acute traumatic brain damage evident on the patient's CT scan; or (3) evidence of post-traumatic amnesia (PTA). Exclusion criteria were (a) a neurological or psychiatric history; (b) a history of alcohol or drug dependency; (c) dementia or learning difficulties; (d) persistent post-injury language deficits; (e) years of age younger than 16 or older than 70. An extra exclusion criterion for the orthopaedic patients was brain injury or post-traumatic amnesia.

Two TBI patients were excluded because they had suffered previous brain injuries. A further five TBI patients and two orthopaedic controls were excluded because they did not return for the 1-year follow-up assessment. Therefore, the analysis of this study involved a sample of 30 TBI patients (25 males and 5 females) and 32 orthopaedic controls (28 males and 4 females). The two groups were matched for age (average age of TBI patients 37.5 [S.D. 16.3] and of orthopaedic controls 35.6 [S.D. 13.3]), for years of education (average years of education of TBI patients 13.2 [S.D. 2.0] and of orthopaedic controls 13.6 [S.D. 2.2]), and matched for socio-economic status (SES, average SES score of TBI patients 4.5 [S.D. 1.95] and of orthopaedic controls 3.7 [S.D. 2.05] according to the UK's National Statistics Socio-Economic Classification (NS-SEC 2005, Office for National Statistics, UK), a lower score indicating a higher SES). The TBI and orthopaedic patient groups were further comparable in that all patients had sustained traumatic injuries, which either included head injuries or were restricted to orthopaedic injuries: 13 TBI patients and 15 orthopaedic controls had road traffic accidents, 5 TBI patients and 8 controls fell from a height, 6 TBI patients and 5 controls had other falls, 5 TBI patients and none of the controls were assaulted, and finally 3 TBI patients and 4 orthopaedic controls suffered injuries from other causes.

Mean duration of PTA in the TBI group, assessed either during the acute phase or retrospectively, was 12.6 days (range 1–90 days) and the mean lowest Glasgow Coma Scale (GCS) score, assessed during the acute phase, was 10 (range 4–15) in this group, but injury severity varied markedly among TBI patients. Following the conventional classification (Teasdale & Jennett, 1974) of mild injury (GCS 13–15 or PTA < 24 h), moderate injury (GCS 9–12 or PTA 1–7 days) and severe injury (GCS < 9 or PTA > 7 days), 10 patients were classed as mild, 9 as moderate and 11 as severe TBI. CT scans or surgical notes indicated that 12 of the TBI patients had damage predominantly in the frontal lobes, 6 patients had lesions predominantly in temporal or parietal areas and 6 had diffuse lesions. No lesion information was available for six patients.

Patients were examined as soon as possible after their injury, typically just before or after the date of discharge from hospital. The average interval between injury and first assessment was 2.1 (S.D. 1.8) months in the TBI group and 1.2 (S.D. 1.0) months in the orthopaedic group; this difference was significant ($p < .05$). Patients were subsequently followed up around 1 year after the initial testing date to document their recovery. The average interval between first assessment and follow-up was 11.8 (S.D. 1.9) months for the TBI group and 11.4 (S.D. 1.8) months for the controls. This difference was not significant. All participants gave informed consent to participate in the study, which had been approved by the Grampian Research Ethics Committee.

2.2. Material

2.2.1. Recognising facial expressions

Three different tests assessed the recognition of facial expressions in TBI patients and controls.

2.2.1.1. Labelling facial expressions. This test consists of 60 photographs from a standard set of facial expressions (Ekman & Friesen, 1976). The expressions depicted were fear, disgust, anger, happiness, sadness or surprise, which were displayed by 10 different individuals. The photographs were presented one by one on a computer screen accompanied by six labels naming the six different emotions. The task was to select the label that best described the facial expression shown. Photographs were presented in random order and the position of the different response labels varied from trial to trial to avoid response bias based on the location of the label. The participants were asked to respond as soon as they made a decision and response times were recorded.

2.2.1.2. Labelling morphed facial expressions, the emotion hexagon. A more sensitive version of Ekman and Friesen's task was developed by Calder et al. (1996). This task used computer-interpolated ('morphed') images that were created on the basis of the expressions of one of the faces in the Ekman and Friesen set. To create these morphed images facial expressions had been ordered by placing each expression adjacent to the one it was most likely to be confused with in Ekman and Friesen's (1976) norms; this gave the sequence happiness-surprise-fear-sadness-disgust-anger. Each expression was blended with the other emotional expression according to the following mixes 90/10%, 70/30%, 50/50%, 30/70%, or 10/90% to form a morphed facial expression. Healthy subjects were able to attribute these 'blended' expressions as belonging to the nearest distinct emotion (Calder et al., 1996). The number of items in this task also permitted identification of impairment of recognition of specific emotions. The photographs were presented one by one on a computer screen accompanied by six labels naming the six different emotions. After 2 s the presentation reverted to an image of the same face with a neutral expression. A response could be made before or after the 2-s presentation. The task was to select the label that best describes the emotional expression shown. Each image was presented twice resulting in 60 trials presented in random order and the position of the different response labels was varied from trial to trial. The par-

Please cite this article in press as: Ietswaart, M., et al., Longitudinal aspects of emotion recognition in patients with traumatic brain injury, Neuropsychologia (2007), doi:10.1016/j.neuropsychologia.2007.08.002

ticipants were asked to respond as soon as they made a decision and response times were recorded.

2.2.1.3. Matching facial expression across identity. In this test five photographs of facial expressions displayed by different individuals presented in a vertical line centrally on a computer screen. The faces came from the standard set of facial expressions (Ekman & Friesen, 1976) as discussed above. The task is to select one of the four faces that matches the facial expression of the face at the top of the screen. Sets were presented in random order and response times were recorded. There were 18 trials, three for each of the 6 expressions: fear, disgust, anger, happiness, sadness and surprise presented in random order.

2.2.2. Recognising emotions in the voice

Recognition of emotional prosody was tested with two subtests from the Florida affect battery (FAB: Bowers, Blonder, & Heilman, 1991).

2.2.2.1. Emotional prosody discrimination. In this test 20 pairs of emotionally neutral sentences (e.g. "The lamp is on the table") were spoken in the same or a different emotional tone of voice. Participants were required to indicate whether the affective prosody of each sentence pair was the same or different. The labels (same, different) were presented on a computer screen, and the participant could select one of the labels at any time after the two sentences were completed, and participants were asked to make a selection as soon as they made a decision. There were 10 correct 'same' and 10 correct 'different' answers. Trials were presented in random order and response times were recorded.

2.2.2.2. Labelling emotional prosody. Twenty emotionally neutral sentences were spoken in one of five possible tones of voice: happy, sad, angry, fearful, neutral. The five possible emotion labels were presented on a computer screen. Participants were required to select the emotion label which best described the affective prosody for each sentence. Sentences were presented in random order and the position of the different response labels was varied from trial to trial. The participants were asked to respond as soon as they made a decision and response times were recorded. There was no second voice labelling task as there is no equivalent of the morphed facial expression task available for expressions in the voice.

2.2.3. Control tasks and tasks of cognitive ability

2.2.3.1. Boston diagnostic aphasia examination. All participants were screened for language comprehension deficits using the complex ideation subtest of the Boston diagnostic aphasia examination (Goodglass & Kaplan, 1983).

2.2.3.2. Digit symbol. The digit symbol test is a subtest of the Wechsler adult intelligence scale (WAIS-III; Wechsler, Wycherley, Benjamin, Crawford, & Mockler, 1998), and is a measure of mental speed. The task consists of a sample line of digits numbered 1–9 and printed below each digit is a simple nonsense symbol. Patients were presented with a sheet containing the digits 1–9 in random order and the task was to write the associated symbol next to the correct digit. The digit symbol score was the number of correct symbols produced within 90 s. The digit symbol test is known to be very sensitive to the effects of brain injury and was included as an indicator of general cognitive processing speed.

2.2.3.3. Brixton spatial anticipation test and alternating fluency test. Executive function was assessed using two standard neuropsychological tests, a non-verbal test, the Brixton spatial anticipation test (Burgess & Shallice, 1997), and a verbal test, the alternating fluency test (Downes, Sharp, Costall, Sagar, & Howe, 1993). The Brixton spatial anticipation task consists of a series of pages showing 10 circle outlines, one of which is filled. The position of this filled circle changes from one page to the next following specific rules. The participants' task is to detect these rules and use these to predict the position of the filled circle on the next page. The Brixton test requires 54 responses and the number of correct responses was recorded.

The verbal alternating fluency test requires continual switching between two semantic 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. The total alternating fluency score was the sum of the correct responses for the three subtasks.

2.2.3.4. National adult reading test (NART: Nelson & Willison, 1991). This test was included as a potential measure of pre-morbid intelligence. The task involves the pronunciation of irregular words, and the rational behind the task is that the ability to read the words correctly is not affected by mental deterioration in dementia. It therefore provides a way to estimate pre-morbid IQ in dementia and possibly other brain damaged populations. The validity of the NART in TBI, however, is somewhat unclear as it has been found that in a large proportion of the TBI patients NART performance was impaired relative to the expected performance based on the patients' education, socio-economic status, age and gender (Freeman, Godfrey, Harris, & Partridge, 2001), and an association was found between NART performance and injury severity in TBI (Morris, Wilson, Dunn, & Teasdale, 2005), thus underestimating pre-morbid intellectual ability. The NART was assessed in the current study for the purpose of documentation; however, the principle method to control for differences in pre-morbid intellectual ability was achieved by matching the TBI and control group for years of education and socio-economic status.

2.2.3.5. Benton facial recognition test (Benton et al., 1983). This test was used to control for possible impairments in face perception which could interfere with expression recognition. In this test, participants were required to identify out of six photographs of unfamiliar faces the picture of the same person as the simultaneously presented target face photograph. The set contained an identical front-view photograph in early trials, but in subsequent trials gradually more challenging matches with different three-quarter views or under different lighting conditions. The short version of the test was used (13 trials), unless the patient made 7 or more errors (indicating a borderline score or less), in which case the full version was used (22 trials). The same accuracy score was obtained for both versions using standard conversion tables for this test.

2.2.3.6. Non-emotional prosody discrimination. This is a control subtest from the Florida affect battery that we used as a control task for possible perceptual deficits which could affect performance on the affective prosody tests. The test consists of 16 pairs of sentences spoken either in an interrogative or a declarative tone of voice. For half the sentence pairs the tone of voice is the same, for half it is different, and participants indicated whether the non-emotional prosody in the two sentences was the same or different.

2.2.3.7. Depression and anxiety. The factor of depression and anxiety in relation to emotion recognition was assessed with the hospital anxiety and depression scale (HADS) (Zigmund & Snaith, 1983). This measure was designed for patients with a physical illness and has been widely used to assess mood amongst patients, without a psychiatric co-morbidity, in general hospitals.

2.3. Procedure

All participants were tested individually either at their home, the School of Psychology or on the hospital ward. Patients were tested twice on all neuropsychological and emotion recognition tasks mentioned above, first shortly after they had sustained their injury (TBI or orthopaedic injury) and again about 1 year after this first assessment.

3. Results

3.1. Control tasks and cognitive ability

Mean scores of the TBI and control groups at first and second assessment on each of the control tasks are shown in Table 1. Scores on these tasks shortly after injury and at follow-up were compared between the TBI and control groups in separate 2 (group) by 2 (time of assessment) repeated measures ANOVAs. Bonferroni corrections were applied to control for the effect

Please cite this article in press as: Ietswaart, M., et al., Longitudinal aspects of emotion recognition in patients with traumatic brain injury, Neuropsychologia (2007), doi:10.1016/j.neuropsychologia.2007.08.002

Table 1
Mean performance on each of the standardised neuropsychological tests for the TBI patient group and the orthopaedic control group, shortly after injury and at 1-year follow-up

Control tasks	Shortly after injury		One year follow-up	
	TBI, *M* (S.D.)	Controls, *M* (S.D.)	TBI, *M* (S.D.)	Controls, *M* (S.D.)
Benton task (% correct)	79 (14.2)	88 (8.2)	85 (8.9)	89 (7.6)
Prosody control task (% correct)	90 (10.5)	93 (9.7)	92 (10.8)	91 (11.5)
Digit symbol test (total score)	56 (18.4)	68 (16.4)	64 (18.0)	77 (15.7)
Brixton (total correct)	37 (5.9)	39 (6.4)	37 (6.9)	41 (4.4)
Fluency (total score)	29 (11.1)	39 (7.5)	34 (10.4)	44 (9.2)
NART (total correct)	22 (9.7)	29 (8.5)	22 (10.6)	30 (8.3)
HADS (total score)	10 (8.0)	9 (5.9)	10 (8.0)	7 (5.5)
Boston language test (total score)	11 (1.3)	11 (1.2)	12 (.7)	12 (.7)

of multiple comparisons, adjusting alpha levels to .05/5 = .01. These analyses showed no significant group differences on the hospital anxiety and depression scale (HADS), the non-emotional prosody discrimination (control) task, or the Brixton spatial anticipation test ($p > .02$), but significantly lower scores in the TBI group than the control group on the digit symbol test ($F(1, 60) = 8.24$, $p < .01$, $\eta_p^2 = .12$), the alternating fluency test ($F(1, 60) = 18.71$, $p < .001$, $\eta_p^2 = .25$), the NART ($F(1, 60) = 10.57$, $p < .01$, $\eta_p^2 = .15$), and the Benton facial recognition task ($F(1, 60) = 8.58$, $p < .01$, $\eta_p^2 = .13$). Although the mean Benton score of the TBI group was below that of the controls, 24 out of 30 TBI patients and 31 out of 32 orthopaedic patients performed within the normal range at initial assessment, and at 1-year follow-up all but one TBI patient and one orthopaedic control performed within the normal range (Benton, Hamsher, Varney, & Spreen, 1983). Significant main effects of time of assessment were found for the Digit Symbol test ($F(1, 60) = 55.84$, $p < .001$, $\eta_p^2 = .50$), and the Alternating Fluency test ($F(1, 60) = 30.55$, $p < .001$, $\eta_p^2 = .36$): performance was better at follow-up than shortly after injury. A trend for an interaction between group and time of assessment was evident on the Benton test ($F(1, 60) = 4.30$, $p < .05$, $\eta_p^2 = .07$), reflecting a relatively stronger improvement over time in the TBI group than in the controls. In fact, at follow-up Benton test scores did no longer differ between the two groups ($p > .10$). None of the patients scored below cut-off on the complex ideational subtest of the Boston diagnostic aphasia examination, which would have indicated language comprehension deficits.

3.2. Emotion recognition tasks

3.2.1. Group differences on global scores for emotion recognition tasks

The global scores (i.e. collapsed across the different emotions) of the TBI and control groups at first and second assessment on emotion recognition tasks are shown in Table 2. The mean number of correct responses and reaction times (based on individuals' median reaction time of correct responses only) shortly after injury and at follow-up were compared between the TBI and control groups in separate 2 (group) by 2 (time of assessment) repeated measures ANOVAs for each of the five emotion recognition tasks. The alpha level was adjusted for the number of comparisons for each measure (accuracy or reaction times): .05/5 = .01. Recognition accuracy in TBI patients was found to be impaired on all expression recognition tasks: matching facial expressions ($F(1, 60) = 7.40$, $p < .01$, $\eta_p^2 = .11$), labelling facial expressions ($F(1, 60) = 9.85$, $p < .01$, $\eta_p^2 = .14$), morphed facial expressions ($F(1, 60) = 13.69$, $p < .001$, $\eta_p^2 = .19$), and

Table 2
Mean performance on each of the emotion recognition tasks

	Shortly after injury				One year follow-up			
	TBI patients		Orthopaedic controls		TBI patients		Orthopaedic controls	
	% correct, *M* (S.D.)	RT (s), *M* (S.D.)	% correct, *M* (S.D.)	RT (s), *M* (S.D.)	% correct, *M* (S.D.)	RT (s), *M* (S.D.)	% correct, *M* (S.D.)	RT (s), *M* (S.D.)
Facial expressions								
Matching expressions	83.2 (13.7)	10.4 (5.59)	91.3 (9.1)	6.5 (2.78)	88.2 (13.03)	7.6 (3.12)	93.9 (8.97)	5.2 (1.31)
Labelling expressions	73.0 (16.43)	6.7 (4.31)	83.3 (7.57)	4.3 (1.22)	79.8 (11.55)	5.4 (1.94)	85.8 (7.06)	3.6 (.61)
Labelling morphed expressions	73.2 (19.43)	4.1 (1.40)	87.6 (9.13)	3.4 (.91)	79.7 (13.91)	4.0 (1.32)	88.6 (8.48)	2.9 (.52)
Vocal expressions								
Discriminating prosody affect	94.5 (10.37)	1.0 (.59)	96.7 (3.27)	.81 (.31)	96.7 (5.14)	.83 (.33)	94.7 (9.50)	.71 (.24)
Labelling prosody affect	77.2 (17.16)	3.0 (1.38)	89.4 (8.87)	1.9 (.90)	81.2 (15.18)	2.7 (1.84)	89.4 (9.98)	1.5 (.71)

The table shows accuracy and reaction times on the emotion recognition tasks for each of the groups, shortly after injury and at 1-year follow-up.

Please cite this article in press as: Ietswaart, M., et al., Longitudinal aspects of emotion recognition in patients with traumatic brain injury, Neuropsychologia (2007), doi:10.1016/j.neuropsychologia.2007.08.002

Table 3
Mean performance on recognition of individual emotions on the three expression labelling tasks

	Shortly after injury				One year follow-up			
	TBI patients		Orthopaedic controls		TBI patients		Orthopaedic controls	
	% correct, *M* (S.D.)	RT (s), *M* (S.D.)	% correct, *M* (S.D.)	RT (s), *M* (S.D.)	% correct, *M* (S.D.)	RT (s), *M* (S.D.)	% correct, *M* (S.D.)	RT (s), *M* (S.D.)
Facial expression								
Happiness	96.0 (8.55)	5.4 (4.58)	98.1 (6.440)	3.4 (.97)	96.3 (8.50)	4.0 (1.51)	99.1 (2.96)	2.8 (.48)
Surprise	83.3 (21.87)	8.5 (10.44)	91.6 (11.10)	4.3 (1.30)	85.3 (14.56)	6.1 (3.44)	93.1 (7.38)	3.6 (.66)
Fear	50.7 (24.77)	9.4 (5.52)	71.3 (22.11)	6.1 (5.41)	61.3 (29.56)	8.2 (6.85)	73.1 (18.74)	4.6 (1.68)
Sadness	74.0 (23.13)	8.0 (4.67)	88.1 (10.91)	5.1 (1.56)	82.3 (17.94)	6.7 (3.88)	90.3 (13.56)	3.9 (.87)
Disgust	68.7 (24.46)	9.5 (7.47)	73.8 (19.47)	5.7 (2.78)	74.7 (20.47)	7.7 (6.17)	74.7 (19.17)	4.2 (1.77)
Anger	65.3 (28.37)	7.1 (4.14)	77.2 (20.67)	4.9 (1.51)	79.0 (19.18)	6.5 (3.39)	85.5 (13.87)	4.0 (1.20)
Morphed expression								
Happiness	90.0 (17.19)	3.5 (3.32)	94.1 (10.53)	3.0 (1.22)	92.5 (12.54)	3.7 (1.56)	97.6 (8.05)	2.6 (.76)
Surprise	76.3 (29.43)	5.9 (5.63)	90.3 (12.19)	3.6 (1.11)	77.9 (22.90)	4.7 (1.77)	82.0 (16.79)	3.2 (.73)
Fear	57.5 (33.41)	5.4 (3.21)	75.8 (25.59)	4.3 (2.61)	69.6 (32.61)	4.4 (1.89)	81.6 (23.75)	3.5 (.81)
Sadness	72.1 (31.26)	5.2 (3.34)	93.4 (19.05)	3.7 (1.42)	82.1 (19.61)	5.0 (2.30)	94.5 (11.43)	3.2 (1.02)
Disgust	71.3 (27.50)	5.4 (4.00)	86.4 (21.61)	3.4 (.73)	85.0 (21.38)	4.4 (1.60)	85.1 (24.48)	3.0 (.76)
Anger	72.1 (30.74)	4.8 (2.56)	81.3 (21.06)	4.0 (1.36)	72.9 (29.93)	4.0 (1.31)	85.5 (21.56)	3.2 (1.06)
Prosody affect								
Happiness	81.8 (21.70)	3.5 (1.74)	86.8 (22.88)	2.6 (2.11)	80.8 (22.45)	4.6 (4.55)	89.0 (16.73)	1.8 (.95)
Fear	63.3 (37.55)	5.8 (4.17)	77.3 (24.08)	3.3 (2.17)	65.8 (33.78)	3.6 (2.55)	75.0 (28.40)	2.3 (1.18)
Sadness	87.5 (22.50)	3.0 (2.03)	95.3 (11.78)	1.8 (1.21)	96.8 (10.85)	2.7 (2.57)	97.8 (7.40)	1.3 (.83)
Anger	77.5 (26.55)	3.6 (2.41)	90.8 (15.23)	2.5 (2.06)	85.8 (20.43)	3.4 (2.87)	93.8 (11.00)	2.3 (2.00)
Neutral	80.8 (26.83)	4.4 (4.11)	94.5 (12.28)	2.3 (1.57)	76.8 (25.38)	3.8 (3.07)	91.5 (17.53)	1.8 (1.26)

The table shows the mean percentage correct and reaction times per emotion on the facial expression task, the morphed expression task, and the prosody affect task for each of the groups, shortly after injury and at 1-year follow-up.

labelling prosody affect ($F(1, 60) = 11.22$, $p < .001$, $\eta_p^2 = .16$), with the exception of discriminating prosody affect ($p = .932$, $\eta_p^2 < .001$). Reaction times for correct responses were longer in TBI patients in all of the above tasks: matching facial expressions ($F(1, 55) = 14.95$, $p < .001$, $\eta_p^2 = .21$), labelling facial expressions ($F(1, 55) = 17.09$, $p < .001$, $\eta_p^2 = .24$), morphed facial expressions ($F(1, 55) = 10.56$, $p < .01$, $\eta_p^2 = .17$), and labelling prosody affect ($F(1, 55) = 13.74$, $p < .001$, $\eta_p^2 = .21$), again with the exception of discriminating prosody affect ($F(1, 55) = 3.74$, $p = .059$, $\eta_p^2 = .07$) where the group difference was not significant. Significant main effects of time of assessment on both accuracy and reaction times were found for all facial expression tasks ($F > 7.7$, $p < .01$), but not for the prosody affect tasks ($p > .04$). There were no significant interactions between group and time of assessment to modify these main effects. In conclusion, although the TBI group had lower accuracy scores and longer reaction time than controls, and both groups performed significantly better at follow-up than at initial assessment, there was no indication that TBI patients improved significantly more than the controls.

3.2.2. *Recognition of individual expressions*

To investigate impairments in the TBI group for recognising specific emotions and the claim that negative emotions would be affected in particular, we compared group differences for individual emotional expressions. The mean accuracy scores and reaction times for correct responses on the three expression labelling tasks (labelling of facial expressions, labelling morphed facial expressions, and labelling prosody affect) separated by expression, are displayed in Table 3. The analysis of individual expressions was limited to the three labelling tasks only because the matching facial expressions task did not include sufficient number of trials to allow such an analysis and the discriminating prosody affect (matching) task did neither have enough trials nor showed differences between TBI patients and controls.

The specificity of the emotion recognition deficit in TBI to particular emotions was explored in analyses on the accuracy scores and reaction times of the three labelling tasks in separate 2 (group) by 2 (time of assessment) by 6 (facial expression) or 5 (vocal expression) repeated measures ANOVAs with emotion and time of assessment as within-subject factors. Interactions between group and emotion would indicate that TBI patients may have selective deficits for particular emotions. The alpha level was adjusted for the number of comparisons for each measure (accuracy or reaction times): $.05/3 = .017$. A main effect of emotion was found for all three tasks both on accuracy ($F > 22.17$, $p < .001$) and reaction times ($F > 8.8$, $p < .001$). On accuracy the interaction between group and emotion for labelling facial expressions did not reach significance ($p > .06$), as was found for morphed facial expressions ($p > .37$) and labelling prosody affect ($p > .39$). Similarly, the same comparisons for reaction times also indicated no evidence for an interaction between group and emotion on any of the three labelling tasks: labelling facial expressions ($p > .08$); morphed facial expressions ($p > .08$); or prosody affect ($p > .10$). No interactions between group, emotion, and time of assessment were

Please cite this article in press as: Ietswaart, M., et al., Longitudinal aspects of emotion recognition in patients with traumatic brain injury, Neuropsychologia (2007), doi:10.1016/j.neuropsychologia.2007.08.002

evident on accuracy of any of the tasks ($p > .10$), or on reaction times of labelling facial expressions or labelling prosody affect ($p > .10$), with the exception of reaction times on morphed facial expressions ($F(5, 265) = 4.90$, $p = .016$, $\eta_p^2 = .06$). Exploration of this interaction showed a trend for an interaction between group and emotion on this task ($F(5, 265) = 2.70$, $p = .022$, $\eta_p^2 = .05$), but not at follow up ($p > .27$).

Lack of a clear pattern of selective expression recognition impairment in the TBI group was further confirmed by high correlations between the mean correct responses on the individual expressions between TBI patients and controls on the labelling of facial expressions ($r = .97$, $p < .01$), morphed facial expressions ($r = .81$, $p < .05$), and prosody affect task ($r = .87$, $p < .05$) for performance at initial assessment. These correlations indicate that the pattern of relative difficulty in the TBI patients was comparable to the pattern of relative difficulty in controls. Expressions that were relatively poorly recognised by controls were also relatively poorly recognised by TBI patients. In both groups facial expressions of fear were recognised worst, followed by anger or by disgust, followed by sadness, surprise and happiness. The pattern of difficulty was slightly different for recognition of expressions in the voice, but both groups performed worst at recognising expressions of fear in the voice and best at recognising expressions of sadness. The pattern of results for performance on individual expressions at follow-up assessment was similar as at initial assessment, with the difference that the correlation between the mean correct responses on the individual expressions between TBI patients and controls on the labelling of morphed facial expressions was not significant ($p = .07$).

3.2.3. The relationship between the tasks

To examine whether TBI patients were equally impaired at labelling emotion expressions in the visual or auditory modality, percentage correct scores at initial assessment on labelling facial expressions and labelling prosody affect were compared in a 2 (group) by 2 (task) ANOVA. This analysis revealed at initial assessment a main effect of group ($F(1, 60) = 13.95$, $p < .001$, $\eta_p^2 = .19$) reflecting better performance in the controls, a main effect of task ($F(1, 60) = 13.55$, $p < .001$, $\eta_p^2 = .18$), but no interaction between group and task ($p = .50$, $\eta_p^2 = .007$). In both groups accuracy was higher on labelling prosody than labelling facial expressions, possibly explained by the fact that the latter task required a choice between six alternatives rather than five choices in the former task. Similar analysis of performance at follow-up assessment also revealed an effect of group ($F(1, 60) = 7.77$, $p < .01$, $\eta_p^2 = .12$), and no interaction of group and task ($p = .51$, $\eta_p^2 = .01$), but the difference between the two tasks over the two groups just failed to reach significance at follow-up ($p = .06$, $\eta_p^2 = .06$).

Correlations within each group between the different measures of emotion recognition accuracy, based on mean scores across emotions at initial assessment showed significant correlations between most tasks. The alpha level was adjusted for the number of comparisons in each group: .05/5 = .01. Within the TBI group, the relation between matching facial expressions and discriminating prosody affect was not significant, but it should be noted that the prosody discrimination task did not differentiate between TBI patients and controls. All other relationships between the different tasks of emotion recognition were highly correlated in the TBI group (see Table 4). In the control group, all emotion tasks, with the exception of prosody discrimination, correlated with each other (see Table 4). At follow-up assessment within the TBI group all emotion tasks, with the exception of prosody discrimination, correlated with each other ($r = >.53$, $p = <.01$), and within the control group a correlation was found between the three expression labelling tasks at follow-up ($r = >.54$, $p = <.001$).

The potential associations between compromised cognitive function following TBI and emotion recognition deficits at initial assessment were also explored (see Table 5). The alpha level was adjusted for the number of comparisons for each task: .05/5 = .01. Within the TBI patient group, significant correlations found were between alternating fluency test scores and all emotion recognition tasks except matching facial expressions ($r = >.60$, $p = <.001$), and between performance on the digit symbol test and all emotion recognition tasks, except discriminating prosody affect task in the TBI group ($r = >.52$, $p = <.01$). Within the control group, similar significant associations were found between digit symbol and performance in all emotion recogni-

Table 4
Correlations between the different emotion recognition test scores within TBI group (A) and control group (B) at initial assessment

	Matching facial expressions	Labelling facial expressions	Morphed expressions	Prosody discrimination
(A) TBI				
Matching facial expressions				
Labelling facial expressions	.725**			
Morphed expressions	.553**	.828**		
Prosody discrimination	.450	.618**	.580**	
Labelling prosody	.592**	.667**	.652**	.632**
(B) Controls				
Matching facial expressions				
Labelling facial expressions	.594**			
Morphed expressions	.530**	.735**		
Prosody discrimination	−.235	−.138	−.263	
Labelling prosody	.550**	.572**	.585**	−.017

** $p < .002$.

Please cite this article in press as: Ietswaart, M., et al., Longitudinal aspects of emotion recognition in patients with traumatic brain injury, Neuropsychologia (2007), doi:10.1016/j.neuropsychologia.2007.08.002

Table 5
Correlations between standard neuropsychological test performance, injury severity and the different emotion recognition correct scores within TBI group (A) and control group (B) at initial assessment

	Matching facial expressions	Labelling facial expressions	Morphed expressions	Prosody discrimination	Labelling prosody
(A) TBI					
HADS	.133	.309	.378	.256	.046
NART	.340	.414	.524*	.206	.410
Digit symbol	.524*	.684**	.682**	.523*	.583**
Brixton	.175	.168	.063	.344	.335
Alternating fluency	.423	.595**	.798**	.478*	.637**
Benton	.727**	.653**	.595**	.644**	.514*
PTA	−.062	−.606**	−.565**	−.408	−.216
GCS	.002	.634**	.516*	.405	.100
(B) Controls					
HADS	.045	−.053	−.051	.320	−.073
NART	.188	.492*	.193	.137	.379
Digit symbol	.517*	.639**	.380	−.038	.490*
Brixton	.094	.324	.326	−.142	.285
Alternating fluency	−.026	.198	.063	.036	.147
Benton	.083	.364	−.123	.232	.236

* $p < .01$.
** $p < .002$.

tion tasks, except discriminating prosody affect task ($r = >.49$, $p = <.01$). Performance on the NART correlated with morphed facial expressions in TBI at initial assessment ($r = .52$, $p = <.01$). At follow-up assessment again associations were found again between performance on the digit symbol test and all emotion recognition tasks, except discriminating prosody affect task in the TBI group ($r = >.53$, $p = <.01$). The only other associations found at follow-up within the TBI group was between labelling prosody affect and several neuropsychological tests, namely the Brixton, NART and alternating fluency tests ($r = >.52$, $p = <.01$). In the control group performance at follow-up assessment also showed associations between performance on the digit symbol test and the three expression labelling tasks ($r = >.55$, $p = <.01$). Significant correlations were also found between the NART and labelling facial expressions and discriminating prosody affect ($r = >.47$, $p = <.01$), and between the Brixton and labelling prosody affect ($r = .51$, $p = <.01$) in controls at follow-up assessment.

At initial assessment the Benton scores correlated with all three facial expression tasks within the TBI group ($r = >.60$, $p = <.001$). However, it should be noted that Benton scores were also significantly associated with the two vocal expression tasks at initial assessment ($r = >.53$, $p = <.001$). These tasks obviously do not rely on face recognition and the correlation with recognition of expressions in the voice suggests that Benton scores may reflect a more general cognitive impairment. This impression is strengthened by the significant correlation at initial assessment within the TBI group between Benton scores and a task known to be sensitive to general cognitive impairment following brain injury, namely the digit symbol test ($r = .55$, $p < .01$). Moreover, controlling for digit symbol scores using partial correlations reduced the magnitude of the correlations between Benton test and the expression tasks to the extent that only the associations with matching facial expressions reached significance ($r = .50$, $p < .01$). At follow-up none of the emotion recognition tasks showed significant correlations with the Benton within the TBI group, but there was a trend for an association with performance at both labelling facial expressions and morphed facial expressions ($r = >.47$, $p = <.013$).

Analyses reported above have shown that group differences on the Benton were evident at initial assessment, but not at follow up. Yet, at both time intervals group differences were found on emotion recognition tasks. To examine whether performance on the Benton test was related to accuracy on the facial expression recognition tasks, group differences on the three facial expression tasks were re-analysed in separate 2 (group) by 2 (time of assessment) repeated measures ANCOVAs with Benton score at initial assessment as a covariate, and with adjusted alpha levels: .05/3 = .017. These analyses showed that when controlling for Benton performance group differences were no longer evident for matching facial expressions or labelling facial expressions ($p > .10$), while a trend was found for the group difference on the morphed facial expression task ($F(1, 60) = 5.67$, $p = .02$, $\eta_p^2 = .09$).

Furthermore, because the TBI group had lower digit symbol scores compared to controls, we examined whether slow performance on the expression tasks could be accounted for by the effect of general processing speed. For this purpose reaction time group differences on the expression tasks were re-analysed in separate 2 (group) by 2 (time of assessment) repeated measures ANCOVAs with digit symbol score at initial assessment as a covariate, for each of the tasks and with adjusted alpha levels: .05/4 = .0125. These analyses demonstrated that even when controlling for processing speed the group differences were still evident for matching facial expressions ($F(1, 55) = 5.03$, $p < .01$, $\eta_p^2 = .15$), labelling facial expressions ($F(1, 55) = 7.17$, $p < .01$, $\eta_p^2 = .12$), and labelling prosody affect ($F(1, 55) = 8.32$, $p < .01$, $\eta_p^2 = .14$), while the group difference for morphed facial expressions did not reach significance when controlling for general processing speed ($F(1, 55) = 4.86$, $p = .03$, $\eta_p^2 = .09$). However,

Please cite this article in press as: Ietswaart, M., et al., Longitudinal aspects of emotion recognition in patients with traumatic brain injury, Neuropsychologia (2007), doi:10.1016/j.neuropsychologia.2007.08.002

the digit symbol task is not just a test of processing speed potentially affecting reaction times, but also a test of sustained attention that may affect accuracy performance. For this reason group differences on the accuracy scores of the expression tasks were also re-analysed in separate 2 (group) by 2 (time of assessment) repeated measures ANCOVAs with digit symbol score at initial assessment as a covariate, for each of the tasks and with adjusted alpha levels: .05/4 = .0125. In this case none of the group differences were significant when controlling for digit symbol performance ($p > .02$). Finally, group differences were also found on the alternating fluency test. Alternating fluency performance is considered an index of cognitive flexibility or the ability to switch between response alternatives. To control for the effect of these abilities on expression recognition impairments, 2 (group) by 2 (time of assessment) repeated measures ANCOVAs on accuracy scores of the expression tasks were conducted with alternating fluency score at initial assessment as a covariate. Again, no group differences were found on the different expression tasks when controlling for alternating fluency performance ($p > .08$).

3.3. The factor of injury severity

At initial assessment, significant correlations were found between accuracy on labelling facial expressions and GCS scores ($\rho = .63$, $p < .001$) and PTA ($\rho = -.58$, $p < .001$), and between labelling morphed facial expressions and GCS ($\rho = .52$, $p < .01$) and PTA ($\rho = -.56$, $p < .01$), but associations between GCS or PTA and other emotion recognition tasks were not significant at the adjusted alpha level (.05/5 = .01). Reaction times of labelling morphed facial expressions correlated with GCS ($\rho = -.52$, $p < .01$) and PTA ($\rho = .55$, $p < .01$), and labelling facial expressions correlated with PTA ($\rho = .56$, $p < .01$) at initial assessment, but reaction times on other expression tasks did not ($p > .02$).

At follow-up assessment significant correlations were found between accuracy on labelling facial expressions and GCS scores ($\rho = .52$, $p < .01$) and PTA ($\rho = -.49$, $p < .01$), but not between GCS or PTA and other emotion recognition tasks ($p > .02$). At follow-up PTA significantly correlated with the reaction times of matching facial expressions ($\rho = .51$, $p < .01$), and labelling facial expressions ($\rho = .52$, $p < .01$). Reaction times at follow-up on the other expression tasks did not significantly correlate with GCS or PTA ($p > .02$).

3.4. Lesion analysis

In the literature, frontal damage has been associated with both changes in social behaviour and impaired emotion recognition (e.g. Hornak et al., 1996, 2003), but Green et al. (2004) suggested that right posterior areas may be particularly associated with emotion recognition. To examine whether emotion recognition impairments were more severe following frontal lesions, performance was compared between the subgroups of TBI patients with frontal lesions and those with lesions elsewhere or with diffuse damage. Of the TBI patients 12 had frontal lobe damage, 6 patients had lesions predominantly in temporal and parietal regions and 6 diffuse lesions. No lesion information was available for six patients. Performance of two subgroups was compared: (1) the group of 12 patients with frontal damage and (2) the group of 12 patients with damage to posterior regions or with diffuse damage. Emotion recognition accuracy scores of the two groups were compared in a separate 2 (group) by 2 (time of assessment) repeated measures ANOVAs for each of the measures (adjusting alpha levels to .05/5 = .01) with GCS as a covariate. The GCS covariate was added as a measure of injury severity, because the two groups differed significantly on injury severity. The group of patients with frontal damage had on average a higher GCS (mean GCS 11.6 [S.D. 3.4] compared to 6.7 [S.D. 3.6] in the group with posterior or diffuse damage), and also had shorter duration of PTA (mean PTA 4.4 [S.D. 6.2], compared to 25.4 [S.D. 30.8] days in the group with posterior or diffuse damage). A trend for a group difference was evident on morphed facial expressions ($F(1, 22) = 5.90$, $p = .024$, $\eta_p^2 = .219$), showing that the patients with frontal damage performed better. This difference was less evident on the other four emotion recognition tasks ($p > .07$). No interactions between time of assessment and lesion group were found ($p > .19$).

4. Discussion

A consecutive sample of TBI patients showed impairments on facial and vocal emotion recognition compared to an orthopaedic control group, shortly after sustaining their first TBI and 1 year later. Over time, performance of TBI patients and orthopaedic controls improved to the same extent, probably reflecting retest effects. For this enhancement to have reflected recovery, improved test performance in the TBI group had to exceed improvements in the control group over the same time interval. Retest effects would affect performance in both groups, but recovery of function, in addition to retest effects, was only expected in the TBI group. Emotion recognition performance in the TBI group showed no sign of recovery over a 1-year interval, as improvement in test performance in the TBI group did not exceed what was expected from repeated testing.

Overall the level of brain injury in the current sample of TBI patients was less severe than in previous studies of emotion recognition in TBI, which generally examined severe cases of TBI. The present study included virtually equal numbers of patients with mild, moderate, and severe injury. It is of interest that despite the substantial number of milder injuries in the present sample, TBI patients as a group were nevertheless impaired on emotion recognition. Furthermore, the consecutive recruitment of the current sample suggests that previously reported emotion recognition deficits in TBI are not the result of a bias towards selecting those patients with cognitive, social or emotional behavioural problems following TBI when recruiting from rehabilitation settings. Moreover, our results show no indication that emotion recognition difficulties developed at a later stage in these patients or worsen over time. Impaired emotion recognition was evident early after injury and was still present 1 year later. The fact that impaired emotion recognition appeared soon after TBI and was stable over time

Please cite this article in press as: Ietswaart, M., et al., Longitudinal aspects of emotion recognition in patients with traumatic brain injury, Neuropsychologia (2007), doi:10.1016/j.neuropsychologia.2007.08.002

suggests a direct result of brain injury (Prigatano, 1992), and not primarily a secondary consequence of changes in the social environment.

Analysis of the recognition of individual emotions in the three tasks that required patients to label emotional expressions, revealed no selective deficits for particular emotions in our sample of patients. Previous studies in TBI have reported that patients were more impaired on recognition of negative emotions (Braun et al., 1989; Croker & McDonald, 2005; Hopkins et al., 2002; Jackson & Moffat, 1987). The current study also found that accuracy of recognition of a positive emotion such as happiness was preserved in TBI patients while recognition of emotions such as fear and sadness showed clear impairment. However, this finding most likely reflects relative task difficulty, because the pattern of accuracy and latency on the recognition of individual emotions in the TBI patients of this study closely follows the general pattern of relative difficulty in the control group, as revealed by lack of group differences on the within-subject factor of emotion and by the high correlations between recognition of individual emotions in the TBI and controls groups. Response latency may provide a more sensitive measure of impairment. In particular, differentiation between individual emotions could be more pronounced in latency data compared to response accuracy. However, analysis of reaction times did not show selective impairments affecting particular expressions. Therefore, we would argue that a general emotion recognition deficit exists in TBI without differential deficits affecting specific expressions. Selective or differential impairments recognising specific emotional expressions have previously been associated with focal lesions (e.g. Adolphs, Tranel, Damasio, & Damasio, 1994; Calder, Keane, Manes, Antoun, & Young, 2000; Weniger & Irle, 2002). The multifocal and diffuse nature of brain damage following TBI may account for the lack of specific impairment affecting particular expressions.

This study examined recognition of facial expressions as well as recognition of emotional expressions in the voice. TBI patients were found to be impaired on both and a strong association between the two modalities was found. Recently, McDonald and Saunders (2005) found that emotion recognition on the basis of auditory information was particularly poor in TBI while emotion recognition on the basis of visual information was unimpaired in their sample of severe TBI patients. The fact that McDonald and Saunders (2005) did not find impaired emotion recognition on the basis of visual information is in contrast with previous studies in TBI. The authors acknowledge that their dynamic visual displays may have been easier than still pictures used previously. A proportion of their particular sample of TBI patients were also examined on recognition of Ekman and Friesen (1976) pictures, as were used in the current study, and with these stimuli Croker and McDonald (2005) indeed found that TBI patients were impaired on recognising facial expressions. However, Croker and McDonald (2005) do not touch on auditory emotion recognition in that report. The lack of association between judgement of emotion through visual and auditory channels in McDonald and Saunders' (2005) study, was argued to be in line with proposition by Adolphs, Damasio, and Tranel (2002) that the two modalities represent different neural systems. Our findings do not support this idea. We found a strong association between visual and auditory emotion recognition. Furthermore, the association between the modalities in our sample of TBI patients was found early after injury suggesting a direct relationship with neural damage. The fact that an emotion recognition deficit was found in both modalities is of interest as it suggests a generic emotion recognition deficit. The fact that impaired emotion recognition is associated with emotional content in these patients is of interest in relation to the proposition that emotion recognition deficits may underlie behavioural changes following TBI. Furthermore, the literature indicates that injury severity is the best-known predictor of social outcome following TBI (Tate & Broe, 1999). For emotion recognition to be a potential predictor of social and behavioural change there should be an association between injury severity and performance, as was found for task performance on certain emotion recognition tasks presented in this study.

General perceptual deficits do not fully account for the emotion recognition impairments found. Although TBI patients performed worse on the Benton face recognition test (a task of general face perception) compared to controls at initial assessment, few patients actually scored in the abnormal range. Furthermore, TBI patients showed recovery on the Benton test but not on any of the emotion recognition tasks. On the control task for general auditory perception, the non-emotional prosody discrimination task, no differences between TBI patients and controls were found. This suggests that the stable pattern of impaired emotion recognition is relatively independent of general face and prosody recognition. However, performance on the Benton test was significantly associated with performance on facial expression tasks, namely matching and labelling facial expressions. But the Benton test also correlated highly with the ability to recognise emotion in the voice within the TBI group. The Benton test may therefore reflect general cognitive impairment, as suggested by the strong correlation between the Benton and the digit symbol test. The strong association between digit symbol score and injury severity (i.e. GCS) commonly found, may further explain the fact that group differences on the expression tasks accuracy appeared to be largely be accounted for by performance on the digit symbol task. However, also alternating fluency task performance appeared to account for group differences on the expression tasks. These findings demonstrate that deficits in emotion recognition are associated with other cognitive deficits. It remains unclear, however, whether impaired emotion recognition is actually caused by these other cognitive deficits. For example, it is possible that all deficits are manifestations of the same underlying mechanism. These findings in relation to the multitude of factors identified in the current study in association with emotion recognition, demonstrates the importance of considering other factors before drawing conclusions of selective emotion recognition impairment in patients. In conclusion, although emotion recognition may not be seen as entirely independent of other cognitive deficits, the current study demonstrates the difficulty TBI patients have in identifying emotions in others both shortly after injury and 1 year later.

Please cite this article in press as: Ietswaart, M., et al., Longitudinal aspects of emotion recognition in patients with traumatic brain injury, Neuropsychologia (2007), doi:10.1016/j.neuropsychologia.2007.08.002

No firm conclusions can be made about the potential association between neuropathology and emotion recognition impairments in this study, for two reasons. First, lesion analysis on the basis of clinical information in TBI patients is generally limited. The available CT scans were usually made during the acute phase to establish the need for surgical intervention. The extent of the damage may not be evident at this early stage. Furthermore, the nature of neural damage following TBI is often not visible on CT scans when it involves widespread diffuse axonal damage. Secondly, the attempt in this study to group TBI patients according to the lesion locations as revealed by CT scans, demonstrated that the patients for whom the scan indicated lesions including the frontal lobes sustained less severe brain injury than the group with temporal, parietal or diffuse lesions. Comparing the two lesion groups while controlling for injury severity showed a trend for patients with frontal damage to perform better at labelling morphed facial expressions, but no group differences were found on other expression tasks. Overall, there was no evidence for emotion processing difficulties being more pronounced in those patients with frontal lesions.

In conclusion, given the fact that emotion recognition impairments arise early after TBI, probably reflecting a direct consequence of the brain injury, it is possible that emotion recognition impairments contribute to changes in social behaviour following TBI (Kendall & Terry, 1996). However, it should be acknowledged that other deficits, such as deficits in executive function, impulsivity, or frustration tolerance, could also contribute to social behaviour changes. The TBI patients in our sample, for example, performed worse at one of the executive function tasks, alternating fluency, compared to controls, and poor alternating fluency performance was found to be associated with impaired emotion recognition. An association between emotion recognition and social behaviour has previously been demonstrated in frontal patients (Blair & Cipolotti, 2000; Cicerone & Tanenbaum, 1997; Hornak et al., 1996) and in schizophrenia (Hooker & Park, 2002). In TBI patients Milders et al. (2003) explored the association between emotion recognition deficits and changes in emotional and social behaviour assessed with questionnaires completed by patients and relatives, but found no relationship. Recently, Croker and McDonald (2005) examined TBI patients on the relationship between the ability to recognise facial expressions and the subjective experience of each of the assessed emotions. The patients were asked to indicate the extent to which their experience of perception of the emotions had changed following TBI. Croker and McDonald (2005) found that reduced subjective experience was associated with matching facial expressions but not with labelling facial expressions. Clearly more work is required to clarify the relation between acquired emotion recognition impairment and behavioural changes following TBI, and follow-up over intervals may be needed to confirm the absence of recovery. If it is confirmed that emotion recognition impairments following brain injury show little spontaneous recovery, it may be useful to incorporate training in aspects of recognising emotions in others in the rehabilitation of TBI patients.

Acknowledgement

This research was supported by a grant from the Chief Scientist Office of the Scottish Executive Department of Health (CZH/4/14).

References

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

Adolphs, R. (2002). Neural systems for recognizing emotion. *Current Opinion in Neurobiology*, *12*, 169–177.

Adolphs, R., Damasio, H., & Tranel, D. (2002). Neural systems for recognition of emotional prosody: A 3D lesion study. *Emotion*, *2*, 23–51.

Adolphs, R., Damasio, H., Tranel, D., & Damasio, A. R. (1996). Cortical systems for the recognition of emotion in facial expressions. *Journal of Neuroscience*, *16*, 7678–7687.

Adolphs, R., Tranel, D., Damasio, H., & Damasio, A. (1994). Impaired recognition of emotion in facial expressions following bilateral damage to the human amygdale. *Nature*, *372*, 669–672.

Benton, A., Hamsher, K., Varney, N., & Spreen, O. (1983). *Facial recognition. Stimulus and multiple choice pictures*. New York: Oxford University Press.

Biehl, M., Matsumoto, D., Ekman, P., Hearn, V., Heider, K., Kudoh, T., et al. (1997). Japanese and Caucasian facial expressions of emotion (JACFEE) reliability data and cross-national differences. *Journal of Non-Verbal Behaviour*, *21*, 3–21.

Blair, R., & Cipolotti, L. (2000). Impaired social response reversal: A case of 'acquired sociopathy'. *Brain*, *123*, 1122–1141.

Bowers, D., Blonder, X. L., & Heilman, K. M. (1991). *Florida affect battery*. University of Florida, Center for Neuropsychological Studies.

Braun, C., Lussier, F., Baribeau, J., & Ethier, M. (1989). Does severe traumatic closed head injury impair sense of humour? *Brain Injury*, *3*, 345–354.

Burgess, P., & Shallice, T. (1997). *Hayling and Brixton tests*. London: Harcourt Assessment.

Calder, A. J., Keane, J., Manes, F., Antoun, N., & Young, A. W. (2000). Impaired recognition and experience of disgust following brain injury. *Nature Neuroscience*, *3*, 1077–1078.

Calder, A. J., Young, A. W., Rowland, D., Perrett, D. I., Hodges, J. R., & Etcoff, N. L. (1996). Facial emotion recognition after bilateral amygdala damage: Differentially severe impairment of fear. *Cognitive Neuropsychology*, *13*, 699–745.

Cicerone, K., & Tanenbaum, L. (1997). Disturbances of social cognition after traumatic orbitofrontal brain injury. *Archives of Clinical Neuropsychology*, *12*, 173–188.

Croker, V., & McDonald, S. (2005). Recognition of emotion from facial expression following traumatic brain injury. *Brain Injury*, *19*, 787–799.

Downes, J., Sharp, H., Costall, B., Sagar, H., & Howe, J. (1993). Alternating fluency in Parkinson's disease. An evaluation of the attentional control theory of cognitive impairment. *Brain*, *116*, 887–902.

Ekman, P., & Friesen, W. (1976). *Pictures of facial affect*. Palo Alto, CA: Consulting Psychologists Press.

Freeman, J., Godfrey, H. P., Harris, J. K., & Partridge, F. M. (2001). Utility of a demographic equation in detecting impaired NART performance after TBI. *British Journal of Clinical Psychology*, *40*, 221–224.

Goodglass, H., & Kaplan, E. (1983). *Boston Diagnostic Aphasia Examination*. Media PA: Williams & Wilkins.

Green, R. E. A., Turner, G. R., & Thompson, W. F. (2004). Deficits in facial emotion perception in adults with recent traumatic brain injury. *Neuropsychologia*, *42*, 133–141.

Hooker, C., & Park, S. (2002). Emotion processing and its relationship to social functioning in schizophrenia patients. *Psychiatry Research*, *112*, 41–50.

Hopkins, M. J., Dywan, J., & Segalowitz, S. J. (2002). Altered electrodermal response to facial expression after closed head injury. *Brain Injury*, *16*, 245–257.

Please cite this article in press as: Ietswaart, M., et al., Longitudinal aspects of emotion recognition in patients with traumatic brain injury, Neuropsychologia (2007), doi:10.1016/j.neuropsychologia.2007.08.002

Hornak, J., Bramham, J., Rolls, E. T., Morris, R. G., O'Doherty, J., Bullock, P. R., et al. (2003). Changes in emotion after circumscribed surgical lesions of the orbitofrontal and cingulate cortices. *Brain*, *126*, 1691–1712.

Hornak, J., Rolls, E. T., & Wade, D. (1996). Face and voice expression identification inpatients with emotional and behavioural changes following ventral frontal lobe damage. *Neuropsychologia*, *34*, 247–261.

Jackson, H. F., & Moffat, N. J. (1987). Impaired emotional recognition following severe head-injury. *Cortex*, *23*, 293–300.

Kendall, E., & Terry, D. J. (1996). Psychosocial adjustment following closed head injury: A model for understanding individual differences and predicting outcome. *Neuropsychological Rehabilitation*, *6*, 101–132.

Kington, J. M., Jones, L. A., Watt, A. A., Hopkin, E. J., & Williams, J. (2000). Impaired eye expression recognition in schizophrenia. *Journal of psychiatric research*, *34*, 341–347.

Levin, H. S., Williams, D. H., Eisenberg, H. M., High, W. M., & Guinto, F. C. (1992). Serial MRI and neurobehavioral findings after mild to moderate closed head-injury. *Journal of Neurology Neurosurgery and Psychiatry*, *55*, 255–262.

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.

Milders, M., Fuchs, S., & Crawford, J. R. (2003). Neuropsychological impairments and changes in emotional and social behaviour following severe traumatic brain injury. *Journal of Clinical and Experimental Neuropsychology*, *25*, 157–172.

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.

Mueser, K. T., Doonan, R., Penn, D. L., Blanchard, J. J., Bellack, A. S., Nishith, P., et al. (1996). Emotion recognition and social competence in chronic schizophrenia. *Journal of Abnormal Psychology*, *105*, 271–275.

Nelson, H.E. & Willison, J.R. (1991). *The National Adult Reading Test (NART): Test Manual (2nd Edition)*. Windsor, UK: NFER-Nelson.

Pettersen, L. (1991). Sensitivity to emotional cues and social-behavior in children and adolescents after head-injury. *Perceptual and Motor Skills*, *73*, 1139–1150.

Prigatano, G. P. (1992). Personality disturbances associated with traumatic brain injury. *Journal of Consulting and Clinical Psychology*, *60*, 360–368.

Spell, L. A., & Frank, E. (2000). Recognition of nonverbal communication of affect following traumatic brain injury. *Journal of Nonverbal Behavior*, *24*, 285–300.

Sprengelmeyer, R., Rausch, M., Eysel, U. T., & Przuntek, H. (1998). Neural structures associated with recognition of facial expressions of basic emotions. *Proceedings of the Royal Society of London Series B: Biological Sciences*, *265*, 1927–1931.

Tate, R. L., & Broe, G. A. (1999). Psychosocial adjustment after traumatic brain injury: What are the important variables. *Psychological Medicine*, *29*, 713–725.

Teasdale, G., & Jennett, B. (1974). Assessment of coma and impaired consciousness. *Lancet*, *2*, 81–84.

Wechsler, D., Wycherley, R. J., Benjamin, L., Crawford, J. R., & Mockler, D. (1998). *Manual for the Wechsler adult intelligence scale* (3rd ed.). London, UK: The Psychological Corporation.

Weniger, G., & Irle, E. (2002). Impaired facial affect recognition and emotional changes in subjects with transmodal cortical lesions. *Cerebral Cortex*, *12*, 258–268.

Zigmund, A. S., & Snaith, R. P. (1983). Hospital anxiety and depression scale. *Acta Psychiatry Scandinavia*, *67*, 361–370.

Please cite this article in press as: Ietswaart, M., et al., Longitudinal aspects of emotion recognition in patients with traumatic brain injury, Neuropsychologia (2007), doi:10.1016/j.neuropsychologia.2007.08.002