

**Hyposmia, not emotion perception, is associated with psychosocial outcome after severe
traumatic brain injury**

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Abstract

Objective: The current study aimed to determine whether two variables associated with orbitofrontal damage, hyposmia and emotion perception deficits, are associated with socially disinhibited behaviour and psychosocial outcome after traumatic brain injury (TBI).

Methods: The *Brief Smell Identification Test* (BSIT), an emotion labelling task and an emotion intensity rating task, and an observational measure of social disinhibition were completed by 23 individuals with severe TBI. The disinhibition domain of the *Neuropsychiatric Inventory* (NPI-D) and the interpersonal relationships subscale of the *Sydney Psychosocial Reintegration Scale* (SPRS-IR) were completed by a close other. Fifteen control participants provided norms against which to assess performance on the emotion intensity rating task.

Results: BSIT scores predicted informant-reported change in interpersonal relationships on the SPRS-IR. Hyposmia, though, was not associated with informant-reported or observed social disinhibition. An impairment in accuracy scores on both emotion perceptions tasks was found for participants with TBI, yet intensity ratings did not differ between groups suggesting that people with TBI are not actually impaired at detecting intensity of emotion but are less likely to perceive the target emotion as the dominant one. Emotion perception was not related to disinhibition or change in interpersonal relationships.

Conclusions: These results support previous claims that hyposmia has prognostic significance following TBI. On the other hand, emotion perception impairment measured by standardised tasks does not appear to be an important factor in interpersonal outcomes. Finally, these results suggest that standardised emotion perception tasks may underestimate the emotion perception capabilities of people with TBI.

Keywords: Traumatic brain injury (TBI), head injury, social disinhibition, socially inappropriate behaviour, hyposmia, smell deficit, emotion perception, emotion recognition

26 Social disinhibition, the inability to inhibit socially inappropriate behaviours, is a
27 commonly experienced outcome of traumatic brain injury (TBI) and likely contributes to
28 commonly reported problems with social relationships, community reintegration and
29 employment after TBI (Brooks, Campsie, Symington, Beattie, & McKinlay, 1986; McKinlay,
30 Brooks, Bond, Martinage, & Marshall, 1981; Winkler, Unsworth, & Sloan, 2006). Social
31 disinhibition after TBI is thought to result from damage to the orbitofrontal cortex (Namiki et
32 al., 2008), an area of the brain known to be particularly susceptible to damage in TBI (Levin
33 & Kraus, 1994). Despite this, there is little research that has examined the neuropsychological
34 correlates of social disinhibition in TBI. While numerous studies have focused on
35 impairments associated with general social outcomes after TBI, none have investigated those
36 associated with social disinhibition specifically. The current study aimed to determine
37 whether two variables also associated with orbitofrontal damage, hyposmia and emotion
38 perception deficits are associated with socially disinhibited behaviour after TBI. The first
39 might be anticipated to correlate simply on the basis of proximity of neural substrate while
40 the latter may also play a causative role. Examining these relationships potentially serves two
41 roles; identification of simple tests that could be used to indicate when an individual is at risk
42 of developing this debilitating syndrome and shedding light on mechanisms that underlie
43 social disinhibition and thus aid in targeting rehabilitation.

44 **Hyposmia**

45 TBI can result in the shearing of, or abrasive injury to, the olfactory nerves causing
46 partial or total loss of smell, known as hyposmia and anosmia respectively. This damage to
47 the olfactory nerve is typically associated with contusions and lacerations of the surrounding
48 orbital frontal cortical areas (Jennett & Teasdale, 1981) leading researchers to suggest that
49 anosmia can be used as an indicator of orbitofrontal damage following brain injury (Varney,
50 1988). Recent research has repeatedly demonstrated this association (for a review see

51 Roberts, Sheehan, Thurber, & Roberts, 2010). As an indicator of orbitofrontal damage, then,
52 it might be expected that hyposmia would be associated with socially disinhibited behaviour
53 following TBI, which likely results from damage to the same brain region. Although research
54 has not investigated this link directly, a number of studies have focused on the ability of
55 hyposmia to predict related psychosocial outcome, such as employment difficulties. Varney
56 (1988) found that of a group of brain injured participants with total anosmia, 92% showed
57 chronic unemployment problems despite having normal physical health and adequate
58 intellectual and mnemonic resources. The patients often reported that these employment
59 problems stemmed from an inability to get along socially with co-workers and supervisors,
60 among other problems. On the basis of this finding, Varney (1988) suggested posttraumatic
61 anosmia, as a sign of orbitofrontal damage, has prognostic significance in closed head injury.
62 In a partial replication of this study, Martzke, Swan, and Varney (1991) reported a rate of
63 80% vocational dysfunction among people with head injuries and anosmia.

64 More recent studies, however, have failed to replicate this result, generally finding
65 that those with post-traumatic anosmia do not have different occupational outcomes to those
66 without anosmia (Correia, Faust, & Doty, 2001; Crowe & Crowe, 2013). Correia et al. (2001)
67 found that only one of a group of fifteen patients with mild TBI and anosmia reported chronic
68 unemployment problems, using the same criteria as Varney. Another study found no
69 difference between an anosmic and a nonanosmic group of TBI patients of varying severity in
70 employment status after injury (Crowe & Crowe, 2013). Further the review by Roberts et al.
71 (2010) concluded that there was not enough data on real world outcomes, such as vocational
72 dysfunction, to draw conclusions about whether post-traumatic anosmia has ecological
73 validity as an indicator of poor psychosocial prognosis.

74 Other studies have focused on investigating associations between smell identification
75 and neuropsychological tests of disinhibition, with mixed results. In one study, patients with

76 TBI and anosmia made more errors on the Controlled Oral Word Association Test (COWAT)
77 than did matched patients (Crowe, 1996). However, these errors mainly constituted repeats of
78 previously presented words, rather than neologism or other rule breaks. Another study found
79 olfactory dysfunction was related to inhibition of prepotent verbal responses on the Color-
80 Word Interference Test (CWIT), and to response inhibition and flexibility as assessed by
81 verbal fluency tasks (Sigurdardottir, Jerstad, Andelic, Roe, & Schanke, 2010). Crowe and
82 Crowe (2013), on the other hand, did not find any differences between patients with TBI with
83 and without anosmia on errors or disinhibited responding on a number of neuropsychological
84 measures. Overall, while some studies have found associations between hyposmia and
85 disinhibition assessed by formal tests, and others have found associations between hyposmia
86 and psychosocial outcomes such as employment difficulties, no studies have specifically
87 investigated whether post-traumatic hyposmia is associated with socially disinhibited
88 behaviours after TBI. This was the first aim of the current study.

89 **Emotion Perception Deficits**

90 Emotion perception refers to the ability to perceive and understand affective
91 information from facial expressions, emotional prosody and body posture (Bornhofen &
92 Mcdonald, 2008) all of which are critical to social competence. Emotion perception deficits
93 are common after TBI (for a review see Bornhofen & Mcdonald, 2008) and have been linked
94 specifically to orbitofrontal damage (Barrash, Tranel, & Anderson, 2000; Blair, Morris, Frith,
95 Perrett, & Dolan, 1999; Heberlein, Padon, Gillihan, Farah, & Fellows, 2008). Studies have
96 demonstrated this impairment after TBI both acutely and several years post-injury (Borgaro,
97 Prigatano, Kwasnica, Alcott, & Cutter, 2004; Green, Turner, & Thompson, 2004). Further,
98 Ietswaart, Milders, Crawford, Currie, and Scott (2008) examined longitudinal changes in
99 emotion perception deficits after TBI and found that impairments persisted at one-year

100 follow-up, suggesting that deficits are stable overtime and likely the result of brain damage
101 rather than secondary factors such as depression developing after brain injury.

102 Not only do emotion perception deficits and social disinhibition share the same
103 underlying neuropathology, there is good reason to suggest a functional relationship between
104 the two. Since facial and vocal expressions of emotion can act as social rewards or
105 punishments, impairment in the ability to recognise these emotions has clear implications for
106 social behaviour and learning. Outside the domain of TBI research, emotion perception
107 impairments have been linked with impairment in social functioning. For example, normal
108 adults who are poor at reading social cues also demonstrate poor social skills (Morrison &
109 Bellack, 1981; Trower, 1980). Further, poor emotion perception in children has been related
110 to poor social adjustment (Leppanen & Hietanen, 2001). Evidence from clinical groups,
111 including schizophrenia (Hooker & Park, 2002; Sergi, Rassovsky, Nuechterlein, & Green,
112 2006), autism (Boraston, Blakemore, Chilvers, & Skuse, 2007), and children with ADHD
113 characteristics (Kats-Gold, Besser, & Priel, 2007), has also demonstrated an association
114 between emotion perception deficits and social functioning.

115 Despite these clear associations in other clinical groups, research investigating the
116 link between emotion perception and social functioning following TBI has had mixed results.
117 Spikman et al. (2013) found that impaired emotion recognition, particularly of sad and angry
118 expressions, was related to informant-reported behavioural problems on the Dysexectuvie
119 Questionnaire. Similarly, Watts and Douglas (2006) found a correlation between impairment
120 in interpretation of facial emotion after TBI and informant-rated communication competence.
121 Another study found a relationship between facial emotion recognition and social integration
122 after controlling for cognitive factors (Knox & Douglas, 2009). Further, McDonald,
123 Flanagan, Martin, and Saunders (2004) found that emotion recognition was related to the
124 ability to use humour appropriately in a social context, as rated from a videotaped interaction.

125 These findings suggest that impaired recognition of facial emotion after TBI reduces the
126 capacity to respond appropriately in social interactions. Conversely, though, Milders and
127 colleagues (Milders, Fuchs, & Crawford, 2003; Milders, Ietswaart, Crawford, & Currie,
128 2008) failed to find any significant relationships between recognition of facial or vocal
129 emotion after TBI and a number of different questionnaires designed to assess emotional and
130 behavioural functioning of neurological patients. Further, Beer, Heerey, Keltner, Scabini, and
131 Knight (2003) found inappropriate social behaviour in participants with orbitofrontal damage,
132 despite evidence of intact recognition of basic facial expressions. Thus, the findings of
133 studies investigating the relationship between emotion perception deficits and social
134 competence have been inconsistent.

135 One reason for this inconsistency may be the nature of the emotion perceptions tasks
136 used. Previous studies have tended to use forced-choice recognition tasks to assess emotion
137 perception deficits. In such tasks, participants must choose the correct label for the presented
138 emotion among provided alternatives. These types of emotion perception tasks may not
139 represent an ecologically valid measure of the emotion perception deficits which impact upon
140 social behaviour, since providing a verbal label for an expressed emotion is not a usual
141 requirement in social interactions. Furthermore, in everyday interactions a given emotion
142 may be expressed fleetingly, subtly, or in combination with others, requiring judgments of its
143 relative intensity and salience. Another source of inconsistency might arise from the wide
144 range of outcome measures used to measure the construct of social competence. The current
145 study sought to address these potential issues by examining detection of emotional intensity
146 as well as conventional emotion labelling and by determining whether emotion perception
147 deficits are associated with socially disinhibited behaviour specifically, rather than social
148 competence more broadly.

149 Thus, this study investigated whether two variables, impaired sense of smell and
150 impaired emotion perception, both associated with orbitofrontal damage, were related to
151 social disinhibition specifically and psychosocial outcome more broadly following severe
152 TBI. It was hypothesised that impaired smell and impaired emotion perception, as measured
153 by both a labelling task and an intensity rating task would be associated with disinhibited
154 behaviours observed in the laboratory, informant-rated social disinhibition and also
155 informant-rated psychosocial outcome.

156 Method

157 Participants

158 Participants were 23 individuals (18 male) who had sustained severe TBI of mean age
159 45.43 years ($SD=15.44$, range: 22 - 69) and with an average of 13.61 years of formal
160 education ($SD=2.74$, range: 9 - 22). Participants were recruited from the outpatient records of
161 three metropolitan brain injury units in Sydney. The TBI group had a mean post-traumatic
162 amnesia of 67.43 days ($SD=44.22$, range: 12 – 189 days) and were, on average, 14.59 years
163 post injury when tested ($SD=11.05$, range: 2 – 45 years). TBIs were caused by motor vehicle
164 accidents ($n=14$), falls ($n=6$) and assaults ($n=2$). Demographics of the TBI group are outlined
165 in Table 1. Their performance on standard neuropsychological tests measuring new learning
166 (Logical Memory I from the Wechsler Memory Scale III) processing speed (Digit Symbol
167 subtest from the Wechsler Adult Intelligence Scale III: WAISIII; Trails A) and attention
168 (Digit Span subtest from the WAISIII, Trails B) is outlined in Table 2. As can be seen, the
169 TBI participants were, on average, within the average range on Wechsler subtests.

170 Tables 1 and 2 about here

171 Additionally, there were 15 control participants (12 males) with a mean age of 42.67 years
172 ($SD=15.27$, range: 20 - 63) and an average of 14.87 years of formal education ($SD=1.69$,
173 range: 12 - 18) who also undertook the emotion intensity task and the smell test. Controls

174 were recruited from the community via online and local newspaper advertisements.
175 Participants with a TBI did not differ significantly from controls with respect to age, $t(36)=-$
176 $.54, p=.591$, or number of years of formal education completed, $t(36)=1.58, p=.123$.

177 **Materials**

178 **Measures of emotion perception**

179 Two tasks were included to measure emotion perception, one designed to measure
180 sensitivity to emotional intensity and the other, a more conventional emotion labelling task
181 using naturalistic audiovisual displays.

182 *Emotion Recognition Intensity Rating Task*

183 Stimuli were 21 static images of one of four actors (two male and two female)
184 portraying one of six emotions (happiness, surprise, sadness, anger, fear and disgust), or a
185 neutral expression. The stimuli were still images taken from the emotion recognition task
186 (ERT; Montagne, Kessels, De Haan, & Perrett, 2007), a computer-generated program which
187 shows a series of 216 video clips of facial expressions across different intensities. The stimuli
188 were developed using algorithms (Benson & Perrett, 1991) which created intermediate
189 morphed images between a neutral face (0% emotion) and a full-intensity expression (100%
190 emotion). Data from a study by Rosenberg, McDonald, Dethier, Kessels, and Westbrook
191 (2014) which used the ERT video stimuli suggest that fear, sadness and surprise are the most
192 difficult emotions to recognise for controls, while happiness is exceptionally easy to
193 recognise. Thus, in order to avoid floor and ceiling effects in recognition of emotion in the
194 current study, 100% intensity of expression was used for fear, sadness and surprise stimuli,
195 80% intensity of expression was used for anger and disgust stimuli, while 30% intensity was
196 used for happy stimuli.

197 Following the protocol of Heberlein et al. (2008), participants were asked to rate each
198 facial expression for how intensely each of the six basic emotions were expressed on six

199 corresponding scales from 0 (none of the specified emotion detected) to 10 (an intense
200 amount of the specified emotion detected). Thus, for each stimulus, participants provided six
201 ratings of intensity (corresponding to six emotions) before proceeding to the next stimulus.
202 For each participant, three scores were derived for each emotional category.

203 The emotion intensity score measured *general sensitivity to the intensity of the target*
204 *emotion* and was corrected for baseline biases in participant rating tendencies. To calculate
205 the emotion intensity score, following Adolphs and Tranel (2004) and Heberlein et al. (2008),
206 the mean intensity rating provided for target emotion on the corresponding scale was first
207 calculated for each participant. The mean intensity rating provided for 3 neutral stimuli was
208 then subtracted. For example, the emotion intensity score for happiness would be calculated
209 by deriving the mean happiness rating provided for the 3 happy stimuli and subtracting the
210 mean happiness rating provided for the 3 neutral stimuli. This created a simple measure of the
211 detected intensity for each emotion, adjusted for any baseline biases in participants' rating
212 tendencies.

213 The difference score measured *differential sensitivity to the target emotion*. The
214 difference score was the mean difference between the intensity rating provided for the target
215 emotion and the next highest intensity rating provided for that stimulus. For example, the
216 difference score for happiness would be calculated by averaging the difference between the
217 happiness rating provided and the next highest rating provided for each of the 3 happy
218 stimuli. Thus, this difference score was a measure of the participants' ability to differentiate
219 the target emotion from other emotions in each stimulus. More positive scores indicated
220 greater ability to differentiate the target emotion and more negative scores indicated that the
221 participant had confused the target emotion for another emotion.

222 Finally, an overall score measured the *overall accuracy in detecting the target*
223 *emotion*. This score was derived for each participant by counting the number of trials on

224 which the target emotion (the emotion actually expressed by the actor in the photograph) was
225 given the highest intensity rating. This was a score out of 18, as there were 18 non-neutral
226 stimuli.

227 ***The Awareness of Social Inference Test (TASIT) – Emotion Evaluation Test (EET)***

228 TASIT (McDonald, Flanagan, Rollins, & Kinch, 2003) is an audiovisual clinical
229 assessment tool designed to measure social perception in a TBI population. Part one, the
230 EET, measures recognition of basic emotions and comprises 28 short video vignettes in
231 which a professional actor engages in an everyday interaction. The target actor in each
232 vignette enacts a neutral script according to one of six basic emotions – happiness, surprise,
233 fear, anger, sadness or disgust – or no particular emotion. Participants were asked to decide
234 from a list of alternatives which of these emotions was expressed. Participants' EET scores
235 represented the total number correct. The test-retest reliability of the EET has been reported
236 as .74 (McDonald et al., 2006).

237 **Brief Smell Identification Test (BSIT)**

238 The BSIT (Doty, Marcus, & Lee, 1996) is a 12 item test of olfactory function. The 12
239 different odourants are embedded in ureaformaldehyde polymer microcapsules and are
240 released by scratching the odour strips with a pencil. For each odourant, participants are
241 asked to identify which of the four provided response options the odour smells most like.
242 Norms provided for this test allow the administrator to determine whether a smell deficit is
243 present relative to individuals of the same sex and age. This deficit is defined by scoring
244 below the 5th percentile of those of the same sex and in the same 5 year age bracket. The test-
245 retest reliability coefficient of the BSIT has been reported as .71 (Doty, McKeown, Lee, &
246 Shaman, 1995). Prior to administration of the BSIT, participants were asked if they were
247 aware of having any problems with their sense of smell and a yes or no response was
248 recorded for this question.

249 **Measures of social disinhibition**

250 Two measures of social disinhibition were included, one involved observing
251 behaviour directly while the other was an informant-based questionnaire.

252 ***Observational Measure of Social Disinhibition***

253 The current study used an adaptation of the self-disclosure task developed by Beer,
254 John, Scabini, and Knight (2006). Participants were initially told that they would be asked a
255 number of questions about themselves and their experiences, it was their choice how much
256 information they wished to disclose and they could skip any question at any time. These
257 instructions were designed to minimise an expectation of excessive self-disclosure.
258 Participants were then asked a series of nine questions, which included: “Tell me about an
259 embarrassing moment you’ve had” and “Tell me about something someone has done to make
260 you angry”. The interviews were videotaped and rated by two independent judges, blind to
261 whether the participant had sustained a TBI or was a control. Judges rated the frequency of
262 each participant’s socially inappropriate behaviour on a scale of 1 to 5 (1 =‘never’ and 5
263 =‘always’) on items such as: ‘While talking with the interviewer, the participant spoke too
264 candidly’, ‘The participant made inappropriate jokes or remarks’, ‘The participant did not
265 know when to stop talking’. Thus, the disinhibition ratings can range from 8 to 40. The
266 judges were trained in the use of the rating scales on five practice recordings, which were not
267 used in the final data analyses. The length of the interview varied depending on the
268 participant but no interview ran longer than 15 minutes. The judges were asked to watch each
269 recording in full before providing a rating for each of the 8 statements before moving onto the
270 next recording. The inter-rater absolute agreement was acceptable (Barker, Pistrang, & Elliot,
271 1994), $\alpha=.69$, and so an average of the two ratings for each participant was calculated and
272 was used in all analyses that follow.

273 ***Neuropsychiatric Inventory Disinhibition Domain (NPI-D)***

274 The NPI (Cummings et al., 1994) uses informant ratings to evaluate neurobehavioural
275 disturbances across 12 domains. For each domain, a screening question determines whether
276 problems in that domain are present and is followed by seven to nine questions which address
277 specific symptoms. The informant then rates the severity and frequency of behaviours as well
278 as the level of distress caused by these symptoms. Only the disinhibition domain was of
279 interest in this study. The NPI has well-established psychometric properties including an
280 overall Cronbach's alpha of .88, inter-rater agreement ranging from 93.6% to 100% for
281 different behaviours, and a 3-week test-retest reliability estimate of .79 for frequency scores
282 and .86 for severity scores (Cummings, 1997; Cummings et al., 1994). Since its initial
283 validation in dementia patients, the NPI has been used to successfully describe
284 neuropsychiatric symptoms after TBI (Cantagallo & Dimarco, 2002; Ciurli, Formisano,
285 Bivona, Cantagallo, & Angelelli, 2011; Monsalve, Guitart, Lopez, Vilasar, & Quemada,
286 2012). For use in a TBI population, it has the advantage of being developed and normed
287 especially for individuals with neurological impairment. The current study did not use the
288 screening questions but rather had all caregivers complete the full form. This approach was
289 recommended by Kilmer et al. (2006) who found a high false negative rate for the
290 disinhibition subscale, such that caregivers who did not endorse the screening item went on to
291 endorse a number of metric items. The severity scale was adjusted to include a 'not
292 applicable – disinhibition not present' response item to reflect this. A NPI-D total score was
293 derived by adding the frequency, severity and distress scores for each participant. Informants
294 were a family member or close friend who knew the participant well both before the injury
295 and after the injury. Of the 23 participants with a TBI in the current study, data for the NPI-D
296 was only available for 21 participants.

297 **Sydney Psychosocial Reintegration Scale - Interpersonal Relationship Scale**
298 **(SPRS-IR)**

299 Finally, the Sydney Psychosocial Reintegration Scale 2 Form A (Tate, Hodgkinson,
300 Veerabangsa, & Maggiotto, 1999) was completed by a relative or close friend of each TBI
301 participant to provide a measure of broad psychosocial outcome. The SPRS-2 was designed
302 to measure reintegration of people after a TBI in three domains; occupation, interpersonal
303 relationships and independent living skills. In each domain there are four items which
304 measure level of change in a particular behaviour or activity since the injury. Response items
305 range from 0 (an extreme amount of change) to 4 (no change at all). Total scores for each
306 domain range from zero to 16, with higher scores representing better levels of psychosocial
307 reintegration. The current study was only concerned with the interpersonal relationships scale
308 of the SPRS. Form A of the SPRS-2 has good psychometric properties, with high inter-rater
309 reliability, intraclass correlation (ICC)=.95, and one-week test-retest reliability (ICC=.90), as
310 well as good concurrent validity with the London Handicap Scale ($r_s=-.85$) (Tate et al., 1999).
311 The SPRS-2 was completed by the same informant who completed the NPI-D. Of the 23
312 participants with a TBI in the current study, SPRS-IR data was only available for 22
313 participants.

314 **Procedures**

315 All participants were informed of the study procedures and gave informed written
316 consent to participant in the study. The procedures were approved by the Human Research
317 Ethics Committee of the Sydney South West Area Health Service (Royal Prince Alfred
318 Hospital Zone) and were conducted at the neuropsychology laboratory at the University of
319 New South Wales. In a single visit, participants with TBI were administered the observation
320 measures, the emotion intensity rating task, the BSIT and the DASS. On this visit they were
321 given a package of questionnaires, which included the NPI and SPRS as well as other
322 measures not used for this study, to be filled out by a family member or close friend who had
323 known the participant since before their injury. Thus, the same caregiver provided both the

324 NPI and the SPRS ratings. The TASIT had been administered to all participants on a previous
325 visit no longer than two years prior. Controls were administered the BSIT and the emotion
326 intensity rating task on a single visit.

327 **Results**

328 **Hyposmia**

329 Of the 23 individuals with TBI tested, eight (35%) were identified by the BSIT as
330 having a smell deficit relative to others of the same gender and age. This compared to two of
331 the 15 (13%) control participants who were identified as having a smell deficit. Of the eight
332 TBI participants with hyposmia, only three were aware of having any trouble with their sense
333 of smell.

334 A hierarchical multiple regression was run using participants with TBI to determine if
335 the addition of BSIT score improved the prediction of change in interpersonal relationships
336 on the SPRS above age, post traumatic amnesia and time since injury. Results can be
337 observed in Table 3.

338 Table 3 about here

339 The full model of BSIT score, PTA, TSI and age to predict SPRS-IR was significant, $R^2=.44$,
340 $F(3, 20)=3.19$, $p=.032$, adjusted $R^2=.31$. The addition of BSIT score led to a significant
341 increase in R^2 of .27, $F(1,16)=7.75$, $p=.013$. Similar models conducted to determine whether
342 BSIT scores could predict observed disinhibition or informant reported disinhibition above
343 age, PTA and TSI revealed no significant results.

344 **Emotion Recognition**

345 Table 4 provides means and standard deviations for all emotion perception scores for
346 both groups.

347 Table 4 about here. *General sensitivity to intensity of target emotion*

348 A repeated measures ANOVA (emotion category by group) was conducted to
349 determine whether participants with TBI rated emotions as being expressed with less
350 intensity than did controls. There was no significant effect of group, $F(1,36)=.18, p=.678$, and
351 no significant interaction, $F(5,180)=.78, p=.562$. There was, however, a significant main
352 effect of emotional category, $F(5,180)=13.34, p<.001$. Pairwise comparisons with Bonferroni
353 adjustment for multiple comparisons revealed a general pattern showing that happy and sad
354 were rated as less intense than the other four emotions, which can be observed in Table 4.

355 *Differential sensitivity to intensity of target emotion*

356 Difference scores for each emotional category are detailed in Table 4. A repeated
357 measures ANOVA (emotion category by group) was conducted to determine whether
358 participants with TBI were impaired at differentiating emotions compared with controls.
359 There was no significant effect of group, $F(1,36)=1.86, p=.181$, and no significant
360 interaction, $F(5,180)=1.01, p=.415$. There was, however, a significant main effect of
361 emotional category, $F(5,180)=19.94, p<.001$. Pairwise comparisons with Bonferroni
362 adjustment for multiple comparisons revealed a general pattern showing that happy and
363 disgust were the most well differentiated emotions while fear was the least well
364 differentiated.

365 *Overall accuracy in detecting target emotion*

366 A Levene's test for equality of variance revealed that the group of participants with
367 TBI had a larger variance in overall accuracy scores ($SD=3.12$) than did the control group
368 ($SD=1.54$), $F(1,37)=7.61, p=.009$. An independent samples t-test with equal variances not
369 assumed revealed that TBI participants scored significantly lower overall ($M=11.09$) than did
370 control participants ($M=12.80$), $t(36)=2.063, p=.046$, as shown in Table 4.

371 *Accuracy on TASIT*

372 The performance of the group with TBI on TASIT was compared to the normative
373 data provided by McDonald et al. (2003). A one sample t-test revealed that the mean TASIT
374 EET score for the TBI group ($M=22.05$, $SD=5.03$) was significantly poorer than the mean
375 ($M=24.86$, $SD=2.11$) for a group of 169 normal adults, $t(20)=-2.57$, $p=.018$, as shown in
376 Table 4.

377 *Relationships between emotion perception and disinhibition/psychosocial outcome*

378 In the TBI group, Pearson correlations were performed to determine whether impaired
379 emotion perception was related to observed or reported disinhibition or change in
380 interpersonal relationships since injury. For emotion intensity ratings, a mean z-score
381 representing overall accuracy was created. This was derived by converting the average
382 emotion intensity score across all emotional categories to a z-score, using the control mean
383 and standard deviation. This was taken as an index of the level of deficit in the ability to
384 detect emotion intensity relative to control participants. Neither observed disinhibition,
385 informant-reported disinhibition nor informant-reported change in interpersonal relationships
386 were significantly correlated with any of the intensity z-scores. In addition, the overall
387 accuracy score was not significantly related to observed disinhibition ($r=.11$, $p=.619$),
388 informant-reported disinhibition ($r=.036$, $p=.876$) or informant-reported change in
389 interpersonal relationships ($r=.04$, $p=.845$). Similar correlations were conducted to examine
390 the relationship between overall emotion recognition as measured by TASIT. TASIT EET
391 scores were not significantly related to observed disinhibition ($r=.35$, $p=.117$), informant-
392 reported disinhibition on the NPI-D ($r=.38$, $p=.114$), or informant-reported change in
393 interpersonal relationships on the SPRS ($r=-.34$, $p=.143$).

394 **Discussion**

395 The current study sought to determine whether two variables associated with
396 orbitofrontal damage, hyposmia and emotion perception deficits, are associated with socially

397 disinhibited behaviour and resulting problems with interpersonal relationships following
398 traumatic brain injury. It was found that while hyposmia was associated with interpersonal
399 problems, but not disinhibited behaviour, emotion perception deficits were not related to
400 either socially disinhibited behaviour or interpersonal problems,.

401 **Hyposmia**

402 The current study found that eight of the 23 individuals with TBI (35%) had hyposmia
403 with only three of those participants aware of having any difficulties with their smell. Due to
404 sampling bias and methodological variations in published studies, the true incidence of post-
405 traumatic hyposmia has been difficult to ascertain. Reported incidence rates among studies
406 utilising modern standardised olfactory function tests vary greatly, ranging from 13% to 69%
407 across all severity levels of TBI (for a recent review see Schofield, Moore, & Gardner, 2014).
408 This variability may arise from differences in methods of olfactory testing, sampling biases
409 and differences in spectrums of TBI severity within study samples (Haxel, Grant, & Mackay-
410 Sim, 2008). Of the two studies investigating anosmia among patients with a severe TBI, one
411 reported an incidence rate of 61% (Callahan & Hinkebein, 2002), while the other reported
412 33% (Sigurdardottir et al., 2010), the latter being consistent with the rate observed in the
413 current study. Additionally the current data supports previous findings that many post-
414 traumatic hyposmics are unaware of their olfactory deficits (Callahan & Hinkebein, 1999,
415 2002; Fortin, Lefebvre, & Ptito, 2010), illuminating the importance of using standardised
416 tests of smell perception rather than self-report.

417 The current study further found BSIT scores significantly predicted informant-
418 reported change in interpersonal relationship since injury, even when controlling for age,
419 injury severity (measured by post-traumatic amnesia) and time since injury. This finding
420 supports previous claims that post-traumatic hyposmia has prognostic significance in TBI and
421 can predict psychosocial outcome. Further, while past studies have demonstrated a

422 relationship between total anosmia (complete loss of smell) and social outcome (Martzke et
423 al., 1991; Varney, 1988), the current study is the first to show that a partial loss of smell has
424 similar predictive power. This finding has clinical significance since, unlike psychosocial
425 outcome, smell impairment can be measured objectively soon after injury and may indicate a
426 patient's susceptibility to developing problems with maintaining social relationships causing
427 significant distress to themselves and those close to them. Thus, the current and past findings
428 suggest that routine use of an odour identification test such as the BSIT could act as a simple
429 and fast way to identify individuals at risk of social isolation after TBI.

430 Although it has been suggested that past findings of an association between hyposmia
431 and psychosocial outcome reflect problems with inappropriate social behaviour (Varney,
432 1988), no previous studies have directly investigated this claim. It was predicted that
433 hyposmia would be related to social behaviour as research attests to hyposmia as a good
434 indicator of damage to the orbitofrontal cortex (Bitter et al., 2010), a region associated with
435 social disinhibition in a range of neurological patient groups (Blair & Cipolotti, 2000; Namiki
436 et al., 2008; Rosen et al., 2005). The current study, however, found no relationship between
437 hyposmia and social disinhibition observed in the laboratory or reported by an informant.
438 This suggests that the ability of hyposmia to predict psychosocial outcome is not due to its
439 ability to predict disinhibited social behaviour. Smell impairment after TBI has been shown
440 to be related to a number of cognitive and other neuropsychological and functional outcomes
441 which may help explain why olfactory impairment is predictive of interpersonal outcome. For
442 instance, olfactory deficits have been found to be associated with emotion recognition and
443 empathy (Neumann et al., 2012), verbal fluency (Sigurdardottir et al., 2010), tasks of
444 executive functioning such as Trailing Making Test B and the Wisconsin Card Sorting Task
445 (Callahan & Hinkebein, 1999; Crowe & Crowe, 2013) and disinhibition measured by rule
446 breaks on the Controlled Oral Word Association Test (Crowe, 1996). Thus, that smell

447 impairment is associated with interpersonal outcomes or return to work may be due to it
448 being predictive of a general frontal lobe dysexecutive syndrome, rather than an orbitofrontal
449 disinhibition syndrome more specifically. Further, olfactory impairment, particularly
450 complete anosmia, may also indicate greater injury severity (Green, Rohling, Iverson, &
451 Gervais, 2003; Sigurdardottir et al., 2010), although this is not a consistent finding (Fortin et
452 al., 2010). Further research should seek to determine the nature of the relationship between
453 hyposmia and psychosocial outcome. With a better understanding of the variables that
454 mediate this relationship, hypsomia may be a useful tool in indicating rehabilitation targets
455 with the aim of alleviating social dysfunction before long-term changes in relationships
456 occur.

457 **Emotion Perception**

458 Consistent with past research, participants with TBI in the current study demonstrated
459 impairment in their capacity to *discriminate* between specific emotions evidence by their
460 TASIT scores and overall accuracy scores on the intensity rating task. Despite this
461 impairment, the participants with TBI did not actually differ from the control group in their
462 ability to *detect the intensity* of emotions. Furthermore, participants with TBI did not differ
463 from controls in the degree to which they perceived the target emotion as being expressed at
464 greater intensity than other emotions (their difference scores). Thus while participants with
465 TBI were more likely to rank the wrong emotion as the most intense some of the time (as
466 captured in the accuracy data) their relative rankings of differential intensity were actually
467 close to that of the control group. This suggests that participants with TBI are not insensitive
468 to emotional intensity per se, but demonstrated difficulty identifying which was the
469 preponderant emotion. Importantly, these findings suggest that forced-choice labelling tasks
470 do not provide a full picture of emotion perception capabilities and impairments after TBI.
471 The results highlight that failure to select the correct label does not imply an inability to

472 recognise that the target emotion is present or even to appreciate at what intensity the target
473 emotion is being expressed. Research should aim to further tease apart processes
474 underpinning the recognition of emotionality versus the differentiation of different emotions
475 following TBI.

476 Differences in the intensity ratings and difference scores across the emotions were
477 also examined. Participants rated happiness as being expressed at lower intensity than other
478 emotions, which is consistent with the actual intensity of happy stimuli (30%). Interestingly,
479 sadness was also rated as less intense than other emotions, despite it actually being expressed
480 at 100% intensity. This may indicate that sadness is a more subtle facial emotion than others.
481 Comparisons of difference scores across emotion categories revealed that fear was the least
482 well differentiated emotion, while happiness and disgust were the best differentiated
483 emotions. The negative difference score for fear seen in Table 4 indicates that both
484 participants with TBI and controls, on average, confused fear with other emotions, despite the
485 fact that fear stimuli were presented at 100% intensity in an attempt to eliminate floor effects
486 identified in previous research. This suggests that fear is extremely difficult to differentiate,
487 even for healthy controls, and is consistent with past findings (Rosenberg et al., 2014). In
488 contrast, happiness was very well differentiated by both control participants and participants
489 with TBI in the current study, despite happiness stimuli being presented at only 30%
490 intensity, also consistent with Rosenberg et al. (2014). Happiness is so easily discernable
491 from other emotions probably because it can be recognised on the basis of the presence of a
492 single feature; a smile. In contrast, distinguishing between emotions such as fear and surprise
493 may be more difficult, since it requires attention to multiple aspects of face configuration
494 (Adolphs, 2002). Interestingly, disgust was also well differentiated from other emotions,
495 which may be because it is easily identified by the distinctive scrunching of the nose.

496 Finally, the current study attempted to improve the quality of emotion perception
497 measurement used in prior research with people with TBI in order to detect its relationship to
498 social disinhibition, in particular, or psychosocial outcome more broadly. In contrast to
499 predictions, no relationship was found, regardless of the kind of task used. This is consistent
500 with a number of prior studies (Beer et al., 2003; Milders et al., 2003; Milders et al., 2008)
501 but contradicts others (Spikman et al., 2013; Watts & Douglas, 2006). These findings suggest
502 that the behaviours which have the largest impact on psychosocial wellbeing may be driven
503 by problems other than impairments in recognition of another's emotional state. For instance,
504 a person with TBI may act in a socially inappropriate manner due to an inability to inhibit an
505 urge, regardless of whether emotional feedback from others is positive or negative. Further
506 research should seek to clarify the role of emotion perception impairments in a broader model
507 of social behaviour which accounts for other neuropsychological deficits such as inhibition.

508 There are some limitations of the current study that should be noted. Although
509 assumptions were made about OFC damage underlying hyposmia and emotion perception
510 deficits after TBI, the current study cannot confirm the origins of these observed
511 impairments. That neither hyposmia nor emotion perception deficits were associated with
512 observed or informant-reported disinhibition suggests that the neuropathology underlying
513 these deficits is complex and not isolated to the OFC region. The use of high resolution
514 imaging technology in combination with the measures used here could clarify these findings.
515 Another limitation of the current study was that the TBI sample varied greatly with respect to
516 time since injury. Thus, it cannot be determined whether disinhibited behaviour observed in
517 participants developed as a direct result of their injury or if the behaviours developed later
518 perhaps as the result of advanced age interacting with injury-related changes. Finally, this
519 study was limited by the small sample size of the comparison group, and thus results may be
520 influenced by low power. However, the current study was able to replicate established

521 differences between people with TBI and controls on both smell identification and emotion
522 labelling.

523 **Conclusions**

524 The current study found an association between hyposmia and informant-reported
525 change in interpersonal relationships, supporting past claims that hyposmia has prognostic
526 significance following TBI. Contrary to suggestions that the association between hyposmia
527 and psychosocial outcome results from the presence of inappropriate social behaviour,
528 however, the current study found no relationship between hyposmia and social disinhibition
529 after TBI. That hyposmia was associated with psychosocial outcome more broadly may be
530 due it being an indicator of impact at the front of the head and thus damage to the frontal
531 brain areas generally.

532 The current study further found evidence of impairment in differentiating emotion but
533 not in recognising emotional intensity among participants with TBI, suggesting that forced-
534 choice labelling tasks may distort characterisation of impairments in the perception and
535 understanding of emotion following TBI. Sensitivity to emotional intensity was surprisingly
536 intact, and may represent a useful target for remediation or compensatory approaches in this
537 group. Finally, emotion perception after TBI was not found to be related to either social
538 disinhibition or change in interpersonal relationships since injury, indicating that there may
539 be more important predictive factors to consider when investigating social disinhibition and
540 psychosocial outcome.

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742

743 *Figure 1.* Intensity ratings provided by the TBI and control group for each emotion compared
744 to the actual intensity of emotion used in stimuli for that emotion category

745 *Figure 2.* Intensity rating difference scores for the TBI and control group for each emotion
746 category

Table 1

Means, standard deviations, ranges and results of group comparisons for demographic variables

	Mean (SD), Range		Diff (<i>p</i>)	Cohen's <i>d</i>
	TBI (<i>N</i> =23)	Control (<i>N</i> =15)		
Demographics				
PTA (days)	67.43 (44.22), 12-189			
Time Since Injury (years)	14.59 (11.05), 2-45			
Age	45.43 (15.44), 22-69	42.67 (15.27), 20-63	.591	.18
Years of education	13.61 (2.74), 9-22	14.87 (1.69), 12-18	.123	.55

Table 2

Performance of the TBI group on standard neuropsychological tests

Cognitive Variables	Mean	SD	Range
WMS-III Logical Memory I	9.77	3.32	2-17
WAIS-III Digit Span	10.14	2.25	7-13
WAIS-III Digit Symbol Coding	7.24	3.02	4-15
Trails A (secs)	41.43	14.54	24-69
Trails B (secs)	91.10	38.85	44-194

Table 3

Multiple regression predicting SPRS-2 ratings from age, PTA, TSI and BSIT scores

Variable	B	β	<i>p</i>
Constant	.85		
Age	.07	.26	.261
PTA	.03	.27	.194
TSI	-.13	-.33	.156
BSIT	.82	.54	.013*
Adjusted R ²		.31	
F		3.19	.042*

*PTA = Post-Traumatic Amnesia, TSI = Time since injury, BSIT = Brief Smell Identification Test. Note. N=23 *p<.05*

Table 4

Means, standard deviations and results of group comparisons for all emotion perception scores for both groups

Emotion Perception Scores	Mean (SD)			
	TBI (N=23)	Control (N=15)	Diff (<i>p</i>)	Cohen's <i>d</i>
Emotion Intensity Score				
Happy (30%)	2.81 (1.35)	2.82 (1.27)	.986	<.01
Fear (100%)	3.66 (2.27)	4.73 (2.65)	.195	.43
Surprise (100%)	4.73 (2.26)	5.02 (1.94)	.687	.14
Sad (100%)	3.39 (3.04)	3.20 (1.85)	.826	.08
Anger (80%)	4.88 (2.30)	4.64 (1.83)	.737	.12
Disgust (80%)	5.22 (2.17)	5.60 (2.06)	.591	.18
Difference Score				
Happy	2.68 (2.65)	3.20 (2.96)	.576	.19
Fear	-1.55 (1.08)	-1.08 (1.92)	.398	.30
Surprise	-0.07 (1.71)	0.46 (1.24)	.415	.26
Sad	0.69 (3.06)	0.40 (2.73)	.769	.10
Anger	0.14 (2.00)	0.93 (1.77)	.219	.42
Disgust	1.16 (2.61)	2.93 (2.37)	.041*	.71
Overall Score	10.91 (3.12)	12.67 (1.54)	.028*	.72
TASIT Accuracy	22.05 (5.03)		.018*	.73