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Emotional recognition from dynamic facial, vocal and musical expressions following traumatic brain injury

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ABSTRACT
Objectives: To assess emotion recognition from dynamic facial, vocal and musical expressions in subgroups of adults with traumatic brain injuries (TBI) of different severities and identify possible common underlying mechanisms across domains.
Methods: Forty-one adults participated in this study: 10 with moderate–severe TBI, nine with complicated mild TBI, 11 with uncomplicated mild TBI and 11 healthy controls, who were administered experimental (emotional recognition, valence-arousal) and control tasks (emotional and structural discrimination) for each domain.
Results: Recognition of fearful faces was significantly impaired in moderate–severe and in complicated mild TBI subgroups, as compared to those with uncomplicated mild TBI and controls. Effect sizes were medium–large. Participants with lower GCS scores performed more poorly when recognizing fearful dynamic facial expressions. Emotion recognition from auditory domains was preserved following TBI, irrespective of severity. All groups performed equally on control tasks, indicating no perceptual disorders. Although emotional recognition from vocal and musical expressions was preserved, no correlation was found across auditory domains.
Conclusions: These preliminary studies may contribute to improving comprehension of emotional recognition following TBI. Future studies of larger samples could usefully include measures of functional impacts of recognition deficits for fearful facial expressions. These could help refine interventions for emotional recognition following a brain injury.

Introduction
Traumatic brain injury (TBI) is an acquired injury to the brain from an external force that can result in physical, cognitive and/or behavioural alterations. Difficulties in psychosocial functioning also typically appear following TBI, including disruption of intimate relationships and reduced social network [1,2]. Some authors have suggested that these difficulties may be related, at least in part, to a poor ability to recognize emotions from non-verbal communication channels, such as facial and vocal expressions [3–6]. Indeed, as emotional recognition plays a crucial role in social interactions by helping individuals to understand intentions and to guide behaviour, impairments might, thus, contribute to psychosocial difficulties following a TBI.

Furthermore, important brain regions involved in emotional processing from facial and vocal expressions, such as the prefrontal cortex (i.e. ventromedial prefrontal cortex and the orbitofrontal cortex) and limbic structures (i.e. amygdala, temporal lobes, fusiform gyrus, regions of the parietal lobe) [7–9] are frequently damaged following a moderate–severe TBI [10]. Even in the case of mild TBI, some authors suggest that structural changes and neurochemical alterations may occur in these same brain areas, as well as in white matter integrity [11–14]. Recent work has proposed that impairments in emotional processing from facial expressions following TBI can be linked to damage in specific white matter tracts, such as the inferior longitudinal fasciculus and inferior fronto-occipital fasciculus [15], as well as to lower neural activation in the right fusiform gyrus [16]. Moreover, particular lesion localization can lead to greater impact on negative emotional recognition. Indeed, previous lesion studies showed impairments in fearful and/or disgusted facial expression recognition following anteromedial temporal lobe resection [17], ventromedial prefrontal hypoperfusion [18] or bilateral damage to the amygdala [19], as well as fearful and/or angry non-linguistic vocal expression recognition deficits following unilateral temporal lobe resection [20] or bilateral lesions to the amygdala [21].

The emerging literature on emotional recognition following TBI demonstrates impairments from both facial and vocal expressions [3–6,22–32] and especially in the case of negative emotions, such as fear, sadness, disgust and/or anger [4,6,22,23,27,28,31]. In general, these previous studies used facial and vocal stimuli expressing six basic emotional categories (happiness, sadness, fear, anger, surprise, disgust). The majority of these studies did not, however, look at the effect of TBI severity; they included mixed samples of mild-to-severe...
injuries. Even the mild TBI classification is heterogeneous as it can be complicated by intracranial lesions not necessitating neurosurgical intervention [33–35]. Thus, mild TBI classification can be divided into two sub-types: uncomplicated mild TBI (negative CT-scan) and complicated mild TBI (positive CT-scan). Some studies indicate greater cognitive disturbances for individuals having sustained a complicated mild TBI as compared to an uncomplicated mild TBI [36–38]. Greater cognitive disturbances are also reported for individuals having sustained a severe TBI as compared to a complicated mild TBI [39]. Consequently, when investigating cognitive functioning such as emotional recognition, it is important to distinguish uncomplicated mild; complicated mild; and moderate–severe TBI groups.

Additionally, to evaluate emotional recognition from facial expressions in individuals with TBI, most previous studies used static visual stimuli, i.e. photographs [3,6,22–25,27–29,31,32], which may reflect real-world abilities less well than videos. Dynamic properties may facilitate processing of emotional facial expressions [40–42]. In addition, to evaluate emotional recognition from voices following TBI, previous studies used vocal stimuli with verbal content, i.e. affective prosody [5,22,26,27,31]. Stimuli were expressed with an emotional voice tone, but verbal content was semantically neutral (e.g. ‘I will be back later’) or composed of logatomes (e.g. ‘Someone mugged the pazing’), which could possibly be very difficult for individuals with TBI because of the dual demand of listening to verbal meaning and emotional voice tone. To minimize the interaction between the emotional and the linguistic functions of vocal expressions, non-linguistic vocalizations, such as screaming, crying or laughing, could be more appropriate. It has also been proposed that non-linguistic vocalizations are the auditory equivalent of facial expressions [43]. To date, no study has looked at emotional recognition from non-linguistic vocalizations following TBI.

Music is another highly powerful non-verbal communication channel to express emotions [44,45], which has been shown to depend on the same brain structures as facial and vocal expressions that are known to be involved in emotional processing, such as the amygdala, nucleus accumbens, hypothalamus, hippocampus, insula, cingulate cortex and orbitofrontal cortex [46]. No previous study has examined emotional recognition from music in individuals with TBI. Yet, one group has suggested that musical intervention can help with cognitive and emotional issues after brain injury; daily music listening may improve cognitive functions (selective attention, verbal memory) and reduce negative mood (depression, confusion) and it has also been claimed may induce long-term neuroplasticity changes in the brain after stroke [47–49]. However, it is unknown whether therapeutic effects could be based on the preservation of emotional recognition from music after brain damage; the underpinnings of emotional recognition from musical expressions following TBI thus need to be investigated. Moreover, as for facial and vocal emotional expressions, injury severity as well as localization of brain lesions could have differential impacts on recognition of emotional expressions from music following a TBI. For example, previous lesion studies have shown impairments in fearful (and to some extent sad) music recognition following temporal lobe excision, including amygdala [17,50,51].

While emotional recognition involves similar brain areas for facial, vocal and musical domains, it is not clear whether neural pathways are shared [45,52]. Comparisons across these three domains following a TBI would be of interest to provide a better understanding of possible shared mechanisms. Few studies have examined recognition of both facial and vocal emotional expressions in the same group of TBI participants and results have been variable [22,26,27,31]. A recent study with a large moderate–severe TBI sample (n = 203) [31] demonstrated that recognition of emotional facial expressions was significantly more impaired than that of vocal expressions, which supports overlapping emotion recognition processes in the context of distinct neural systems for visual and auditory modalities. The relationship between auditory channels, such as those underlying the recognition of vocal vs musical expressions, is, however, not understood following TBI. Although music and vocal expressions are substantially different in their respective natures, emotional recognition processes from these auditory domains appear to depend upon, at least partially, similar neural regions, such as the amygdala [53].

The primary objective of the present study was to determine if emotional recognition from dynamic facial, vocal and musical expressions differed in adults having sustained a mild-to-severe TBI (uncomplicated mild vs complicated mild vs moderate–severe), as compared to healthy adults without a history of TBI. As a secondary objective, this study aimed to identify whether there was a relationship between performances across domains that could suggest common underlying mechanisms. Based on the existing literature, it was hypothesized that TBI participants would be significantly impaired in recognizing negative emotions from dynamic facial, vocal and musical expressions, as compared to adults without a history of TBI. It was also expected that impairments would vary according to TBI severity, i.e. moderate–severe TBI > complicated mild TBI > uncomplicated mild TBI. As an exploratory hypothesis, it was postulated that performances across auditory channels, i.e. emotional vocal and musical expressions, would be correlated. To test these assumptions, experiments were conducted in which dynamic faces, non-linguistic vocalizations and music expressed three basic emotions commonly recognized from these domains: happiness, sadness and fear. Control task were administered to eliminate the possibility of a perceptual disorder underlying a potential deficit in emotional recognition.

Methods

Participants

A total of 41 adults participated in the study: 11 participants with uncomplicated mild TBI, nine participants with complicated mild TBI, 10 participants with moderate–severe TBI and 11 healthy controls. TBI participants were recruited from the Centre de réadaptation Lucie-Bruneau and Centre de réadaptation Constance-Lethbridge in Montréal, Québec, Canada. Clinical and research coordinators solicited patients’ permission to be contacted to participate in the research project. Clinical coordinators recruited participants with TBI

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during their rehabilitation (at least 2 months post-injury) and research co-ordinators recruited TBI participants having completed rehabilitation from patient databases (maximum 36 months post-injury). Healthy controls were recruited through advertisements in the community.

All participants with TBI had been diagnosed by an emergency or rehabilitation medicine physician according to the following parameters [54], which were confirmed in medical records:

1. Glasgow Coma Scale (GCS) score (preponderant criteria)
   - Mild TBI: GCS 13–15/15, and
   - Moderate–severe TBI: GCS ≤ 12/15;
2. Post-traumatic amnesia (PTA) duration
   - Mild TBI: PTA < 24 h, and
   - Moderate–severe: PTA ≥ 24 h; and
3. Alteration or loss of consciousness (LOC) duration
   - Mild TBI: LOC ≤ 30 min, and
   - Moderate–severe TBI: LOC > 30 min.

Uncomplicated mild TBI and complicated mild TBI were distinguished according to CT-scan results. Participants with complicated mild TBI presented intracranial lesions (positive CT-scan) which had not required neurosurgical intervention [33–35]. Of the 19 participants with complicated mild or moderate–severe TBI, four had predominantly frontal lobe damage, one had predominantly parietal lobe damage, one had predominantly temporal lobe damage, three had lesions in the frontal and temporal regions, two had lesions in the frontal and parietal regions, one had lesions in the temporal and parietal regions and seven had diffuse lesions involving the frontal, temporal and parietal lobes.

Exclusion criteria for TBI groups were: (1) younger than 18 or older than 55; (2) a psychiatric or neurological history, including more than one TBI; (3) a penetrating brain injury, such as assault with blunt or sharp object; (4) hearing or visual impairment; and (5) history of previous cognitive impairment, such as language deficit or attention deficit disorder. This information was documented in the medical records or during the first appointment. An additional exclusion criterion for healthy controls was a history of TBI. All participants had minimal or no musical training; they had not received musical training for more than five years and, if so, they had not played their instrument for at least 15 years before testing.

Demographic and clinical characteristics of the participants are shown in Table I. TBI groups and healthy controls did not differ according to age, gender, years of education, musical experience, and intellectual functioning indexes (verbal IQ [vocabulary] and performance IQ [matrix reasoning] of the Wechsler adult intelligence scale-III [WAIS-III] [55]) \((p > 0.05, \chi^2\) tests). TBI groups differed significantly according to GCS scores \((\chi^2 = 20.722, p = 0.001, \chi^2\) Kruskal Wallis H tests), but did not differ according to time post-injury, post-concussion symptoms scores [56] and Beck Depression Inventory-II (BDI-II) scores [57] \((p > 0.05, \chi^2\) Kruskal Wallis H tests). Healthy controls and TBI groups differed significantly according to post-concussion symptoms scores \((\chi^2 = 15.439, p = 0.001, \chi^2\) Kruskal Wallis H tests) and BDI-II scores \((\chi^2 = 12.664, p = 0.005, \chi^2\) Kruskal Wallis H tests). All participants presented a BDI-II score below 20 (i.e. below the cut-off for the presence of a possible moderate–severe depression), except for two with uncomplicated mild TBI and two with complicated mild TBI. However, those four participants scored higher on ‘somatic’ and ‘cognitive’ items (e.g. fatigue, sleep disturbances, concentration difficulties) compared to ‘affective’ items (e.g. sadness), which could be more related to the TBI than depression. Indeed, BDI-II scores were highly correlated with post-concussion symptoms scores \((r = 0.696; p = 0.001)\).

### Materials and procedure

#### Stimuli

**Facial expressions.** Thirty videos of facial expressions (500 milliseconds) were selected from a validated database named STOIC ([http://www.mapageweb.umontreal.ca/gosselif/sroye tal_sub.pdf]) [58]. Facial expressions were created by professional actors (five men, five women) and were intended to express happiness, sadness or fear (10 stimuli per emotional category).

**Vocal expressions.** Thirty non-linguistic vocalizations (385–2229 milliseconds) were selected from a validated database named The Montreal Affective Voices ([http://vnl.psy.gla. ac.uk]) [59]. Stimuli were created by professional actors (five men, five women) and consisted of short interjections using the

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Healthy controls (n = 11)</th>
<th>Uncomplicated mild TBI (n = 11)</th>
<th>Complicated mild TBI (n = 9)</th>
<th>Moderate–severe TBI (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>34 (7.8)</td>
<td>32.8 (7.9)</td>
<td>40.7 (10.6)</td>
<td>35.6 (12)</td>
</tr>
<tr>
<td>Gender</td>
<td>6/5</td>
<td>9/2</td>
<td>2/7</td>
<td>4/6</td>
</tr>
<tr>
<td>Education (years)</td>
<td>15.5 (2)</td>
<td>14.6 (2.4)</td>
<td>12.6 (3.7)</td>
<td>14.7 (2.5)</td>
</tr>
<tr>
<td>Musical training (years)</td>
<td>1.3 (1.6)</td>
<td>2 (3)</td>
<td>1 (3)</td>
<td>1 (3)</td>
</tr>
<tr>
<td>Verbal IQ index</td>
<td>103.6 (5)</td>
<td>100.9 (13.4)</td>
<td>100.7 (9)</td>
<td>106 (10.2)</td>
</tr>
<tr>
<td>Performance IQ index</td>
<td>118.2 (7.5)</td>
<td>110.5 (11.3)</td>
<td>112.8 (10.9)</td>
<td>114 (12.9)</td>
</tr>
<tr>
<td>GCS scores</td>
<td>—</td>
<td>15 (0)</td>
<td>14.4 (0.7)*</td>
<td>7.8 (3.1)*</td>
</tr>
<tr>
<td>Time post-TBI (months)</td>
<td>—</td>
<td>10.6 (7)</td>
<td>11.3 (10.1)</td>
<td>16 (8.9)</td>
</tr>
<tr>
<td>Post-concussion symptoms scores</td>
<td>7.8 (6.4)</td>
<td>45.8 (29)*</td>
<td>25.2 (26.2)</td>
<td>19.8 (9.6)*</td>
</tr>
<tr>
<td>BDI-II scores</td>
<td>4.9 (4.4)</td>
<td>15.4 (8.3)*</td>
<td>12.7 (8.8)</td>
<td>11.3 (4.5)*</td>
</tr>
</tbody>
</table>

* \(p < 0.05\), as compared to healthy controls.
French vowel ‘ah’, expressing happiness, sadness or fear, i.e. laughs, cries or screams (10 stimuli per emotional category).

**Musical expressions.** Thirty novel musical excerpts (8–12 seconds), computer-generated (Musical Instrument Digital Interface files) in a piano timbre and written according to the rules of the Western tonal system, were selected from a validated database from Vieillard et al. [60] (www.brams.umontreal.ca/plab/publications/article/96). Stimuli (musical excerpts) expressed happiness, sadness or fear emotions (10 stimuli per emotional category).

**General procedure**

Participants performed a total of 12 tasks (described below): two blocks of experimental tasks (emotional recognition and valence-arousal) and two blocks of control tasks (emotional discrimination and structural discrimination), in which each of the three domains (dynamic facial, vocal and musical expressions) were presented. The order of the four blocks of experimental and controls tasks was counterbalanced across participants. Within each block, the order of each domain (facial, vocal and musical expressions) was counterbalanced across participants. Each stimulus was presented in a pseudorandom order (no more than two consecutive presentations of the same emotion) in a self-paced manner. Tasks were displayed on a 17-inch screen computer and auditory excerpts were presented through Professional Beyer Dynamic DT770 headphones at a comfortable volume level. E-prime software was used for stimuli presentation and response recording.

**Experimental tasks**

**Emotional recognition.** In three separate tasks, 30 dynamic facial expressions, 30 non-linguistic vocalizations and 30 musical excerpts were presented. For dynamic facial and vocal expressions, participants were asked to select the emotion that best corresponded to each stimulus among six choices of emotions (i.e. six basic emotional categories usually expressed by facial and vocal expressions and which were included in initial validation studies: happiness, sadness, fear, anger, surprise and disgust). For musical excerpts, participants were asked to select the emotion that best corresponded to each stimulus among four choices of emotions (i.e. four emotional categories which were part of initial validation studies: happiness, sadness, fear and peacefulness). If necessary, participants were allowed to repeat each stimulus in order to prevent any possible effect of working memory impairment.

**Valence and arousal.** In three separate tasks, the same stimuli as in the emotional recognition tasks were presented. Participants were asked to rate the stimuli on both emotional valence (very negative to very positive) and emotional arousal/intensity (not at all intense to very intense) using a visual analogue scale (see Figure 1).

**Control tasks**

**Emotional discrimination.** Three separate tasks for each domain were administered, consisting of 36 pairs of dynamic facial expressions, 36 pairs of vocalizations and 36 pairs of musical excerpts. Music was segmented in short excerpts from 1–2 seconds with Adobe Audition software. Each pair consisted of two consecutive stimuli expressing the same or different emotions. For each domain, six possible emotional combinations were designed (six pairs per emotional combination: happy-happy, sad-sad, fear-fear, happy-sad, happy-fear, sad-fear). Participants were asked to determine if the two stimuli expressed the same or different emotions. A practise trial consisting of six examples (one of each possible emotional combinations) was provided with feedback before moving on to the task, during which participants were not allowed to repeat the pairs of stimuli.

**Structural discrimination.** Three separate tasks for each domain were administered, consisting of 36 pairs of static facial expressions (pictures version of STOIC [58]), 36 pairs of vocalizations and 36 pairs of short musical excerpts. Each pair included two consecutive stimuli, one upward and one downward. For static facial expressions, pictures were inverted 180° with Photoshop. Vocalizations were cut in small units and reversed with Adobe Audition software. Musical excerpts were retrograded with Sibelius software. Half of the pairs expressed the same stimuli and the other half expressed two different stimuli. Participants were asked to determine if the pairs represented the same or different stimuli. A practise trial consisting of six examples was provided with feedback before moving on to the task, during which participants were not allowed to repeat the pairs of stimuli.

**Data analysis**

As primary analyses, non-parametric Kruskal Wallis H ($\chi^2$) tests were performed to see if at least one of the groups was different from the other groups. When Kruskal Wallis H tests gave significant results, post-hoc Mann-Whitney U tests (U) were conducted, to examine which group was significantly different from the others. Effect size ($r$) of each significant Mann-Whitney U test was also calculated (i.e. $Z/\sqrt{N}$).

As secondary analyses, Pearson correlations ($r$) and Chi-square ($\chi^2$) were calculated to determine the relationships between tasks performance across domains (facial, vocal and musical expressions) and emotional expressions (happiness, sadness, fear), as well as to assess the relationship between tasks performance and clinical/demographical variables (injury severity, lesions localization, time post-TBI, age, gender, level of education, verbal IQ, performance IQ).
Results

Emotional recognition

Dynamic facial expressions

Mean percentages of correct responses for emotional recognition from dynamic facial expressions are shown in Figure 2, according to emotions (happiness, sadness, fear) and groups. Analysis revealed a significant effect of group for fearful facial recognition (χ² = 14.072, p = 0.003). More specifically, recognition of fearful faces was significantly impaired in adults with moderate–severe TBI, as compared to adults with uncomplicated mild TBI (U = 11.000, Z = -2.970, p = 0.003, r = 0.65) and healthy controls (U = 9.500, Z = -3.100, p = 0.002, r = 0.68). Recognition of fearful faces was also significantly impaired in adults with complicated mild TBI, as compared to adults with uncomplicated mild TBI (U = 23.000; Z = -2.049, p = 0.040, r = 0.46) and healthy controls (U = 23.500; Z = -2.020, p = 0.043, r = 0.45). No significant differences were found between adults with uncomplicated mild TBI and healthy controls (U = 60.000; Z = -0.034, p = 0.973) or between adults with complicated mild TBI and moderate–severe TBI (U = 29.500; Z = -0.993, p = 0.321). Of note, there was no significant group effect in terms of error patterns between emotions (ps > 0.05).

Vocalizations

Mean percentages of correct responses for emotional recognition from vocalizations are shown in Figure 3, according to emotions and groups. All groups performed equally for recognition of happiness, sadness and fear (ps > 0.05, Kruskal Wallis H tests).

Music

Mean percentages of correct responses for emotional recognition from music are shown in Figure 4, according to emotions and groups. All groups performed equally for the recognition of happiness, sadness and fear (ps > 0.05, Kruskal Wallis H tests).

Valence and arousal/intensity tasks

Mean percentages of ratings for valence and arousal/intensity from dynamic facial expressions, vocalizations and music are shown in Figure 5, according to emotional expressions and groups. There were no significant group differences in valence and arousal/intensity ratings for all emotional expressions (happiness, sadness, fear) from all domains (dynamic facial, vocal and musical expressions) (ps > 0.05, Kruskal Wallis H tests).

Control tasks: emotional discrimination and structural discrimination

For the emotional discrimination and structural discrimination tasks from facial, vocal and musical expressions, no significant difference (ps > 0.05, Kruskal Wallis H tests) was found between the three TBI groups, as compared to healthy controls (see Table II). Each participant performed well above chance (50%).

Comparisons across domains

Accuracy for the different tasks across domains (facial, vocal and musical expressions) and emotional expressions (happiness, sadness and fear) showed only one significant correlation (ps > 0.05), that is for the recognition of happy facial and vocal expressions (r = 0.452, p = 0.003).

Demographic and clinical variables

Secondary analyses indicated that there were no significant correlations between emotional expressions (happiness, sadness, fear) from all domains (dynamic facial, vocal, musical expressions) and demographic variables such as age, gender, level of education and IQ indexes (ps > 0.05). For participants with TBI, significant correlations were found between Glasgow Coma Scale (GCS) scores and recognition of fearful faces (r = 0.402; p = 0.031), showing that participants with lower GCS scores (or more severe injuries) performed more
poorly when recognizing fearful dynamic facial expressions. No significant correlation was found between emotional expressions from all domains and time post-injury or lesions localization ($p_s > 0.05$).

**Discussion**

The aims of this study were to assess emotional recognition from dynamic facial, vocal and musical expressions in adults having sustained an uncomplicated mild, complicated mild or moderate–severe TBI, as compared to healthy adults without a history of TBI, and to determine whether there was a correlation in performances across domains that could suggest common underlying mechanisms.

Results indicated that recognition of dynamic fearful facial expressions was significantly impaired in adults with moderate–severe TBI and in adults with complicated mild TBI, as compared to adults with uncomplicated mild TBI and healthy controls. Effect sizes were medium–large, indicating substantively significant and, thus, strong results. Furthermore, significant correlations confirmed that participants with more severe injuries as reflected in lower Glasgow Coma Scale scores performed more poorly on recognition of dynamic fearful facial expressions. These novel findings are not explained by a perceptual disorder, as shown by results on control tasks, and add to previous studies that showed, using static visual stimuli, impaired recognition of negative emotions from facial expressions, such as fear, following TBI [4,6,22,23,27–31].

The presence of a recognition deficit for fearful facial expressions in complicated mild TBI and not in uncomplicated mild TBI, the latter showing comparable performance to healthy controls, highlights the importance of distinguishing these two sub-groups of mild TBI when conducting clinical research, as they do represent different gradients of brain injury severity and cognitive outcomes [36–38]. Furthermore, it is possible that such behavioural tasks are not sensitive enough to discriminate between adults with uncomplicated mild TBI and those without TBI. Indeed, previous studies of cognitive functioning suggested that standard neuropsychological tests or behavioural methods most often fail to detect dysfunctions in the post-acute stages of uncomplicated mild TBI, whereas more precise measures, such as event-related potentials (ERPs), can identify subtle neurofunctional alterations [61–64]. Further studies using more sensitive techniques may be needed to tap further into emotional recognition and its neural substrates following uncomplicated mild TBI.

Valence-arousal ratings did not differ between groups, even if adults with moderate–severe TBI and adults with complicated mild TBI performed worse than participants...
with mild TBI and healthy controls on recognition of fearful facial expressions. These results were unexpected since some lesions studies showed that fearful facial expressions, which are poorly recognized, are rated as less intense [17]. However, it is consistent with other findings highlighting a tendency for TBI adults with frontal lesions to perceive sadness, disgust, surprise and fear in facial expressions as intense, even if these emotions are incorrectly labelled [28]. Sixteen out of the 19 participants with complicated mild or moderate–severe TBI did in fact present damage involving the frontal lobes, according to CT-scan reports available in medical files.

The deficit found for fearful expressions after a moderate–severe TBI or a complicated mild TBI appears to be limited to the visual domain. No such discrepancy was found in emotional recognition from non-linguistic vocal and musical expressions, as compared to healthy controls. The absence of a deficit in fear processing involving auditory domains does not seem to reflect a lack of sensitivity of the tasks, since impairments in recognition of fearful non-linguistic vocalizations (screams) as well as of fearful musical excerpts have been shown following brain lesions using quite similar stimulus paradigms [17,20,50,51].

The dissociation between visual and auditory channels following TBI is consistent with some previous studies revealing that the recognition of emotional facial expressions appears to be significantly more impaired than that of emotional vocal expressions [27,31]. Nevertheless, recognition deficits of emotional vocal expressions, such as fear, following TBI have been previously evidenced [5,22,26,27,31]. The nature of tasks used, that is those evaluating affective prosody in previous studies vs those of the present study using emotional non-linguistic vocalizations (screams, laughs, cries), may account for this inconsistency. Indeed, affective prosody requires dual demand of listening to verbal meaning and emotional voice tone, whereas this interaction is minimized with emotional non-linguistic vocalizations. Moreover, even in healthy individuals, emotional non-linguistic vocalizations have been shown to hold a superior decoding effect over affective prosody [65]. Recent work also indicated that screaming occupies a privileged acoustic function (roughness or dissonance) and induces larger responses in the amygdala, as opposed to speech prosody [66]. Since lesions to the amygdala can occur following TBI [11], the preserved recognition of fearful vocalizations remains, however, to be explained. This could be achieved by conducting future studies in larger TBI sub-groups of different severities and lesion localizations.

Despite the dissociation observed between facial expressions and vocal as well as musical expressions, correlations across auditory domains were not found. This result may be attributed to methodological differences between the emotional recognition tasks using vocal and musical expressions; in the musical task, participants had to select the emotion that best corresponded to stimulus among four choices of emotions, rather than six choices of emotion, as in the vocal task. Consequently, more confusion could occur with voices than with music.

More studies of emotional recognition involving facial, vocal and musical expressions would be of interest to provide better understanding of possible overlapping neural pathways between domains and eventually contribute to refining intervention models following TBI. For example, in the case of common underlying mechanisms, it would be interesting to investigate if a specific type of training (for example, musical training) could generalize to another domain (for example, voices or faces) via stimulation of shared brain structures involved in emotional recognition. In any case, preservation of emotional recognition from music following TBI could encourage the use of musical intervention in this clinical population, which should also be the object of future well-controlled effectiveness studies. As music listening modulates activity in brain structures involved in emotional processing [46] has been reported to improve cognitive functions and have a positive effect on mood as well as on long-term brain neuroplasticity [47–49], the use of musical intervention may be promising following TBI to address neurological dysfunctions and resulting functional impairments.

Finally, future studies in larger samples should include measures of the functional impact of recognition deficits of fearful facial expressions. For instance, difficulties in recognizing fearful facial expression might lead to a poor perception of threatening situations and to more risk-taking behaviour. These also could help to enrich intervention models for emotional recognition after a brain injury.

Conclusions

This study is one of the first systematic explorations of emotional recognition from dynamic facial, non-linguistic vocal and musical expressions in the same group of participants with TBI and which specifically looked at the effect of TBI severity (uncomplicated mild vs complicated mild vs moderate–severe). The present findings confirm a deficit in fear recognition from dynamic facial expressions following a moderate–severe TBI and a complicated mild TBI, as compared to adults with uncomplicated mild TBI and healthy individuals. The results also show that emotional recognition from vocal and musical expressions appear to be preserved in participants with TBI, irrespective of severity. This study may contribute to improving comprehension of emotional recognition following TBI, with eventual implications for intervention aimed at improving emotional recognition following brain injury.

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Declaration of interest

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