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Recognizing vocal expressions of emotion in patients with social skills deficits following traumatic brain injury

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Abstract

Perception of emotion in voice is impaired following traumatic brain injury (TBI). This study examined whether an inability to concurrently process semantic information (the "*what*") and emotional prosody (the "*how*") of spoken speech contributes to impaired recognition of emotional prosody and whether impairment is ameliorated when little or no semantic information is provided. Eighteen individuals with moderate-to-severe TBI showing social skills deficits during inpatient rehabilitation were compared with 18 demographically matched controls. Participants completed two discrimination tasks using spoken sentences that varied in the amount of semantic information: that is, (1) well-formed English, (2) a nonsense language, and (3) low-pass filtered speech producing "muffled" voices. Reducing semantic processing demands did not improve perception of emotional prosody. The TBI group were significantly less accurate than controls. Impairment was greater within the TBI group when accessing semantic memory to label the emotion of sentences, compared with simply making "same/different" judgments. Findings suggest an impairment of processing emotional prosody itself rather than semantic processing demands which leads to an over-reliance on the *"what"* rather than the *"how"* in conversational remarks. Emotional recognition accuracy was significantly related to the ability to inhibit prepotent responses, consistent with neuroanatomical research suggesting similar ventrofrontal systems subserve both functions. (*JINS*, 2010, *16*, 369–382.)

Keywords: Emotion perception, Prosody, Semantic, Inhibitory control, Filtered, Nonsense

INTRODUCTION

Research documenting sequelae of traumatic brain injury (TBI) consistently show that changes in socio-emotional functioning are more common than neuropsychological deficits. Such deficits increase with severity of the TBI, occurring in up to 80% of the severely injured population (e.g., Brooks, Campsie, Symington, Beattie, & McKinlay, 1986; Thomsen, 1984). Such changes reflect, in part, an inability to recognize and regulate responses to emotional cues during social interactions (Croker & McDonald, 2005; Hornak, Rolls, & Wade, 1996; Ietswaart, Milders, Crawford, Currie, & Scott, 2008). Individuals with TBI have difficulty identifying emotions in face (Green, Turner, & Thompson, 2004; Jackson & Moffatt, 1987; Milders, Fuchs, & Crawford, 2003; Spell & Frank, 2000) and voice (Marquardt, Rios-Brown, Richburg, Seibert, & Cannito, 2001; McDonald & Pearce, 1996; Milders et al., 2003). However, impairment is greater for vocal emotion (Spell & Frank, 2000) even when paired with visual emotional cues (McDonald & Saunders, 2005), and improves less over time, compared with facial emotion perception (Ietswaart et al., 2008). Yet relatively few studies have examined vocal affect deficits in TBI (Zupan, Neumann, Babbage, & Willer, 2009).

Most research examining emotional prosody has focused on patients with focal brain lesions. There is some evidence for right hemispheric specialization in processing emotional prosody (Bowers, Coslett, Bauer, Speedie, & Heilman, 1987; Heilman, Bowers, Speedie, & Coslett, 1984; Ross & Monnot, 2008), although others find no distinction (Baum & Pell, 1999; Pell & Baum, 1997; Pell, 2006; Schlanger, Schlanger, & Gerstmann, 1976). Processing of both emotional and grammatical prosody involves the superior temporal gyrus bilaterally, although evidence continues to favor right hemisphere specialization for emotion (Adolphs, 2002; Mitchell, Elliott, Barry, Cruttenden, & Woodruff, 2003). In addition, overlapping frontal–subcortical circuits become selectively

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activated depending on task demands. The orbito and ventral medial frontal regions, amygdale, and basal ganglia are engaged, especially during encoding and maintenance of meaningful representations of emotional prosody (Buchanan et al., 2000; Johnstone, van Reekum, Oakes, & Davidson, 2006; Kotz, Meyer, Alter, Besson, von Cramon, & Friederici, 2003; Pell & Leonard, 2003). The dorsolateral prefrontal cortex is also engaged during effortful access of semantic memory for labeling an emotional cue (Hariri, Bookheiner, & Mazziotta, 2000; Oschner & Barrett, 2001; Phillips, Drevets, Rauch, & Lane, 2003). Ventral frontal and temporal regions implicated in emotion processing are commonly compromised following TBI (Fujiwara, Schwartz, Gao, Black, & Levine, 2008; MacKenzie et al., 2002). Impairment is not, however, contingent on the presence of particular focal injuries (Ietswaart et al., 2008) but may also be due to diffuse axonal injury causing a shearing of connections between critical areas mediating emotion perception (Adolphs, Damasio, Tranel, Cooper, & Damasio, 2000; Green et al., 2004).

In part, judgments of vocal emotion are driven by the distinctiveness of prosodic elements including pitch, intonation, loudness, and tempo. Patterns of errors suggest they are caused by similarities in prosodic parameters between emotions (Leinonen, Hiltunen, Linnankoski, & Laakso, 1997) with some emotions easier to identify than others. Anger is characterized by increased speech rate, wider range in pitch variations and greater intensity, making it one of the most identifiable emotions in voice (Scherer, 2003). Fear is also relatively easy to identify, while happiness is more difficult to recognize in vocal than facial expressions (Scherer, 2003; Zupan et al., 2009) and surprise is the most difficult to distinguish (Pell, 2006). Although some have reported that TBI causes impairment across all emotions (Ietswaart et al., 2008; McDonald & Saunders, 2005), Spell and Frank (2000) found adults with TBI were more accurate identifying anger and happiness compared with the fearful voice. This pattern is difficult to reconcile with an emotion perception problem based on acoustic features alone and suggests other factors underpin deficits following TBI.

An important consideration is the interplay between speech prosody (the *how)* and the content of what is being said (the *what*). Speech prosody delivers the emotion behind the words in a spoken message (Mitchell & Ross, 2008). While prosodic information is available and used early in comprehension (Kaganovich, Francis, & Melara, 2006; Steinhauer, Alter, & Friederici, 1999), there is a bias for processing semantic content over prosody (Lew, Chmiel, Jerger, Pomerantz & Jerger, 1997). Semantic information is less open to interference than prosody (Jerger et al., 1993; Morgan & Brandt, 1989). Furthermore, in a modified Stroop task, incongruent semantic information interferes more with the identification of prosody than vice versa (Grimshaw, 1998) and while directions to ignore prosody are easily complied with, semantic information is difficult to completely ignore when focusing on prosody (Besson, Magne, & Schön, 2002; Wambacq & Jerger, 2004).

It is possible that some of the difficulties people with TBI experience with vocal emotion stem from a failure to manage dual processing demands. Many people with TBI show an overly literal interpretation of indirect conversational remarks such as sarcasm (McDonald & Flanagan, 2004). Although various explanations have been considered (e.g., McDonald & Flanagan, 2004; Shamay-Tsoory et al., 2005) a consistent finding is that deficits in information processing speed, working memory, and reasoning are commonly associated (McDonald et al., 2006; McDonald & Pearce, 1996, Martin & McDonald, 2004). These cognitive deficits appear to lead to an over-reliance upon the salient semantic information at the expense of contextual cues, some of which are prosodic. If people with TBI have difficulty processing both prosody and semantic content, reducing semantic content should lead to a shift in processing resources toward prosody (Creusere, Alt, & Plante, 2004) improving accuracy. This is unless TBI causes impaired processing of emotional prosody itself (Zupan et al., 2009). Semantic information can be reduced by using a "nonsense" language that conveys little semantic meaning (Grandjean et al., 2005) or "filtering" out high frequencies in speech making the semantic content inaudible whilst preserving the prosodic elements (Kotz et al., 2003).

Although studies of patients with focal unilateral lesions have largely found a specific impairment in processing emotional prosody (Bowers et al., 1987; Pell & Baum, 1997; Pell, 2006), some have found that perception of prosody improves with removal of semantic information in patients with left-hemisphere lesions (Behrens, 1985; Heilman et al., 1984; Lalande, Braun, Charlebois, & Whitaker, 1992; Ross & Monnot, 2008; Ross, Thompson, & Yenkowsky, 1997). TBI is characterized by diffuse, multifocal damage that is often bilateral affecting frontal and temporal systems (Levin, Williams, Eisenberg, High, & Guinto, 1992). Consequently, it is unclear whether removing semantic information will ameliorate deficits in recognition of vocal emotion.

The following study aimed to replicate findings of vocal emotion perception problems in a sample of adults with TBI presenting with postmorbid changes in social skills. We hypothesized that if an inability to manage the dual processing requirements of understanding the *how* and the *what* of spoken speech contributes to impaired emotional prosody recognition, then this impairment should be ameliorated when little (nonsense sentences) or no semantic information (filtered sentences) is provided. Alternatively, if TBI causes impairment in the processing of emotional prosody itself, then we anticipated performance would become more degraded with reduced semantic information.

Lesions in the orbito and ventral medial frontal cortices cause perseveration of prepotent/automatic responses (Bechara et al., 1996; Freedman et al., 1998) and disinhibited, impulsive behavior (Starkstein, 1997) concurrently with deficits in emotion recognition (Damasio, 1994; Hornak et al., 1996; Pettersen, 1991). These regions, with connections to subcortical and brain stem nuclei (Vogt, 1986) may mediate a reciprocal function where effective recognition of emotional cues assists with regulation of behavioral responses (Oschner & Barrett, 2001). Emotion recognition has been linked to the display of socially appropriate behavior in brain-injured patients (Hornak et al., 1996; Pettersen, 1991) and cognitive measures of inhibitory control (Dujardin et al., 2004; Uekermann, Daum, Schlebusch, & Trenckmann, 2005) although not always (Langenecker, Bieliauskas, Rapport, Zubieta, Wilde, & Berent, 2005; Milders et al., 2003). The second aim of this study was to examine the relation between emotion perception, inhibitory control, and behavioral impulsivity. We hypothesized that there would be a positive association among these three constructs.

METHODS

Participants

Nineteen adults with moderate–severe TBI were recruited from metropolitan Brain Injury Units in NSW, Australia. All participants had suffered brain injuries of sufficient severity to warrant inpatient rehabilitation, and were recruited on the basis of clinical judgment that they (1) were experiencing social difficulties as a result of the TBI and (2) had sufficient cognitive and motor capacity to understand and comply with instructions. Exclusion criteria included premorbid neurological or psychiatric conditions; current aphasia or agnosia; current psychosis. One participant was subsequently excluded because of an insufficient number of attempted responses to allow meaningful statistical analysis. The remaining 18 participants (13 males, 5 females) were aged 22 to 63 years (Mean 45.2; *SD* 11.7) (Table 1).

Posttraumatic amnesia (PTA) was established from medical records. Mean duration was 79.8 days (range, 1–270 days), no different (one sample *t*-test; $p = .94$) to that reported in a consecutive series of TBI inpatients (e.g., Tate, Broe & Lulham, 1989: PTA mean = 81.2 days; range 4 to >168 days). That is, this sample was representative of the severity of injury typically seen in this population. Our sample did include two participants with PTA of 1 day or slightly less (Pts 15 and 21) which is identified as a mild TBI by some grading classifications (Mild Traumatic Brain Injury Committee of the Head Injury Interdisciplinary Special Interest Group of the American Congress of Rehabilitation Medicine, 1993) and moderate by others (Jennett, 1976), although the presence of radiological abnormalities suggests that these injuries were more complicated. Both participants experienced social difficulties as a consequence of their brain injuries and had undergone inpatient rehabilitation. Mean time post injury for the group was 15.0 years (*SD* 9.5 months). Before the injury, all participants had been in full-time work (four professional, eight skilled, four unskilled) or studying (2). Following their injuries, two participants were in full-time employment while six worked on a part-time basis and 10 were unemployed. On average, TBI participants had 12 years (*SD* 2.2 years) of education. One patient with TBI was deaf in his right ear due to peripheral damage. While unilateral deafness affects speech localization and reduces ability to screen background noise, speech discrimination in the good ear remains intact. Thus, the participant's ability to perform the tasks was unaffected, and this was confirmed with the participant during practice trials.

Eighteen control participants (12 males) aged 23–62 years (Mean 44.4; *SD* 12.1), with 11.3 years education (*SD* 1.6) and without neurological impairment, were also tested. These were volunteers recruited through community newspaper advertisements and flyers in local hospitals. They were screened for neurological, psychiatric, and motor–sensory impairments before acceptance into the study. The groups did not differ with respect to age ($p = .837$) or education ($p = .317$). All participants spoke fluent English and had normal or corrected-to-normal vision.

Stimuli

Three sets of prosody stimuli were presented over two emotion recognition tasks. Two sets (Pell, Paulmann, Dara, Alasseri, & Kotz, 2009) consisted of short, digitally recorded declarative sentences (Mean Length: 1.7 s; Range: 0.9 to 2.5 s) produced by two male (Mean Pitch: 192 Hz; Range: 114–388 Hz) and two female (Mean Pitch: 237 Hz; Range: 112–388 Hz) actors. Sentences were sampled at a rate of 48 kHz, at an intensity of 75dB, and were spoken in either (1) semantically well-formed American English (e.g., *That car just splashed me!*) or (2) a nonsense language with appropriate phonetic and prosodic structure for English (e.g., *Someone migged the pazing*). Sentences were spoken as: happy, pleasantly surprised, angry, and afraid (see Table 2 for acoustic characteristics). The semantically well formed stimuli provided emotionally biased semantic content that facilitated discrimination for happy, angry, and afraid. (The pleasantly surprised content was more ambiguous (e.g., *You cleaned the entire garage!*). In contrast, nonsense words provided little linguistic information while leaving emotion prosody intact. Each actor gave two exemplars of each emotion resulting in a set of 32 stimuli for the *semantic* stimuli and a different set of 32 stimuli for the *nonsense* stimuli.

A third set of 32 stimuli was created by low-pass filtering the semantically-well formed stimuli using a Hann band filter in Praat (v 5.0.2; www.praat.org) with a cutoff at 360 Hz for male actors and 400 Hz for female actors (Koff et al., 1999), and a smoothing width of 100 Hz. Cutoff points were selected following analysis of the fundamental frequency (f_0) maximum across emotions and incrementally adjusting the cutoff by 30 Hz around this point until linguistic information was subjectively inaudible. The resultant *filtered* stimuli retained pitch and contour variations over time whilst offering no linguistic information, sounding like "muffled" speech. Five postgraduate students listened to a subset of the stimuli ($n = 10$), and all reported that no linguistic information was identifiable.

Tasks

The design of the emotion discrimination and emotion labeling tasks is depicted in Figure 1.

Table 1. Demographic and clinical characteristics of participants with TBI

ID	Age	Gender	PTA (days)	Injury Severity Classification	Time since injury (years)	Cause of injury	Site of injury/initial CT scan	Problems in social skills resulting from the injury
1	57	M	126	Ext. severe	16	MVA	R frontal hematoma	[1] Repeats self a lot. Does not understand meaning behind what people are saying. Easily frustrated in social situations as difficult to get point across.
2	58	F	90	Ext. severe	30	MVA	Intracerebral hemorrhage	[1] Slow to pick up on social cues. Hard to concentrate on what people are saying. Gets frustrated and irritated.
5	52	M	72	Ext. severe	5	Assault	R subdural hematoma, L intracranial hemorrhage, 5-mm midline shift	[2] Wooden and awkward socially, doesn't pick up cues.
6	63	F	84	Ext. severe	9	MVA	—	[3] Giggles a lot, doesn't know when to stop talking; cannot take another's perspective.
7	52	F	28	Very severe	42	Fall	Large atrophic lesion in R temporal lobe	[2] No humor, black and white in social situations, rigid.
8	38	M	270	Ext. severe	19	Assault	Parieto-occipital fracture; focal atrophy of R frontal and temporal lobes	[2] Inappropriate verbal sexual comments. Misguided humor. Frustration with self and others. Dogmatic and rigid in expressing opinions.
9	33	M	150+	Ext. severe	9	MVA	Extensive R temporal encephalomacia, R frontal extradural collection, lateral and ventricular dilation	[3] Lost sense of humor. Lost ability to pick up social cues, e.g., appropriate conversation. Timid in social situations. Repeats himself. Only talks to people he likes otherwise can become rude. Decreased eye contact.
10	29	F	120+	Ext. severe	9	MVA	Cerebral edema, L fronto-temporal and occipital lobe contusions	[2] Overfriendly, presents as very immature. Giggles a lot and sulks. Excessive, unrelenting and loud conversation. Some inappropriate comments and touching.
11	22	M	32	Ext. severe	4	Assault	R frontal contusion, L parietal and occipital contusions, depressed fracture of R frontal bone	[2] Reserved and unresponsive in social situations
15	51	M	<1	Moderate-severe	4	MVA	Mild frontal bruising	[1] Cannot cope with multiple conversations. Inability to focus. Short tempered with people.
21	43	F	1	Moderate–severe	11	Blow to Head	Occipital fracture	[2] Problems regulating speech quality, overly loud and brusque.
22	45	M	90	Ext. severe	6	Assault	Bilateral subdural hematoma	[1] Feels like a social void. Frustrated with not understanding social cues. Listens but does not speak as others cannot understand.
23	41	M	10	Very severe	13	MVA	L frontal hematoma	[1] Finds it hard to read signals and pick up on cues in romantic relationships.
24	40	M	42+	Ext. severe	23	MVA	Ischemic impact on L parietal region and small hematoma at level of 4th ventricle	[3] Loss of confidence. Finds it difficult to pitch humor appropriately. Improving slowly over the years but impact on sociability still clear.

(Continued)

Table 1. Continued

ID	Age	Gender	PTA (days)	Injury Severity Classification	Time since injury (years)	Cause of injury	Site of injury/initial CT scan	Problems in social skills resulting from the injury
25	49	M	41	Ext. severe	13	MVA Ped	R temporal lobe fracture; extradural hematoma and contusion L temporal lobe	[1] Finds socializing difficult. Lost sense of humor. Does not appreciate jokes and takes things very seriously. More trusting of others and gullible. Colder and more defensive.
27	52	M	150	Ext. Severe	21	MVA Ped	—	[1] Not good with people any more. Isolated. Others have difficulty understanding him. Slow and cannot pick up on detail.
28	58	M	12	Very Severe	15	Fall	Subdural hematoma in R parieto-occipital region	[2] Concrete and rigid; fails to understand irony and sarcasm; inert in social settings.
31	28	M	GCS 6	Severe	18	MVA	R side injury; Possible brainstem damage, air/fluid in ethmoid and maxillary sinuses	[1] Does not socialize at all as too difficult. Does not understand social situations. Misses cues, e.g., when to leave, when to talk. No longer has a sense of humor and cannot make jokes. Slow to comprehend people.

Note. Severity classification as recommended by Jennett (1976, 1996); Ext = extremely; GCS = Glasgow Coma Scale; MVA = motor vehicle accident; MVA Ped = motor vehicle accident as a pedestrian; R = right; L = left;
[1]Self-report.
[2]Clinician report.
[3]Maternal report.

Emotion discrimination

In the emotion discrimination task 32 pairs of nonsense stimuli and 32 pairs of filtered stimuli were presented and participants made same/different judgments regarding the emotion in the voice pairs. Response options were presented on computer screen and participants responded with either a left (different) or right (same) button press on a keyboard. Each trial began with a 500-ms warning stimulus followed by the first stimulus, a 500-ms inter-stimulus-interval, and then the second stimulus. Participants had 10 seconds to respond after the second speaker. The task consisted of eight blocks of eight stimuli pairs, alternating between blocks of nonsense and filtered stimuli. Pairings of "same" and "different" emotional prosody were equiprobable (50%) across the task. All pairings involved sentences of different semantic content spoken by different speakers of the same gender. The first block of each nonsense and filtered stimulus set began with three practice trials.

Emotion labeling

In the emotion labeling task participants were required to identify emotional tone in speech using either prosodic features alone or with semantic information. Participants listened to a single stimulus and identified whether the emotion in the voice was *happy, surprised, angry,* or *afraid* in a forced-choice task. Use of only four options reduced working memory demands (Pell, 2006) as did presentation of the response options on both computer screen and keyboard buttons. The task consisted of eight blocks (eight trials/block) of alternating semantic and nonsense stimuli (i.e., four blocks for each stimulus type).[1] Each trial began with a warning stimulus for 500 ms, followed by the speech stimulus and then a request to match the speech stimulus to the appropriate emotion (within 10 s). In the first four blocks, the response options on screen consisted of written words, with participants required to press the corresponding labeled keyboard button. In the second set of four blocks, the response options were four black and white photographs (two male, two female) (Ekman & Friesen, 1976) representing the four emotions. Participants again were required to press the corresponding labeled keyboard button (in the same order as above). The first block of each semantic and nonsense stimulus set began with three practice trials.

Measures of Impulsivity and Inhibition

Trait impulsiveness

Participants completed Barratt's Impulsiveness Scale (BIS-11), a 30-item self-report survey measuring Motor

[1] A pilot of the three stimulus sets on 13 undergraduate medical students revealed filtered stimuli were labeled as one of four emotions with the percentage of correct responses no better than chance (50%). Thus, we excluded this stimulus set from the labeling task.

Table 2. Acoustic characteristics of emotional prosody stimuli

	Pitch Mean (Hz)	Pitch Range (Hz)	Pulse rate	Voice breaks (count)	Duration (s)
Angry	232.3	292.6	249	4.5	1.9
Afraid	274.2	239.9	251	3.8	1.4
Happy	185.1	205.8	228	3.1	1.8
Surprised	301.3	364.4	322	2.9	1.6

Note. "Voice breaks" was estimated as the number of distances between consecutive pulses that are longer than 1.25 divided by the pitch floor (Boersma & Weenink, 2007).

Impulsiveness (i.e., acting without thinking), Attentional Impulsiveness (i.e., easily bored when sustained attention required) and Nonplanning Impulsiveness (i.e., a lack of concern for future consequences) (Patton, Stanford, & Barratt, 1995). Internal consistency reliability ranges from 0.79 to 0.83 for healthy adults, substance-abuse patients and prison inmates (Patton et al., 1995) and is approximately 0.78 (Votruba et al., 2008) for adults with TBI, who show greater total impulsiveness scores than controls (Dyer, Bell, McCann, & Rauch, 2006; McHugh & Wood, 2008). Scores for each sub-factor and an overall Impulsiveness score were calculated

Inhibitory control

Inhibition of a prepotent, automatic response was evaluated using the Haylings Sentence Completion Test (Burgess & Shallice, 1997) whereby participants are asked to provide a word to finish a sentence that either completes the sentence ("initiation" task) or is completely unconnected ("inhibition" task). TBI patients (Draper & Ponsford, 2008) and frontal-injured patients (Burgess & Shallice, 1996) show poor performance on this test. A response time score and an error score for the inhibition task as well as an overall response score across tasks were calculated and scaled using a scoring system in Burgess and Shallice (1997) and converted to Sten scaled scores (differences between Sten scores = 0.5 of an *SD*). Scores ranged from 1 (outside normal range) through to 10 (99th percentile or very superior). A scaled score of 2 (1%) or below is considered impaired (Burgess & Shallice, 1997). Test–retest reliability of the inhibition error score ranges from 0.41 for healthy controls to 0.72 for brain injured (lesion) patients (Burgess & Shallice, 1997).

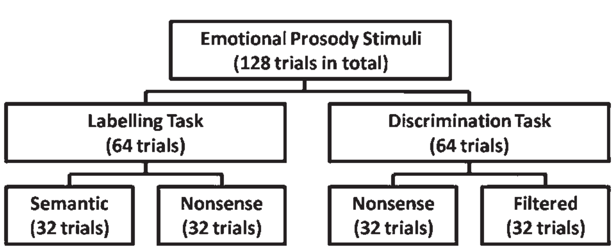

Fig. 1. In this experimental design, each participant completed an emotion labeling and an emotion discrimination task, each consisting of two stimulus sets (32 trials each), resulting in a total of 128 emotional prosody trials.

Procedure

The discrimination and labeling tasks were presented on a computer in counterbalanced order across participants. Participants listened to prosody stimuli over volume-adjustable computer headphones. In the labeling task, participants were told that they would hear a person speaking in either English or a "made-up" nonsense language and that they were to identify the emotion in each voice from the four alternatives offered. In the discrimination task, participants were instructed to listen to both speakers, who would either be speaking in a nonsense language or a muffled tone, before deciding whether the emotion in the two speakers was "same" or "different". Across all tasks, participants were instructed that it was more important that they should listen to "how" the speaker was speaking rather than to "what" they were saying.

Following the experimental tasks, participants completed the BIS-11 and neuropsychological tests including the Wechsler Test of Adult Reading (WTAR), the Trail-Making Test, WMSIII subtests: Logical Memory 1 and Faces 1, WAISIII subtests: Similarities, Digit Span, Digit Symbol-Coding (WAIS-III), and the Haylings Sentence Completion Test. This study and its procedures were approved by the University of NSW Human Research Ethics Committee.

Statistical Analyses

Accuracy rates, converted to percentages of total attempted responses (i.e., omission errors excluded), and RT were calculated. A Repeated-measures 2 × 2 ANOVA was used in the discrimination task, with the within-subject factor CONDITION (nonsense *vs.* filtered) examining participants' accuracy (%) and mean reaction time (MRT). A 2 × 2 × 2 design was used in the labeling task, with the within subjects factors CONDITION (original *vs.* nonsense) and TASK (match-to-words *vs.* match-to-faces). A separate analysis was performed in each task to examine differences between Emotion Types, that is, happy *versus* pleasantly surprised, angry *versus* afraid, and positive (happy + surprised) *versus* negative (angry + afraid). Significant main effects were followed with separate analyses and alpha adjusted for the number of comparisons.

For the Impulsiveness Scale, where data were missing for items (2% of all cells), $mean_{person}$ was used to replace these (Roth, Switzer, & Switzer, 1999), allowing a total score to be calculated for each individual. ANOVAs were used to examine between-group differences on the Impulsiveness subscales and on all neuropsychological measures except the Haylings test for which the Mann-Whitney *U* test was used. Pearson's bivariate correlations were performed between experimental task measures, and neuropsychological and personality measures.

RESULTS

Table 3 presents neuropsychological test scores for individual participants with TBI as well as between-group differences.

Discrimination Task

Participants with TBI showed overall poorer accuracy (69.3%) when making same/different judgments on pairs of emotional prosody stimuli compared with controls (76.6% accuracy rate)($F[1,34] = 7.3$; $p < .05$) (Figure 2).

Accuracy was higher in the nonsense (76.2%) then filtered stimuli (69.7%) ($F[1,34] = 8.9$; $p < .01$), although this effect did not differ between groups ($p = .285$). An analysis for each emotion type on "same" trials only revealed no significant differences between groups in the recognition of different emotion types ($p > .10$).

There were no differences in MRT (Controls: 1.6 *vs*. TBI: 1.9 s; $p > .10$) or the probability of omissions (Controls: 2.8 *vs*. TBI: 2.2 %; $p > .5$).

Labeling Task

Participants with TBI (70.7% accuracy rate) had overall greater difficulty labeling emotional prosody compared with controls (86.5% accuracy rate) ($F[1,34] = 11.2$; $p < .01$) (Figure 3).

Across groups, participants were more accurate when judging semantic (84.9%) than nonsense stimuli (73.5%) ($F[1,34] = 24.7$; $p < .001$). A significant interaction with Group ($F[1,34] = 6.1$; $p < .05$) revealed that this effect occurred only in the TBI group. A significant Task effect revealed that participants were better at matching prosody to words (83.1%) than to faces (75.2%)($F[1,34] = 20.7$; $p < .001$), and this difference was greater for nonsense than semantic stimuli ($F[1,34] = 5.1$; $p < .05$). A Group × Task interaction was not significant ($p = .198$), although difficulty matching prosody to faces appeared greater in the TBI group.

Subsidiary analyses in the matching-to-words condition, with alpha adjusted for the number of comparisons ($\alpha < .0125$), revealed accuracy differed between groups for nonsense ($t[34] = 1.7$; $p < .01$) but not semantic stimuli ($p > .0125$). In the matching-to-faces condition, the groups differed for both nonsense ($t[34] = 3.2$; $p < .01$) and semantic stimuli ($t[34] = 2.8$; $p < .01$).

A significant main effect of Emotion-Type was found ($F[3,32] = 6.1$; $p < .01$), and this interacted with Group ($F[3,32] = 4.7$; $p < .01$) (Figure 4). Subsidiary analyses revealed group differences for happy ($F[1,34] = 19.3$; $p < .001$) and afraid ($F[1,34] = 10.1$; $p < .01$), but not angry ($p = .053$) or surprised ($p = .110$). Both groups performed most poorly when judging surprised. Anger was the easiest of the emotions for TBI participants to identify. There was also a tendency toward more accurate identification of negative than position valence emotions across groups ($F[1,34] = 3.4$; $p = .072$).

Mean reaction time was overall slower in the TBI (4.514 s) than control group (3.457 s)($F[1,33] = 13.7$; $p = .001$), with a tendency toward faster responses when matching emotional prosody with faces (3.9 s) rather than words (4.1 s) ($p = .116$). However, there were no interactions between task, condition, and group. There were also no differences in the probability of omissions committed between TBI (4.5%) and control (4.9%) groups ($p > .05$).

Discrimination *versus* Labeling

Nonsense stimuli were presented in both emotion tasks, therefore, a direct comparison could be made. TBI participants showed greater accuracy in the discrimination (71.3%) task compared with labeling (61.3%), while controls performed similarly across tasks (81.1% *vs*. 83.8%) ($F[1,34] = 10.6$; $p < .01$). Across all conditions, overall performance in the discrimination and labeling tasks was highly correlated ($r = .605$; $p < .001$), as were matching-to-labels and matching-to-faces within the labeling task ($r = .759$; $p < .001$).

Haylings Test

The TBI group scored lower than the control group on Haylings overall (Median score TBI: 3 *vs*. Controls: 6, $U = 22.5$; $p < .001$), inhibition response time (Median score TBI: 4 *vs*. Controls: 6, $U = 49.0$; $p < .001$) and inhibition error scores (Median score TBI: 2 *vs*. Controls: 7, $U = 58.5$; $p = .001$). Eleven TBI participants (and one control participant) obtained an abnormal score (i.e., 2 or less) for Haylings inhibition errors (Table 3)

Impulsivity

The TBI group self-reported greater impulsivity than the control group (73 *vs*. 63, $F[1,36] = 8.7$; $p<.01$). Sub-test scores revealed a significant difference in Nonplanning Impulsiveness (20 *vs*. 25, $F[1,36] = 11.2$; $p < .01$) and almost significant differences for Motor ($p = .083$) and Attentional Impulsiveness ($p = .084$).

Correlations Between Measures

Across groups, Haylings inhibition error rate was positively related with performance on both the discrimination ($r = 0.693$; $p < .001$) and labeling tasks ($r = 0.572$; $p < .001$). Inhibition error rate was also negatively related with Barratt's Nonplanning Impulsiveness ($r = -0.351$; $p < .05$). Impulsiveness scores did not correlate with accuracy scores on the emotion recognition tasks.

Table 3. Neuropsychological test scores for participants with TBI

ID	WTAR	FSIQ	Trails A	Trails B	WMS-III Faces I	WMS-III Logical Memory I	WAIS-III Similarities Verbal Subtest	WAIS-III Digit Span Verbal Subtest	WAIS-III Digit Symbol - Coding Performance Subtest	Haylings Overall Score	Haylings Initiation Reaction time	Haylings inhibition errors
1	122	113	58	110	11	9	7	11	6	1	3	1
2	116	109	42	112	15	11	10	11	8	3	4	2
5	122	115	49	120	8	13	7	6	4	2	1	5
6	120	116	69	126	9	8	9	10	10	1	2	4
7	123	113	33	55	6	12	13	9	6	3	5	1
8	89	93	118	220	7	8	16	7	—	1	4	2
9	103	106	101	275	5	2	8	9	3	2	4	1
10	68	78	50	163	9	8	9	8	7	5	6	3
11	97	98	43	89	10	9	7	7	5	5	6	6
15	110	113	33	76	7	11	10	17	8	4	6	2
21	110	103	29	54	9	16	10	11	9	3	5	1
22	104	102	65	100	9	11	10	9	5	3	6	2
23	119	116	26	42	13	11	11	14	11	6	6	7
24	123	113	41	59	12	10	11	15	7	5	3	8
25	—	—	27	106	13	8	8	6	7	3	4	4
27	96	97	81	238	8	7	9	7	2	1	1	1
28	96	97	61	106	6	14	9	9	6	1	1	2
31	114	113	48	90	10	9	7	8	5	4	5	2
TBI												
Mean	107.76	105.59	54.11*	118.94*	9.28	9.83	9.50	9.67	6.41*			
SD	15.05	10.42	25.41	65.51	2.72	3.07	2.31	3.09	3.27	2.86[1]	4.29	2.29
Control												
Mean	109.67	106.11	34.0	73.0	9.0	9.11	11.39	10.78	10.35			
SD	9.34	6.23	10.99	9.62	3.0	3.01	3.87	2.76	2.18	6.00	6.07	6.50

Note. WTAR = Wechsler Test of Adult Reading; Trails = Trail-Making Test A and B. All scores represent standard scores based on Wechsler manuals except Trails A and B which are presented as seconds taken to complete. *TBI significantly impaired relative to control group ($p < 0.05$).
[1]Haylings scaled scores whereby lower scores reflect poorer performance (see Burgess & Shallice, 1997), and group scores are expressed as medians.

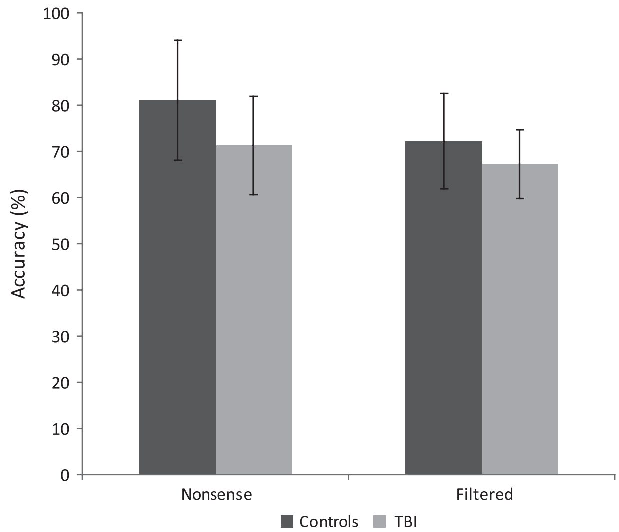

Fig. 2. Mean accuracy (%) and standard deviation (*SD*) of making same/different judgements in the nonsense and filtered conditions for each group; *y*-axis = 50–100%, bar = 1 *SD*. TBI, traumatic brain injury.

There was a positive relationship between two neuropsychological constructs, that is, working memory (Digit Span) and verbal comprehension (Similarities), and emotion labeling ($r = 0.520$; $p < .01$; $r = 0.413$; $p < .05$, respectively), but not discrimination (both $p > .05$). These significant effects remained after controlling for education. No other neuropsychological measures showed significant relationships with emotion perception accuracy. Notably, correlations between measures of RT and Symbol Digit-Coding or Trail Making Tests A and B were nonsignificant. Due to the relationship observed between working memory and the emotion recognition tasks, analyses were conducted with working memory as a covariate. Findings remained significant ($p < .05$).

Individual TBI Profiles

Despite a significant group difference in discrimination accuracy, only one TBI participant was impaired when judging

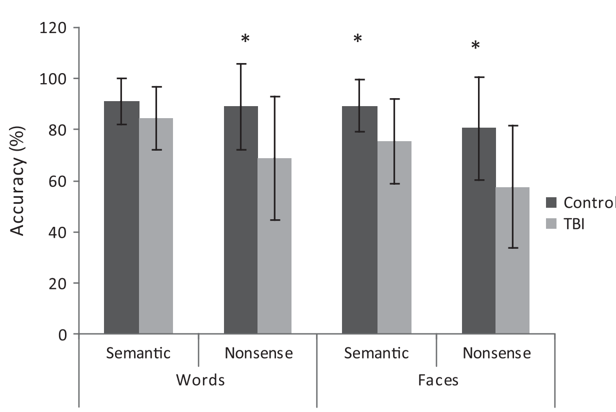

Fig. 3. Mean accuracy (%) and standard deviation (*SD*) when matching emotional prosody to words (left) and faces (right) in the semantic and nonsense conditions for each group. Significant group differences are indicated by asterisks; *y*-axis = 50–100%, bar = 1 *SD*. TBI, traumatic brain injury.

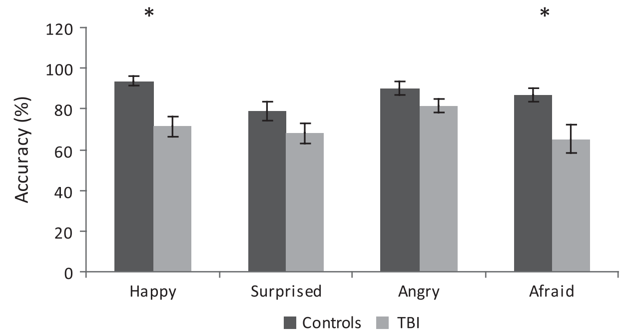

Fig. 4. Mean accuracy (%) and standard deviation (*SD*) of labeling emotional prosody for each emotion type in the control and traumatic brain injury (TBI) groups. Significant group differences for happy and afraid are indicated by asterisks; *y*-axis = 50–100%, bar = 1 *SD*.

nonsense stimuli and one participant was impaired when judging filtered stimuli; no participants were impaired on overall discrimination accuracy (Table 4). In the labeling task, nine participants were impaired in overall labeling accuracy. When matching emotional prosody to words, four were impaired in judging semantic stimuli and five when judging nonsense stimuli. When matching emotional prosody to faces, seven were impaired when judging semantic stimuli and seven when judging nonsense stimuli.

CT scans were available for 16 of the 18 TBI participants. As our group was heterogeneous in their injuries, we could not examine left versus right brain injuries (contrast: Pell & Baum, 1997; Pell, 2006). However, it was interesting to note that participants who were impaired on labeling were those with intracerebral and subdural hemorrhages, cerebral edema, or extensive injuries to the left or right temporal lobes. In contrast, while four participants presented with focal lesions in the right frontal region (Pts: 1, 8, 9, 11) only one was impaired on the labeling task.

Four TBI participants (Pts: 1, 8, 27, 28) had received emotion recognition training three years before testing (Bornhofen & McDonald, 2007), and three of these showed no impaired emotion recognition on the tasks. Thus, discrimination and labeling accuracy were re-analyzed excluding these four participants, as well as the partially deaf participant and five corresponding control participants. The significant group and condition effects remained.

Time since injury was unrelated to any performance measures ($p > .05$). The skewed distribution toward extremely severe injury (i.e., PTA > 28 days) meant a subgroup analysis for injury severity was not possible.

DISCUSSION

Participants with TBI were poorer at both discriminating and labeling emotional prosody, relative to non–brain-injured controls. Contradicting expectations, performance was not improved when there was little or no semantic information. Group differences were observed in both discrimination and

Table 4. Impaired performance of individuals with TBI in emotion discrimination, inhibition, and impulsivity measures

	Haylings test			Barratt's impulsiveness scale		Discrimination Task			Labeling Task - Words		Labeling Task - Faces		Labeling Task
Participant	Overall	Inhibition RT	Inhibition Errors	BIS Total	Non-Plan	F	N	Overall accuracy	S	N	S	N	Overall accuracy
1	**		**	**	**		**						
2			**							**	**	**	**
5	**			**	**				**	**		**	**
6	**	**				**			**	**	**	**	**
7			**								**	**	**
8	**		**	**	**								
9	**		**	**	**				**	**			**
10					**						**	**	**
11					**								
15			**	**	**								
21			**										
22			**						**		**		**
23													
24													
25										**	**	**	**
27	**	**	**								**	**	**
28	**	**	**										
31			**										

Note. Non-Plan = Non-Planning Sub-scale, F = Filtered stimuli, N = Nonsense stimuli, S = Semantic stimuli, ** = abnormal performance score falling below 2 *SD* of the control group's mean.

labeling tasks where semantic information was reduced (nonsense) or completely removed (filtered). In contrast, groups were similar when judging stimuli containing semantically biased information that helped identify the emotional intent.

It is possible that removing semantic information did not have the intended effect of reducing semantic bias, but rather made individuals search harder for this content (Beaucousin, Lacheret, Turbelin, Morel, Mazoyer, & Tzourio-Mazoyer, 2007; Kotz et al., 2003; Meyer, Alter, Friederici, Lohmann, & Von Cramon, 2002). While we cannot determine this, our results highlight the importance in both healthy and TBI participants of semantic content over prosodic information (Pell & Baum, 1997; Pell, 2006), in line with a semantic processing bias (Besson et al., 2002; Grimshaw, 1998; Jerger et al., 1993; Wambacq & Jerger, 2004).

Although TBI performance in the discrimination task was poorer compared with controls, individual participants were not abnormally poor. Same/different discrimination is believed to involve automatic emotion recognition, mediated by the ventral frontal–subcortical circuit (Adolphs, 2002; Kotz et al., 2003; Pell & Leonard, 2003). In our study this ability, while less effective in TBI participants, was not wholly impaired. In contrast, half the TBI group was impaired when making semantic judgments about emotional prosody stimuli. This is consistent with research showing that labeling emotions is more demanding for brain injured individuals than making same/different discriminations (Ietswaart et al., 2008; Pell, 2006; Tompkins & Flowers, 1985) because it requires effortful access of semantic memory, linked with the dorsolateral prefrontal cortex (Adolphs, 2002). This interpretation fits with the association found between working memory and performance on the labeling but not discrimination task. Even so, working memory did not entirely account for group differences which remained when memory was controlled. Rather, a process common to discrimination and labeling (which were highly inter-correlated) appears to be responsible. Overall, our findings suggest that automatic emotion recognition is reduced in effectiveness following TBI, and that increased semantic emotion memory demands cause further impairment.

The TBI individuals were selectively impaired when labeling some emotions (i.e., happy, afraid) but not others (e.g., pleasantly surprised, angry). Pleasantly surprised was difficult for both groups, while anger was easiest for the TBI group. Spell and Frank (2000) also found TBI adults were impaired when judging fear and accurate when judging angry voices, but in contrast to us, they found that happy was well recognized (Spell & Frank, 2000). No differences in accuracy for different emotions were found in the discrimination task. This is in line with the suggestion of Ietswaart et al. (2008) that TBI may selectively impair the semantic component of emotion identification, rather than automatic emotion discrimination *per se*. The salience and distinctiveness of prosodic cues may be essential for effortful-semantic categorization of emotion following TBI. Enhancing some prosodic parameters may, therefore, improve accuracy.

Our TBI participants showed a 9% drop in accuracy when matching semantic prosody to faces rather than words (compared with 2% for controls) and this effect tended toward significance. At an individual level, five participants were impaired when matching semantic prosody to faces but not when matching to words, despite the fact that semantic labels were always visible. This suggests that, for these participants, presence of facial information degraded evaluation of prosody. Neuroimaging has shown that the supratemporal auditory cortex, normally activated to audio-only stimuli, becomes suppressed during audiovisual presentations (Besle, Fort, Delpeuch, & Giard, 2004). McDonald and Saunders (2005) also found more individuals were impaired judging audiovisual than audio-only or visual-only displays of emotion. Clearly further research is needed to examine how bimodal emotion cues of emotion are integrated. This appears to be a unique deficit in some adults with TBI (McDonald & Saunders, 2005).

The heterogeneous make-up of the TBI participants limits discussion of neural correlates. However, it is interesting to note that three of the four participants presenting with focal lesions in the right frontal region (Pts: 1, 8, 11) were not impaired on any emotion recognition tasks, supporting a view of bilateral contributions to emotion processing (Baum & Pell, 1999; Pell & Baum, 1997; Pell, 2006; Schlanger et al., 1976). Given that emotional prosody recognition is a highly integrative process and past studies have not found a correlation between focal injuries in TBI and emotion perception impairment (Green et al., 2004; Ietswaart et al., 2008), future studies should examine the role of diffuse axonal injury.

Consistent with past studies (Dujardin et al., 2004; Uekermann et al., 2005), the TBI group had poor inhibitory control compared with controls and this was associated with poor emotion discrimination and labeling. This highlights the neuroantomical and functional inter-relatedness of these domains (Damasio, 1994; Oschner & Barrett, 2001; Phillips et al., 2003). This relationship did not extend to self-reported trait impulsiveness, which was related to inhibitory control but not emotion recognition. Trait impulsivity may measure a facet of impulsivity that is not relevant to emotion regulation.

In terms of limitations, we cannot exclude the possibility that acoustic deficits affected prosody perception, although differential performance across tasks makes this unlikely. Our sample of people with TBI was selected from those manifesting social difficulties during rehabilitation, so our conclusions do not apply to the general TBI population. Nonetheless, given that changes in social function are prevalent, seen in as many as 80% of adults years after their injuries (Brooks et al., 1986; Thomsen et al., 1984), our findings are likely to apply to a substantial proportion of those with severe TBI. Indeed, the kinds of social problems described of our TBI participants are typical, reflecting withdrawn, inert behavior, rigid thinking, garrulous disinhibited social interactions, and/or general inefficiency processing conversation (Hartley and Jensen, 1992; Lezak, 1978; Thomsen, 1984). Self-reported deficits should be treated with caution as adults with TBI may have limited insight into their behavior, although this should lead to an underestimation of reported deficits. The extent to which difficulties with prosody contributes to these deficits awaits further examination. Our group included some who had received specific remediation of emotion perception which may have affected our findings although a re-analysis of the data without these four participants did not alter the pattern of results.

In conclusion, we found an impairment of recognizing emotional prosody may contribute to social skills deficits many years following a TBI. Automatic discrimination of emotional prosody was impaired, although not abnormally so, while additional effortful accessing of semantic memory led to significantly impaired performance in at least half the group. Our results did *not* support our hypothesis that the dual demands of processing the *"what"* and "*how"* in vocal speech underpins poor performance. Indeed, the participants in this study relied upon the *"what"* to recognize vocal emotion. Without this, they were significantly impaired, suggesting problems processing emotional prosody per se. Differences between emotion types suggest that manipulating salience of prosodic cues may be a way to improve vocal emotion recognition.

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