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Sex-Related Differences in Emotion Recognition in Multi-concussed Athletes

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Abstract

Objectives: Concussion is defined as a complex pathophysiological process affecting the brain. Although the cumulative and long-term effects of multiple concussions are now well documented on cognitive and motor function, little is known about their effects on emotion recognition. Recent studies have suggested that concussion can result in emotional sequelae, particularly in females and multi-concussed athletes. The objective of this study was to investigate sex-related differences in emotion recognition in asymptomatic male and female multi-concussed athletes. **Methods:** We tested 28 control athletes (15 males) and 22 multi-concussed athletes (10 males) more than a year since the last concussion. Participants completed the Post-Concussion Symptom Scale, the Beck Depression Inventory-II, the Beck Anxiety Inventory, a neuropsychological test battery and a morphed emotion recognition task. Pictures of a male face expressing basic emotions (anger, disgust, fear, happiness, sadness, surprise) morphed with another emotion were randomly presented. After each face presentation, participants were asked to indicate the emotion expressed by the face. **Results:** Results revealed significant sex by group interactions in accuracy and intensity threshold for negative emotions, together with significant main effects of emotion and group. **Conclusions:** Male concussed athletes were significantly impaired in recognizing negative emotions and needed more emotional intensity to correctly identify these emotions, compared to same-sex controls. In contrast, female concussed athletes performed similarly to same-sex controls. These findings suggest that sex significantly modulates concussion effects on emotional facial expression recognition. (*JINS*, 2017, *23*, 65–77)

Keywords: Sport, Concussion, Emotional facial expression, Gender differences, Anxiety, Depression

INTRODUCTION

Sports-related concussion is defined as a complex pathophysiological process affecting the brain, induced by biomechanical forces (McCrory et al., 2013). It can result in physical signs (post-traumatic amnesia, loss of consciousness), somatic (headaches, dizziness, nausea, vomiting), cognitive (attention and memory deficits, slowed information processing) and emotional symptoms (lability), behavioral changes (irritability), and sleep disturbances (McCrory et al., 2013).

Although these symptoms resolve spontaneously within 7 to 10 days, the cumulative and long-term effects of concussions are now well documented (De Beaumont, Beauchemin, Beaulieu, & Jolicoeur, 2013; De Beaumont, Brisson, Lassonde, & Jolicoeur, 2007; De Beaumont, Henry, & Gosselin, 2012; Gaetz, Goodman, & Weinberg, 2000; Theriault, De Beaumont, Gosselin, Filipinni, & Lassonde, 2009; Theriault, De Beaumont, Tremblay, Lassonde, & Jolicoeur, 2011). Over the past years, several studies have revealed chronic cognitive and motor function alterations in athletes with a history of a previous concussion (Broglio, Eckner, Paulson, & Kutcher, 2012; De Beaumont, Lassonde, Leclerc, & Theoret, 2007; De Beaumont et al., 2011, 2009; Guskiewicz et al., 2005; Iverson, Gaetz, Lovell, & Collins, 2004; Tremblay et al., 2013).

These athletes report more symptoms and take longer to recover than athletes with no previous history (Collins et al., 2002; Colvin et al., 2009; Guskiewicz et al., 2003; Guskiewicz, Weaver, Padua, & Garrett, 2000; Iverson et al., 2004; Schatz, Moser, Covassin, & Karpf, 2011; Slobounov, Slobounov, Sebastianelli, Cao, & Newell, 2007). They are

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also more likely to suffer from persistent post-concussion symptoms, including anxiety and depression (Decq et al., 2016; Didehbani, Cullum, Mansinghani, Conover, & Hart, 2013; Guskiewicz et al., 2007; Solomon, Kuhn, & Zuckerman, 2015; Vargas, Rabinowitz, Meyer, & Arnett, 2015).

More recently, studies have revealed gender differences in the incidence and recovery from a concussion. In sports played by both sexes, females sustain proportionately more concussions than males (Covassin, Swanik, & Sachs, 2003; Dick, 2009; Gessel, Collins, & Dick, 2007; Lincoln et al., 2011; Marar, McIlvain, Fields, & Comstock, 2012). They report a higher number and greater severity of symptoms, including anxiety and depression, and take longer to recover than their male counterparts (Baker et al., 2016; Broshek et al., 2005; Colvin et al., 2009; Dick, 2009; Ellis et al., 2015; Farace & Alves, 2000; Fenton, McClelland, Montgomery, MacFlynn, & Rutherford, 1993; Kutcher & Eckner, 2010; Yang, Peek-Asa, Covassin, & Torner, 2015).

These clinical symptoms reflect primarily a functional disturbance, but may also result from structural damage (McCrory et al., 2013). Early neuroimaging studies of traumatic brain injury (TBI) found that the more commonly affected areas were the frontal and temporal lobes, the ventricular system, and the corpus callosum (Bigler, 2001a, 2001b, 2007; Johnson, Pinkston, Bigler, & Blatter, 1996). Structures of the limbic system such as the amygdala, the hippocampus, and the fornix may also be affected by TBI (Bigler et al., 1996; Gale, Burr, Bigler, & Blatter, 1993; Tate & Bigler, 2000). Recent technological advances allowed the detection of damage to the corpus callosum, putamen, globus pallidus, and internal capsule as well as in several white matter tracts such as the uncinate, fronto-occipital, and longitudinal fasciculi, the thalamic radiations, the corticospinal tract, and the cingulum (Chamard et al., 2013; Chappell et al., 2006; Henry, Tremblay, Tremblay, et al., 2011; Zhang, Heier, Zimmerman, Jordan, & Uluğ, 2006).

The frontal and temporal lobes are involved in higher cognitive processes such as attention, memory, and executive functions, as well as emotion recognition (Chayer & Freedman, 2001; Squire, Stark, & Clark, 2004; Squire & Zola-Morgan, 1991; Stuss, Alexander, & Benson, 1997). Studies of the effects of concussion on cognitive functioning have yielded mixed results. While some studies found persistent alterations in attention, memory, executive functions, visuospatial perception, and information processing speed in concussed athletes beyond the acute post-concussion phase (Echemendia, Putukian, Mackin, Julian, & Shoss, 2001; Guskiewicz, Ross, & Marshall, 2001; Iverson et al., 2004; Lovell, 2004; Lovell et al., 2003; McCrea et al., 2005, 2003), others have not (De Beaumont, Brisson, et al., 2007; De Beaumont, Lassonde, et al., 2007; Dupuis, Johnston, Lavoie, Lepore, & Lassonde, 2000; Iverson, Brooks, Lovell, & Collins, 2006; Theriault et al., 2009).

In addition to their role in cognition, structures such as the amygdala, the anterior cingulate gyrus, the hippocampus, and the prefrontal cortex are also involved in emotion recognition (Adolphs, 1999a; Adolphs, Baron-Cohen, & Tranel, 2002; Adolphs & Tranel, 2004; Adolphs, Tranel, Damasio, & Damasio, 1994; Adolphs et al., 1999; Phillips, Drevets, Rauch, & Lane, 2003). In particular, recognition of emotional facial expressions has been shown to involve the amygdala, ventromedial prefrontal cortex, occipitotemporal regions, right somatosensory cortex, insula, basal ganglia, thalamus, hypothalamus, and brainstem (Adolphs, 1999b, 2001, 2002a, 2002b, 2003; Adolphs, Damasio, Tranel, & Damasio, 1996). Damage to these structures can result in emotion recognition deficits (Adolphs et al., 2002; Adolphs, Damasio, Tranel, Cooper, & Damasio, 2000; Adolphs & Tranel, 2004; Adolphs et al., 1994, 1999). Importantly, several brain structures involved in emotion recognition are vulnerable to concussion (Chamard et al., 2013; Henry, Tremblay, Boulanger, Ellemberg, & Lassonde, 2010; Henry, Tremblay, Leclerc, et al., 2011; Vagnozzi et al., 2010, 2008; Zhang et al., 2010).

In parallel, studies have consistently shown that patients with TBI of various severity, who are not clinically anxious or depressed, are impaired on emotion recognition tasks, compared to healthy controls (Croker & McDonald, 2005; Green, Turner, & Thompson, 2004; Henry, Phillips, Crawford, Ietswaart, & Summers, 2006; McDonald & Flanagan, 2004; McDonald, Flanagan, Rollins, & Kinch, 2003; McDonald et al., 2011; Milders, Ietswaart, Crawford, & Currie, 2008). Notably, recognition of negative emotions such as anger, disgust, fear, and sadness is known to be more impaired than that of positive emotions such as happiness and surprise after TBI (Callahan, Ueda, Sakata, Plamondon, & Murai, 2011; Croker & McDonald, 2005; Hopkins, Dywan, & Segalowitz, 2002; Ietswaart, Milders, Crawford, Currie, & Scott, 2008; McDonald et al., 2003, 2011; Williams & Wood, 2010). While most of these studies focused on moderate to severe TBI, the few that included patients with mild TBI did not statistically stratified according to injury severity. Therefore, it is not clear if patients with milder injuries such as sports-related concussion are impaired on emotion recognition tasks.

Furthermore, these studies have focused on male subjects. However, gender differences in emotion recognition are now well documented, with women being better and faster at recognizing emotions than men (Campbell et al., 2002; Hall & Matsumoto, 2004; Hampson, van Anders, & Mullin, 2006; Montagne, Kessels, Frigerio, de Haan, & Perrett, 2005; Rahman, Wilson, & Abrahams, 2004; Thayer & Johnsen, 2000). More recently, studies have suggested that hormonal levels may partially account for these gender differences. These studies have shown that women taking oral contraceptives or in the follicular phase of their cycle, when estrogen is high relative to progesterone, are better at recognizing emotions, particularly negative emotions such as anger and fear (Derntl, Kryspin-Exner, Fernbach, Moser, & Habel, 2008; Derntl, Windischberger, et al., 2008; Guapo et al., 2009; Pearson & Lewis, 2005). They have also found significant associations between hormonal levels and activations in the amygdala and fusiform face area to emotional facial expressions (Derntl, Kryspin-Exner, et al., 2008;

Derntl, Windischberger, et al., 2008; Guapo et al., 2009; Marečková et al., 2012). It, therefore, appears plausible that gender may play a putative role in emotion recognition after recurrent concussions.

Moreover, most of these studies used conventional emotion recognition tasks with limited sensitivity to characterize and quantify recognition thresholds across emotion types. More sophisticated emotion recognition tasks were designed to offset these limitations. In particular, morphed emotion recognition tasks (Young et al., 1997), where one neutral and six emotional facial expressions are combined at different intensities, can provide information on the accuracy and intensity needed to recognize an emotion. These tasks have been shown to be particularly sensitive to subtle emotion recognition alterations (Bishop, Aguirre, Nunez-Elizalde, & Toker, 2015; Harmer, Grayson, & Goodwin, 2002; Humphreys, Minshew, Leonard, & Behrmann, 2007; Richards et al., 2002) and may thus be useful in the assessment of emotion recognition in concussed athletes.

This study had two objectives. The first was to investigate the effects of multiple concussions on emotion recognition. We hypothesized that concussed athletes would show alterations on a morphed emotion recognition task, particularly for negative emotions, compared to healthy control athletes. The second objective was to study sex-related differences in emotion recognition among concussed athletes. Considering that women are better at recognizing emotions than men, we hypothesized that concussion effects would be significantly modulated by sex.

METHOD

Participants

All 50 participants were active athletes from college and university sports teams (basketball, football, hockey, soccer, or non-contact sports) aged between 19 and 28 years [mean age of 22.04 years, standard deviation (*SD*) = 2.27]. Participants were included if they met all of the following criteria: normal or corrected to normal vision, no history of alcohol and/or substance abuse, no condition requiring daily medication, no history of psychiatric or neurological disorder, no current anxiety or depression as assessed by the Beck Anxiety Inventory (BAI; Beck & Steer, 1993) and the Beck Depression Inventory-II (BDI-II; Beck, Steer, & Brown, 1996), no learning disability or TBI unrelated to contact sports. The study was approved by the research ethics committee of the Université du Québec à Trois-Rivières, and all participants gave written informed consent before testing. Subjects received a financial compensation of $60 CDN for their participation.

The study included four groups. The first group consisted of 15 male athletes with no prior history of concussion. The second group included 10 male athletes who reported at least two sports-related concussions (number of concussions ranged from two to four, mean number of concussions was 2.80 ± .92) that had occurred more than a year before testing (time elapsed since the last concussion ranged from 12.78 to 36.37 months, mean time since the last concussion was 24.14 ± 9.05 months). The third group consisted of 13 female athletes with no prior history of concussion. The fourth group included 12 female athletes who reported at least two sports-related concussions (number of concussions ranged from two to four, mean number of concussions was 3.17 ± .83) that had occurred more than a year before testing (time elapsed since the last concussion ranged from 20.27 to 67.61 months, mean time since the last concussion was 38.08 ± 14.96 months).

Concussion classification was performed by a trained graduate student in clinical neuropsychology and was based on the concussion definition proposed in the 4th Consensus Statement on concussion in sport, including the assessment of a range of domains including clinical symptoms, physical signs, cognitive impairment, neurobehavioural features, and sleep disturbances (McCrory et al., 2013). Groups differed in terms of age ($F(3,49) = 3.86$; $p < .05$), and *post hoc* analyses revealed that female concussed athletes (mean age of 23.84 ± 3.00 years) were significantly older than female control athletes (mean age of 21.43 ± 1.15 years; $p < .05$) and male concussed athletes (mean age of 21.59 ± 1.89 years; $p < .05$). Male and female concussed athletes also differed in terms of time since the last concussion ($t(20) = -2.57$; $p < .05$) (see Table 1).

Table 1. Between-group comparisons in demographic, number of concussions, time since the last concussion, BAI, BDI, and PCSS

	Male concussed (*n* = 10)	Male controls (*n* = 15)	Female concussed (*n* = 12)	Female controls (*n* = 13)
Age	21.59 ± 1.89	21.44 ± 1.97	23.84 ± 3.00	21.43 ± 1.15
Education level	15.30 ± 1.70	15.40 ± 1.92	16.75 ± 2.26	15.38 ± 1.26
Number of concussions	2.80 ± 0.92	0	3.17 ± 0.83	0
Time since the last concussion (months)	24.14 ± 9.05	—	38.08 ± 14.96	—
BDI	2.90 ± 3.03	2.80 ± 2.78	3.25 ± 3.62	2.46 ± 2.30
BAI	1.60 ± 1.58	1.00 ± 1.85	1.92 ± 2.71	2.77 ± 2.13
PCSS	6.00 ± 8.94	4.27 ± 4.80	4.50 ± 6.40	4.31 ± 3.57

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Materials

Concussion history form and Post-Concussion Symptoms Scale

Concussion history was assessed with a standardized concussion history form including questions on the number of previous concussions (if any), approximate date(s) of each concussion, description of the accident(s), nature and duration of relevant post-concussion symptoms (confusion and/or disorientation, anterograde and/or retrograde amnesia, and loss of consciousness), and time before return to play. Post-concussion symptoms were then evaluated with the Post-Concussion Symptoms Scale (PCSS) (Maroon et al., 2000). This scale consists of 19 symptoms commonly experienced after a concussion in three different domains. The first domain includes somatic symptoms such as headaches, dizziness, nausea, vomiting, and balance problems. The second consists of cognitive symptoms such as concentration and memory difficulties, reduced processing speed, and feeling in a fog. The third domain includes neuropsychiatric symptoms such as irritability, sadness, nervousness, and anxiety. Participants were asked to rate the 19 symptoms on a scale from 0 (no symptom) to 6 (severe symptom), for a maximum score of 114. At the time of testing, concussed athletes were asymptomatic (symptom threshold for exclusion was fixed at 25) (Larson-Dupuis et al., 2015) reporting few, if any symptoms on the PCSS (mean of 5.18 ± 7.51).

Neuropsychological testing

To ensure there were no significant differences between concussed and control athletes on cognitive functioning, participants were then administered a battery of neuropsychological tests. This battery consisted of the Rey Auditory Verbal Learning Test (RAVLT; assessing learning as well as immediate and delayed verbal memory), the Rey Complex Figure Test (RCFT; evaluating immediate and delayed visual memory), the Symbol Digit Modalities Test (SDMT; measuring visual working memory, learning, visual scanning, psychomotor speed, and attention), the verbal fluency (assessing verbal fluency and word retrieval) and the Stroop test (evaluating inhibition and mental flexibility) from the Delis-Kaplan Executive Function System (D-KEFS), as well as the Comprehension subtest from the Wechsler Adult Intelligence Scale, fourth edition (WAIS-IV; evaluating verbal reasoning, practical knowledge and social judgment). These tests were found to be valid, reliable, and sensitive measures of cognitive deficits associated with concussion (Echemendia & Julian, 2001; Echemendia et al., 2001; Kosaka, 2006; Maroon et al., 2000).

Morphed emotion recognition task

Finally, emotion recognition was evaluated by a task inspired by the "facial expression megamix paradigm" (Young et al., 1997). This task consists in the categorization of blends of emotional facial expressions, created by morphing two expressions together (Deschênes, Forget, Daudelin-Peltier, Fiset, & Blais, 2015; Tardif, Fiset, & Blais, 2014; Tardif, Hébert, et al., 2014). It allows to assess the accuracy (proportion of trials in which the emotion is recognized when it is dominant in a morph stimulus) and threshold (emotional intensity needed to detect an emotion on 50% of the trials in which it is presented) with each emotion. Recent studies have shown that this task is particularly sensitive to subtle emotion recognition alterations (Bishop et al., 2015; Harmer et al., 2002; Humphreys et al., 2007; Richards et al., 2002).

Facial expression stimuli consisted in photographs of a male face depicting the six basic emotional facial expressions (anger, disgust, fear, happiness, sadness, surprise), taken from the Radboud Faces Database (Langner et al., 2010). The facial expression stimuli were transformed into grayscale, and were put on a neutral gray background. Each inner feature (eyes, nose, mouth) was aligned to the average position of that feature across all facial expression stimuli using a homemade MATLAB program applying rotations, translations, and/or scaling. The mean luminance and the spatial frequency spectrum were also equated across stimuli. The facial expressions were morphed with each other in all possible pairwise combinations using FantaMorph. The proportion of each expression in a given blend varied from 14/86% to 86/14%, in 12% increments. A total of 15 continuums of blend were thereby created (anger/disgust, anger/happiness, anger/fear, and so on) (see Figure 1).

The task consisted of 9 blocks of 105 trials, for a total of 945 trials. On each trial, a morph was randomly selected and presented in the center of a computer screen and lasted up to participants' response. Participants were asked to choose which of six labels (angry, disgusted, fearful, happy, sad, surprised) best described the presented facial expression

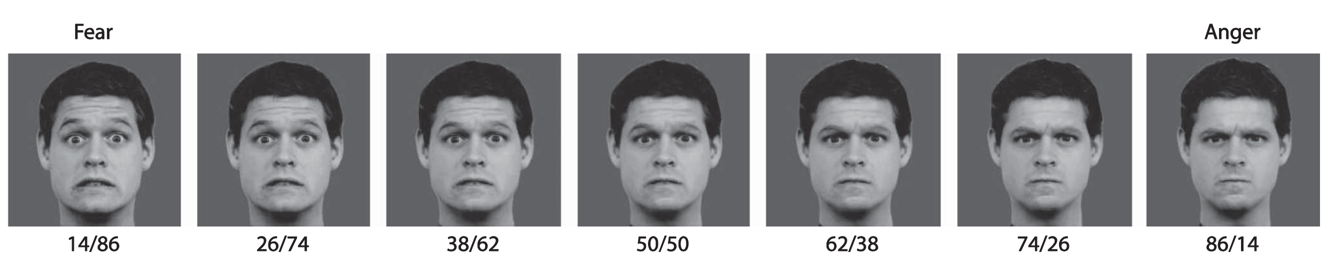

Fig. 1. Example of facial stimuli used in this study, expressing fear and anger from 14/86% to 86/14%.

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using a forced-choice task. No feedback was provided. The stimulus width subtended 10 degrees of visual angle.

Accuracy for each expression was calculated on all trials in which that expression was displayed with an intensity of 50% or more. To calculate the intensity threshold at which an emotional facial expression was detected on at least 50% of the trials in which it was presented, the following procedure was taken for each expression separately. First, all the blend continuums containing the expression under analysis were pooled together. For each intensity level, the proportion of trials the expression was detected was then calculated, and a sigmoid curve was fitted on the proportions of detection across intensity levels. The intensity threshold was obtained using the sigmoid parameters that best-fitted the results.

Procedure

Participants first completed a general health questionnaire, the concussion history form, the PCSS, the BAI, and the BDI-II to verify study eligibility. They then completed a battery of neuropsychological tests. They also completed the morphed emotion recognition task in two separate sessions to minimize fatigue. Both sessions lasted approximately 30 min. Testing was conducted by a trained and experienced graduate student in clinical neuropsychology.

Statistical Analyses

We first analyzed data with descriptive statistics and tests of normality to verify the assumptions of statistical tests. Data that were not normally distributed were transformed with logarithmic or probit function. Analyses of variance (ANOVAs) were conducted on neuropsychological tests as well as on accuracy and intensity threshold for positive (happiness, surprise) and negative emotions (anger, disgust, fear, sadness) separately. Age and time since the last concussion were not entered as covariates in the main analyses as they did not correlate with emotion recognition (all ps > .05). However, given the significant difference in time since the last concussion between male and female concussed athletes and its potential effects on the results, analyses of covariance (ANCOVAs) were then conducted on emotion recognition for male and female concussed athletes, with time since the last concussion as a covariate. Correlational analyses were conducted between clinical variables (number of concussions, time since the last concussion), neuropsychological data and emotion recognition. *Post hoc* tests were conducted with the Tukey's B approach. Two-tailed p values less than .05 were considered statistically significant.

RESULTS

Neuropsychological Tests

There were no group differences in immediate or delayed recall on the RAVLT and the RCFT, in total correct responses on the SDMT, in total correct responses on the verbal fluency, in time and total errors on the Stroop test as well as in the total correct responses on the Comprehension subtest (all ps > .05) (see Table 2).

Emotion Recognition

Accuracy

A two-way ANOVA on accuracy for negative emotions revealed a significant main effect of emotion (F(3,138) = 85.94; $p < .001$; $\eta^2 = .65$). Pairwise comparisons indicated that fear (M = 57.80% ± 11.60%) was significantly more difficult to recognize than anger (M = 77.68% ± 7.61%), disgust (M = 77.96% ± 10.91%), and sadness (M = 85.51% ± 6.29%), while the latter was significantly easier to identify than anger and disgust (all ps < .001). There was also a significant main effect of group (F(1,46) = 8.63; $p < .01$; $\eta^2 = .16$), indicating

Table 2. Between-group comparisons on neuropsychological tests

Tests	Conditions	Male concussed	Male controls	Female concussed	Female controls	*F*	*p*-Value
RAVLT	Immediate recall	10.50 ± 2.07	11.92 ± 2.22	11.80 ± 2.04	11.38 ± 2.26	.94	.43
	Delayed recall	9.90 ± 2.42	11.77 ± 2.55	11.90 ± 1.79	11.00 ± 2.12	1.73	.17
RCFT	Immediate recall	21.35 ± 5.93	24.81 ± 3.31	24.45 ± 5.25	22.92 ± 6.65	.93	.43
	Delayed recall	21.75 ± 4.66	25.27 ± 3.76	23.75 ± 6.24	22.54 ± 6.69	.93	.43
SDMT		61.20 ± 6.71	64.00 ± 8.07	64.70 ± 5.93	65.77 ± 6.89	.84	.48
Verbal fluency		29.13 ± 5.36	32.44 ± 6.47	30.10 ± 6.24	29.95 ± 5.37	.70	.56
Stroop 1	Completion time	25.80 ± 2.78	24.46 ± 2.96	27.30 ± 4.37	24.50 ± 4.32	1.46	.24
	Total errors	0.40 ± 0.84	0.15 ± 0.38	0.50 ± 0.53	0.31 ± 0.48	.78	.51
Stroop 2	Completion time	19.30 ± 1.64	18.38 ± 1.85	20.44 ± 2.30	19.69 ± 2.87	1.62	.20
	Total errors	0.40 ± 0.52	0.08 ± 0.28	0.40 ± 0.70	0.08 ± 0.28	1.91	.14
Stroop 3	Completion time	42.50 ± 7.03	41.77 ± 7.32	43.22 ± 7.73	41.85 ± 5.11	.10	.96
	Total errors	1.30 ± 1.06	1.62 ± 1.61	1.50 ± 1.51	1.62 ± 1.26	.13	.94
Stroop 4	Completion time	51.90 ± 6.08	47.31 ± 6.55	51.00 ± 8.49	49.92 ± 7.27	.92	.44
	Total errors	1.70 ± 1.77	1.23 ± 1.36	1.20 ± 1.40	1.54 ± 1.39	.28	.84
Comprehension		23.70 ± 3.02	25.92 ± 4.42	25.80 ± 3.85	22.77 ± 4.73	1.72	.18

that concussed athletes ($M = 72.58\% \pm 5.74\%$) were significantly worse at recognizing negative emotions relative to control athletes ($M = 76.43\% \pm 5.15\%$). Importantly, analyses revealed a significant sex by group interaction ($F(1,46) = 5.31$; $p < .05$; $\eta^2 = .10$). Tukey's B *post hoc* analyses revealed that male concussed athletes (M = 69.24% ± 6.38%) were significantly worse at identifying negative emotions compared to male control athletes ($M = 76.81\% \pm 4.76\%$; $p < .01$; $d = -1.34$) and female concussed athletes ($M = 75.36\% \pm 3.33\%$; $p < .01$; $d = -1.20$), while female athletes did not show similar concussion effects (concussed athletes: $M = 75.36\% \pm 3.33\%$; control athletes $M = 75.99\% \pm 5.74\%$; $d = -.13$).

ANCOVAs were then conducted on accuracy for negative emotions for male and female concussed athletes, with time since the last concussion as a covariate. Again, there was a significant effect of sex ($F(1,19) = 7.81$; $p < .05$; $\eta^2 = .29$), indicating that time since the last concussion could not account for the significant difference between male and female concussed athletes on accuracy for negative emotions.

In contrast to negative emotions, there was only a significant main effect of emotion on accuracy for positive emotions ($F(1, 46) = 37.10$; $p < .001$; $\eta^2 = .45$), indicating that happiness ($M = 83.22 \pm 8.53\%$) was significantly easier to identify than surprise ($M = 72.44\% \pm 9.55\%$). There were no significant group differences in accuracy for positive emotions (all $ps > .05$) (see Figure 2).

Intensity threshold

A two-way ANOVA on intensity threshold for negative emotions revealed a significant main effect of emotion ($F(3,138) = 75.53$; $p < .001$; $\eta^2 = .62$). Pairwise comparisons indicated that participants needed significantly more emotional intensity to recognize fear ($M = 63.97 \pm 8.47\%$) than anger ($M = 51.79\% \pm 5.28\%$), disgust ($M = 50.42\% \pm 7.11\%$), and sadness ($M = 46.64\% \pm 4.14\%$), while they needed significantly less intensity to identify sadness than anger and disgust (all $ps < .001$). There was also a significant main effect of group ($F(1,46) = 7.31$; $p = .01$; $\eta^2 = .14$). showing that concussed athletes ($M = 54.54 \pm 3.97\%$) needed more intensity to recognize negative emotions than control athletes ($M = 52.15 \pm 3.08\%$). More importantly, analyses revealed a significant sex by group interaction ($F(1,46) = 6.02$; $p < .05$; $\eta^2 = .12$). Tukey's *post hoc* tests revealed that male concussed athletes ($M = 56.68\% \pm 4.56\%$) needed significantly more emotional intensity to identify the negative emotions compared to male control athletes ($M = 51.82\% \pm 3.16\%$; $p < .01$; $d = 1.24$) and female concussed athletes ($M = 52.77\% \pm 2.34\%$; $p < .05$; $d = 1.08$), while there was no difference between female concussed (M = 52.77% ± 2.34%) and same-sex control athletes ($M = 52.53\% \pm 3.05\%$; $p > .05$; $d = .09$) (see Figure 3).

ANCOVAs were then conducted on intensity threshold for negative emotions for male and female concussed athletes, with time since the last concussion as a covariate. Again, there was a significant effect of sex ($F(1,19) = 7.35$; $p < .05$; $\eta^2 = .28$), indicating that time since the last concussion could not account for the significant difference between male and female concussed athletes on intensity threshold for negative emotions.

In contrast to negative emotions, there was only a significant main effect of emotion on threshold for positive emotions ($F(1,46) = 22.44$; $p < .001$; $\eta^2 = .33$), indicating that participants needed less intensity to recognize happiness (M = 48.86% ± 6.53%) than surprise ($M = 54.84\% \pm 5.75\%$). There were no significant group differences in threshold for positive emotions (all $ps > .05$) (see Figure 4).

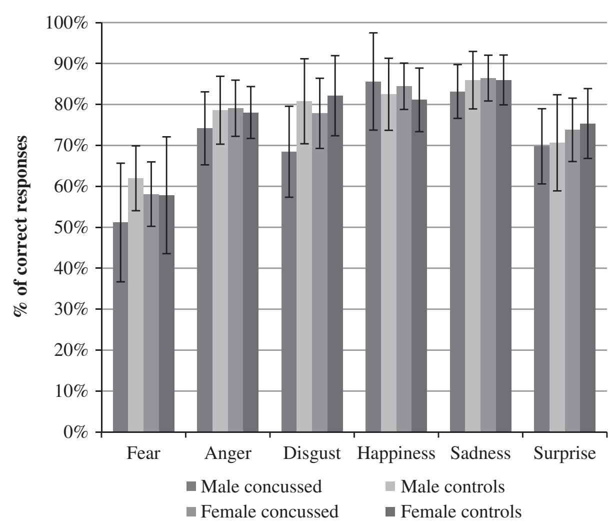

Fig. 2. Figure 2. Between-group comparisons in accuracy for all emotions.

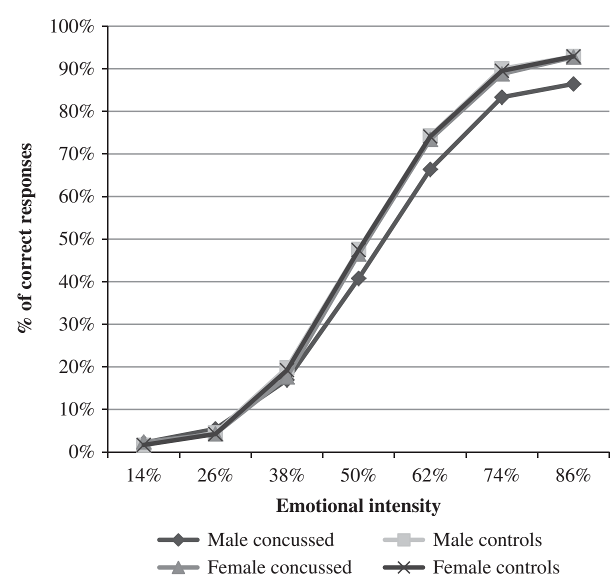

Fig. 3. Between-group comparisons in intensity threshold for negative emotions.

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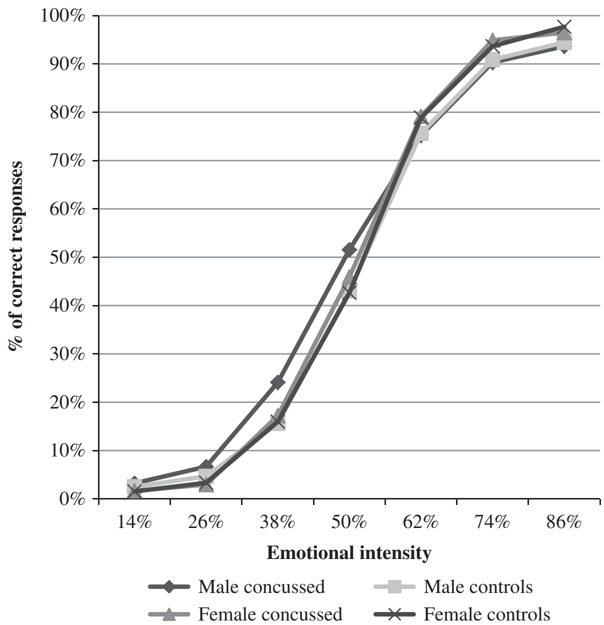

Fig. 4. Between-group comparisons in intensity threshold for positive emotions.

Correlational Analyses

After correction for multiple comparisons, there were no significant correlations between number of concussions, time since the last concussion, and emotion recognition in male and female concussed athletes (see Table 3).

Because of the small sample size, correlational analyses were also conducted among concussed athletes. Again, there were no significant correlations between number of concussions, time since the last concussion, and emotion recognition after correction for multiple comparisons (see Table 3).

To investigate whether subtle cognitive changes could drive negative emotion recognition alterations in male concussed athletes, correlational analyses were conducted between neuropsychological data and emotion recognition. After correction for multiple comparisons, there were no significant correlations between neuropsychological data and emotion recognition in male concussed athletes (see Table 4).

DISCUSSION

The current study investigated the effects of multiple concussions on emotion recognition in asymptomatic male and female athletes tested more than a year since the last concussion. Results revealed emotion recognition alterations in male concussed athletes, but not in females. These alterations were specific to negative emotional facial expressions. Male concussed athletes were worse than same-sex controls in recognizing negative emotions and needed more intensity to correctly identify these emotions. In contrast, female concussed athletes performed similarly to same-sex controls. The effect sizes were medium to large, particularly for the sex by group interaction in negative emotions accuracy and intensity threshold. The robustness of these findings is further supported by several studies that have shown that morphed emotion recognition tasks are particularly sensitive to subtle emotion recognition alterations (Bishop et al., 2015; Harmer et al., 2002; Humphreys et al., 2007; Richards et al., 2002).

Results in male concussed athletes are consistent with several studies in which patients with TBI were found to be impaired in recognizing emotions, particularly negative emotions (Callahan et al., 2011; Croker & McDonald, 2005; Hopkins et al., 2002; Ietswaart et al., 2008; McDonald et al., 2003, 2011; Williams & Wood, 2010). Notably, recognition of positive emotions was preserved in concussed athletes. This result is also consistent with studies of TBI in which recognition of happiness was found to be spared while recognition of all the other basic emotions was affected (Callahan et al., 2011; Croker & McDonald, 2005; Hopkins et al., 2002; Ietswaart et al., 2008; McDonald et al., 2003, 2011; Williams & Wood, 2010).

Several explanations may account for this effect of emotional valence. First, there are fewer positive than negative emotions, which could make it easier to distinguish one positive emotion from another (Adolphs et al., 1996; Callahan et al., 2011; Croker & McDonald, 2005; Williams & Wood, 2010). A related issue is that happiness is often considered to be the only basic positive emotion, which could make it easier to recognize than negative emotions (Adolphs et al., 1996). Second, happiness is the only emotion that is expressed with the stereotypic smile which may also facilitate recognition (Callahan et al., 2011). In contrast, negative emotions are known to share many facial features such as a frown, furrowed brows, and widened jaws, which were suggested to render recognition of negative emotions more difficult (Callahan et al., 2011; Croker & McDonald, 2005; Smith, Cottrell, Gosselin, & Schyns, 2005; Williams & Wood, 2010). In line with this, recent research has suggested that task difficulty may account for the differential impairment in emotion recognition in TBI (Ietswaart et al., 2008; Rapcsak et al., 2000; Rosenberg, Dethier, Kessels, Westbrook, & McDonald, 2015).

In particular, Rosenberg et al. (2015) found that TBI patients were impaired at recognizing emotions in general, while being more impaired at recognizing negative emotions. However, when they examined accuracy across the different intensities, they showed that this differential impairment was driven by some emotions such as happiness being easier to recognize than others. In our study, participants recognized happiness expressed at 62% of emotional intensity in 83% of trials in which it was presented, while they recognized negative emotions such as anger, disgust, fear, and sadness expressed at the same intensity on 72% of trials in which they were presented. In light of these findings, one cannot exclude the possibility that task difficulty may at least partially account for the pattern of results observed in male concussed athletes.

One possible explanation for gender differences in emotion recognition in multi-concussed athletes is that concussion tends to exacerbate premorbid ailments or difficulties

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Table 3. Correlations between number of concussions, time since the last concussion, and emotion recognition in male concussed athletes, female concussed athletes, and concussed athletes as a group

	Male concussed athletes		Female concussed athletes		Concussed athletes	
	No. of concussions	Time since the last concussion	No. of concussions	Time since the last concussion	No. of concussions	Time since the last concussion
Accuracy						
Fear	.20	–.07	.39	–.16	.31	.07
	(.57)	(.84)	(.21)	(.61)	(.16)	(.77)
Anger	.15	.00	–.42	–.34	–.08	–.03
	(.68)	(.99)	(.17)	(.29)	(.74)	(.91)
Disgust	–.38	.03	–.15	.34	–.13	.40
	(.28)	(.93)	(.63)	(.28)	(.55)	(.07)
Happiness	–.60	.04	.33	.19	–.30	–.02
	(.07)	(.91)	(.29)	(.55)	(.18)	(.94)
Sadness	–.04	–.30	–.42	–.21	–.17	–.06
	(.92)	(.39)	(.17)	(.51)	(.45)	(.79)
Surprise	.36	.24	.56	.50	.49	.44
	(.30)	(.51)	(.06)	(.10)	(.02)	(.04)
Intensity threshold						
Fear	–.07	.10	–.38	.15	–.21	–.08
	(.85)	(.78)	(.22)	(.64)	(.35)	(.72)
Anger	–.29	.10	.37	.43	.01	.16
	(.42)	(.79)	(.24)	(.17)	(.96)	(.48)
Disgust	.27	.08	.34	–.21	.18	–.28
	(.45)	(.82)	(.27)	(.51)	(.43)	(.20)
Happiness	.57	–.10	–.32	–.27	.26	–.04
	(.09)	(.77)	(.31)	(.40)	(.24)	(.87)
Sadness	.08	.29	.43	.21	.22	.12
	(.83)	(.41)	(.16)	(.52)	(.32)	(.59)
Surprise	–.30	–.30	–.59	–.57	–.43	–.41
	(.41)	(.40)	(.04)	(.05)	(.04)	(.06)

Note. p-Values are presented in parentheses.

(Bryant et al., 2010; Deb, Lyons, & Koutzoukis, 1999; Deb, Lyons, Koutzoukis, Ali, & McCarthy, 1999; Ellis et al., 2015; Fleminger, 2008; Koponen, Taiminen, Hiekkanen, & Tenovuo, 2011; Koponen et al., 2002). In keeping with this notion, studies have found that baseline differences in symptoms and neuropsychological testing may at least partially account for sex differences after concussion (Brown, Elsass, Miller, Reed, & Reneker, 2015; Covassin, Elbin, Bleecker, Lipchik, & Kontos, 2013; Covassin et al., 2006; Dick, 2009; Zuckerman et al., 2014). A longitudinal study with baseline and post-concussion testing would be helpful in confirming the differential pattern of results across sex.

Alternatively, it is possible that menstrual cycle and hormonal levels could at least partially account for sex-related differences in emotion recognition after concussion. Interestingly, a recent study showed that women injured during the luteal phase of their menstrual cycle, when progesterone is high relative to estrogen, had lower quality of life and neurologic outcome than women injured during the follicular phase of their cycle or those taking oral contraceptives (Wunderle, Hoeger, Wasserman, & Bazarian, 2014). Furthermore, women taking oral contraceptives or in the follicular phase of their cycle are better at recognizing emotions, particularly negative emotions such as anger and fear, and have stronger activation in both the amygdala and fusiform face area (Derntl, Kryspin-Exner, et al., 2008; Derntl, Windischberger, et al., 2008; Guapo et al., 2009; Marečková et al., 2012; Pearson & Lewis, 2005). Another study showed associations between progesterone levels and amygdala response to fearful, sad, and neutral faces (Marečková et al., 2012). Although conjectural, it is plausible that intrinsic and cyclic changes in hormonal levels may have contributed to sex-related emotion recognition differences among concussed athletes. Lastly, given the increased propensity for female concussed athletes to develop affective disorders such as depression and anxiety (Ellis et al., 2015; Fenton et al., 1993; Trojian, 2016; Yang et al., 2015), one target for future studies should be to investigate the interplay between anxiety, depression, and emotion recognition in a sample of concussed athletes presenting with symptoms of anxiety and depression.

There are several methodological limitations to this study. First, our sample size of self-reported concussion cases was relatively small. Second, we tested multi-concussed athletes only, which limits the generalizability of the findings of the current study to a subset of the population of concussed

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Table 4. Correlations between neuropsychological data and emotion recognition in male concussed athletes

	RAVLT		RCFT				Stroop 3		Stroop 4		
	Immediate recall	Delayed recall	Immediate recall	Delayed recall	SDMT	Verbal fluency	Completion time	Total errors	Completion time	Total errors	Comprehension
Accuracy											
Fear	.15	−.17	−.10	.15	.24	.03	−.35	−.67	−.70	.09	.40
	(.68)	(.64)	(.79)	(.68)	(.51)	(.93)	(.32)	(.03)	(.02)	(.81)	(.26)
Anger	−.21	−.30	−.34	−.09	.30	.15	−.20	−.27	−.16	.59	.36
	(.57)	(.39)	(.34)	(.80)	(.40)	(.68)	(.59)	(.44)	(.67)	(.07)	(.31)
Disgust	−.12	.06	−.25	−.53	−.15	−.20	.13	.05	.39	.41	−.03
	(.74)	(.87)	(.49)	(.12)	(.67)	(.58)	(.73)	(.89)	(.26)	(.24)	(.94)
Happiness	−.12	.02	−.25	−.12	−.15	−.20	.03	−.32	−.46	−.53	.05
	(.74)	(.96)	(.48)	(.75)	(.69)	(.57)	(.94)	(.36)	(.18)	(.11)	(.89)
Sadness	.19	.00	.06	.36	.29	.25	−.29	−.44	−.59	−.29	.06
	(.59)	(1.00)	(.87)	(.31)	(.41)	(.49)	(.42)	(.21)	(.07)	(.42)	(.88)
Surprise	.16	.01	.02	−.11	−.37	−.71	.06	−.46	−.54	−.65	.03
	(.67)	(.97)	(.97)	(.76)	(.29)	(.02)	(.88)	(.18)	(.11)	(.04)	(.92)
Intensity threshold											
Fear	−.07	.14	.23	−.02	−.26	.00	.26	.66	.65	−.11	−.35
	(.84)	(.70)	(.53)	(.97)	(.48)	(1.00)	(.47)	(.04)	(.04)	(.75)	(.32)
Anger	.11	.24	.26	.02	−.37	−.22	.19	.24	.14	−.57	−.25
	(.76)	(.51)	(.47)	(.97)	(.30)	(.54)	(.59)	(.51)	(.69)	(.09)	(.49)
Disgust	.14	−.06	.21	.50	.14	.28	−.18	−.07	−.46	−.25	.17
	(.69)	(.88)	(.55)	(.14)	(.69)	(.43)	(.62)	(.84)	(.18)	(.49)	(.63)
Happiness	.06	−.14	.14	.00	−.08	.21	.13	.40	.46	.47	−.10
	(.87)	(.70)	(.71)	(.99)	(.82)	(.56)	(.73)	(.25)	(.18)	(.17)	(.79)
Sadness	−.25	−.16	−.19	−.41	−.38	−.38	.17	.20	.37	.20	−.01
	(.49)	(.66)	(.60)	(.23)	(.28)	(.29)	(.64)	(.58)	(.29)	(.58)	(.98)
Surprise	−.22	−.04	−.10	.09	.53	.56	−.11	.23	.42	.58	−.02
	(.54)	(.91)	(.77)	(.80)	(.11)	(.09)	(.75)	(.52)	(.23)	(.08)	(.96)

Note. p-Values are presented in parentheses.

athletes. Finally, we did not measure menstrual cycle and hormonal levels in females at the moment of testing. Large-scale, follow-up studies conducted with single and multi-concussed athletes including menstrual cycle and hormonal measures are therefore warranted to further confirm the validity of the present study findings. Nevertheless, this study provides evidence that multiple concussions induce long-term changes in the processing of negative emotional facial expressions in asymptomatic male concussed athletes, but not in females.

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