Preserved rapid conceptual processing of emotional expressions despite reduced neuropsychological performance following traumatic brain injury

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Abstract

Objective: Emotional empathy is critical to successful social interactions and is often compromised following traumatic brain injury (TBI). Using the EmoStroop task, we investigated whether adults with moderate to severe TBI (N=26) have problems with rapid conceptual processing of emotional stimuli compared to controls (N=30). Further, we investigated whether rapid conceptual processing of emotions relates to emotion recognition and emotional empathy.

Method: In the EmoStroop task, participants categorise emotional words (e.g. joyous, furious, woeful) into three emotion categories: happy, sad and angry. Each word is superimposed onto an image of a face, which expresses an emotion that is congruent to the word (congruent condition), incongruent to the word (incongruent condition) or is neutral (neutral condition). Slowed responding in the incongruent condition (interference) and speeded responding in the congruent condition (facilitation) indicates rapid conceptual processing of the faces. Participants also completed an emotion perception task, an empathy questionnaire (the BEES) and neuropsychological tests measuring processing speed, working memory and executive function.

Results: Contrary to our hypotheses, we found that rapid conceptual processing of emotional faces was preserved in people with TBI, despite diminished neuropsychological performance, emotion recognition, emotional empathy and slowed responding. Further, the EmoStroop effect was not correlated with self-reported emotional empathy or with emotion recognition.

Conclusions: We conclude that in people with TBI, reduced empathy may be explained by processes downstream of the initial rapid conceptual processing of emotional information, such as flexibly attending and responding to this information in a goal-directed manner in complex environments.

Keywords: Emotional empathy, EmoStroop, Emotion recognition, traumatic brain injury

Public significance statement: Understanding what underpins reduced emotional empathy after traumatic brain injury will be critical to developing successful rehabilitation techniques and thus alleviating the burden to patients and carers. In this study, we found no relationship between rapid conceptual processing and self-reported emotional empathy. As such, future research should explore other avenues to advance our understanding of what causes empathy deficits after TBI.

Emotional empathy, also known as affective empathy, refers to the transfer of subjective emotional states between people, which allows the observer to share, or 'resonate' with, the emotional state of the target (Davis, 2018). Emotional empathy is critical to successful social interactions, as it allows an individual to understand and to respond appropriately to the emotional states of others (Decety, 2010). Following a traumatic brain injury (TBI), people often have a reduced ability to resonate with the emotions of others (de Sousa et al., 2010, 2011; Williams & Wood, 2010; Wood & Williams, 2008), and these changes are thought to contribute to difficulties in psychosocial adjustment (Brooks, Campsie, Symington, Beattie, & McKinlay, 1986) and the well-being of close others (Wells, Dywan, & Dumas, 2005). Despite these significant implications of diminished empathy following TBI, relatively little research has directly investigated the mechanisms behind this failure of empathetic abilities.

One theoretical avenue worth exploring is the perception-action model (PAM; Preston, 2007) of empathy. The PAM proposes that when an observer pays attention to the emotional state of a target, all relevant *conceptual* representations relating to the observed emotional experience are rapidly and automatically activated in the mind of the observer (Preston, 2007). These might include semantic representations of associated labels (e.g. "happy", "sad"), ideas about what it means to feel that way and one's own relevant memories related to that emotion. To the extent that an observer possesses relevant representations, this rapid and automatic activation allows the observer to understand the emotion displayed and resonate with the target. Thus, PAM suggests that rapid activation of all relevant representations allow the observer to rapidly access *meaning* in the stimuli and to gain a 'true understanding'. Critically, this hypothesis stands in contrast to the emotional contagion hypothesis, which suggests that emotional empathy is achieved through the rapid mimicry of the facial expressions of others. While past research has demonstrated that mimicry may play

a role in reduced empathy after TBI (de Sousa et al., 2010, 2011), our study sought to determine whether the rapid conceptual processing proposed by the PAM plays a role.

Evidence that the emotions of others are rapidly understood at a conceptual level was presented by Preston and Stansfield (2008) in the form of the EmoStroop effect. The EmoStroop task involves participants categorising emotional words superimposed on emotional faces which are either congruent to the word (e.g. a happy word superimposed on a happy face), or incongruent to the word (e.g. a happy word superimposed on an angry face). Preston and Stansfield (2008) demonstrated that people are slower to categorise words in the incongruent condition compared with the congruent condition, indicating that the background face, although irrelevant to the task, interferes with the semantic classification of the words. This interference must occur because the face is rapidly processed at a conceptual (i.e. semantic) level. This effect provides evidence that the emotional expressions of others spontaneously activate representations in the observer's brain that facilitate *true understanding*. Thus, observing another's emotional expression does not just generate reflexive mimicry as is suggested by the emotional contagion hypothesis. In fact, mimicry to the EmoStroop task has been found to be more reliable in response to emotional words than faces (Hofelich and Preston, 2012), suggesting that mimicry is actually occurring *as the result of* conceptual processing. Consequently, the loss of emotional mimicry reported in people with TBI might be explained by a loss of rapid conceptual processing of emotional material leading to diminished post-conceptual mimicry, rather than a primary mimicry deficit.

Using the Emotroop task, we investigated the role of rapid conceptual processing of emotional stimuli in the ability to understand emotional expressions (assessed with an emotion recognition task) and to resonate with others (assessed using a self-report emotional empathy questionnaire) in people with TBI. On the assumption that people with TBI have a

problem with the rapid conceptualisation of emotional material, we hypothesised that participants with TBI would not demonstrate the EmoStroop effect. We also predicted that if rapid semantic processing of emotional faces is indicative of *true understanding*, then the EmoStroop effect should be related to performance on an emotion recognition task. Thirdly, we hypothesised that a diminished EmoStroop effect would be related to diminished self-reported trait empathy, on the basis of the proposed role of rapid conceptual processing of emotional faces in empathy. Finally, in line with Hofelich and Preston (2012), we examined mimicry to the emotional words in the EmoStroop task. Given that mimicry is reduced to emotional faces following TBI, we predicted that mimicry to emotional words would also be blunted.

Method

Participants

Twenty-six adults (19 males) who had sustained a moderate to severe traumatic brain injury (TBI) of mean age 45.73 years (*SD*=14.35, range: 21 to 68) with an average of 13.69 years of formal education (*SD*=2.90, range: 9 to 20) participated. We recruited all participants from our database of participants and from internet advertisements. Included participants met the following criteria: they had sustained a moderate to severe TBI, were discharged from hospital and living in the community, were proficient in English and had no substance abuse or dependence. The participants with TBI had experienced post-traumatic amnesia (PTA) ranging from 6 to 180 days (*M*=53.48, *SD*=50.43). Medical records of three participants did not specify PTA. In one of these cases, records specified left frontal craniectomy through the left frontal bone with large atrophy in the left frontal lobe, indicating a severe injury. In another case, medical records specified that a GCS of 3 was recorded at the scene and that a CT scan showed right frontal haematoma, right temporal and left anterior frontal contusion.

In the final case, no records were available because the injury was sustained 48 years prior. In this case, we confirmed that the participant was an in-patient at a brain injury rehabilitation unit after their injury, indicating that the injury was severe. As is typical with this population, the injuries were heterogeneous and included skull fractures, contusions, and intracerebral and subdural or subarachnoid hemorrhages. Participants were 2 to 48 years post injury (*M*=14.65, *SD*=13.78). The brain injuries were sustained as a consequence of motor vehicle accidents (n=18) and falls (n=8).

Control participants were 30 adults (20 males) without brain injury with a mean age of 41.70 years (*SD*=14.97, range: 19 to 68) and an average of 15.00 years of education (*SD*=2.68, range: 10 to 21). We recruited these controls from the community via online and advertisements. The control group did not differ significantly from the TBI group concerning age, $t(54)=1.024$, $p=.310$, number of years of education, $t(54)=-1.76$, $p=.085$ or HADS anxiety, $t(54)=.81$, $p=.421$, or depression score, $t(54)=1.98$, $p=.051$. Both group means were below the cut-off score of 8 indicating clinical anxiety or depression (Bjelland, Dahl, Haug, & Neckelmann, 2002; Zigmond & Snaith, 1983). Pearson's Chi Square analyses also indicated that the groups were comparable in gender ($p = .603$). Exclusion criteria for both groups were; a history of drug or alcohol dependence, a history of stroke or epilepsy, a diagnosis of a learning difficulty or of a significant psychiatric disorder, and any significant perceptual problems that would prevent the participant from completing the task. Demographic characteristics of both groups are displayed in Table 1.

Table 1 about here.

EmoStroop Task

EmoStroop stimuli consisted of emotional adjectives superimposed over pictures of faces. The faces either had a neutral expression, an emotional expression incongruent to the

overlaid word or an emotional expression congruent with the overlaid word. Participants categorised the emotional adjectives into three categories (happy, sad or angry) using the '1' '2' or '3' keys on the keyboard, which were labelled as 'H' for happy 'S' for sad and 'A' for angry. The variable of interest was the reaction time for these key presses.

The pictures of faces were taken from stimuli in the Emotion Recognition Test (Montagne, Kessels, De Haan, & Perrett, 2007). The pictures were of four actors (2 male, 2 female) with a happy, sad, or angry expression at full intensity, or a neutral expression. We converted the pictures to greyscale from their original colour format. The words were in yellow font and were superimposed over the middle of the face image (across the nose). There were six words for each emotion category: happy (*cheerful, glad, gleeful, jolly, joyful, delighted*), sad (*depressed, gloomy, glum, hopeless, sorrowful, woeful*), angry (*enraged, furious, hateful, hostile, outraged, wrathful*). Examples of the congruent, incongruent and incongruent-neutral stimuli in all three emotional word categories are shown in Figure 1. There were 72 possible congruent trials (three emotional expressions x four actors x six possible corresponding words), 72 possible neutral trials, (one expression x four actors x 18 emotional adjectives) and 144 possible incongruent trials (three emotional expressions x four actors x 12 incongruent emotional adjectives). The task consisted of a total of 105 trials (35 congruent trials, 35 incongruent trials and 35 neutral trials), which the program randomly selected for each participant from the pool of possible trials. This was somewhat fewer than the 144 trials used by Hofelich and Preston (2012) in order to make the task length feasible for people with TBI. On each trial, the subject saw an eight-second fixation cross on a black screen before seeing the stimulus. The stimulus remained on the screen until the participant had responded, or for four seconds if the participant did not respond in time. There were six practice trials at the beginning of the task (two congruent, two incongruent and two neutral) which we did not include in the analysis. For analysis, we removed trials on which words

were classified incorrectly or on which the response time exceeded four standard deviations over the participant's mean (following Hofelich & Preston, 2012).

Figure 1 about here

EMG

Facial EMG was continuously recorded during the EmoStroop task from the *corrugator supercilli* (brow; associated with sad or angry affect) and from the *zygomaticus major* (cheek; associated with happy affect) muscles using a Powerlab BioAmp system (AD Instruments, Castle Hill, Australia). Bipolar 9mm gold-plated electrodes were filled with conductive paste and placed on the left side of the face with an interelectrode distance of approximately 1.5 cm. The ground electrode was placed on the upper portion of the forehead. EMG signals were digitized at a sampling rate of 1000 Hz, and integrated with a time constant set to 100 ms. Facial mimicry per trial was calculated by subtracting the mean baseline activity (1000-0 ms before the stimulus onset) from the mean trial activity (500-1000 ms after stimulus onset).

Trait Empathy

Participants completed the *Balanced Emotional Empathy Scale* (BEES; Mehrabian, 1997), a self-report, 30-item, unidimensional measure of emotional empathy with good internal consistency (Cronbach's α=.87), good test-retest reliability (r=.77) and good construct validity in healthy controls. This measure has also been shown to be sensitive to diminished empathy after TBI (Wood & Williams, 2008).

Cognitive Functioning

We assessed each participant for (a) premorbid ability: Shipley-2 Crystallized Knowledge (Shipley, Gruber, Martin, & Klein, 2009), (b) working memory: Wechsler Adult

Intelligence Scale-Fourth Edition (WAIS IV; Wechsler, 2008) Digit Span, (c) processing speed: WAIS-IV Digit Symbol Coding and Symbol Search and Trail Making Test A, (d) executive functions: inhibition; Hayling Sentence Completion Test (Burgess & Shallice, 1997) and flexibility; Trail Making Test B (Reitan & Wolfson, 1995).

Emotional Functioning

Each participant completed the *Hospital Anxiety and Depression Scale* (HADS; Snaith & Zigmond, 1994) to assess symptoms of depression and anxiety.

Emotion Perception

All participants completed an emotion intensity rating task as described in (Osborne-Crowley & McDonald, 2016). Stimuli were 21 static images of one of four actors (two male and two female) portraying one of six emotions (happiness, surprise, sadness, anger, fear and disgust), or a neutral expression. The stimuli were still images taken from the Emotion Recognition Test (ERT; Montagne et al., 2007) a computer-generated program that shows a series of 216 video clips of facial expressions across different intensities. The stimuli were developed using algorithms which created intermediate morphed images between a neutral face (0% emotion) and a full-intensity expression (100% emotion). To avoid floor and ceiling effects, based on data from Rosenberg et al. (2014) we used 100% intensity of expression for fear, sadness, and surprise stimuli, 80% intensity of expression for anger and disgust stimuli, and 30% intensity for happy stimuli. Following the protocol of Heberlein et al. (2008) participants were asked to rate each facial expression for how intensely each of the six basic emotions was expressed on six corresponding scales from 0 (*none of the specified emotion detected*) to 10 (*an intense amount of the specified emotion detected*). Thus, for each stimulus, participants provided six ratings of intensity (corresponding to six emotions) before proceeding to the next stimulus. Of interest for this study was the overall accuracy score,

which was calculated by determining the number of trials on which the target emotion was rated as the most intense emotion present.

Procedure

All participants were informed of the study procedures and gave informed written consent to participate in the study. The Human Research Ethics Committee of the Sydney South West Area Health Service (Royal Prince Alfred Hospital Zone) approved the study procedure. We conducted this study across two sessions, which took place between one week and two months apart. Participants completed all cognitive functioning tests at Time 1. If a participant had completed a neuropsychological assessment in our lab in the past 12 months, we did not repeat the test but took the score from the previous assessment. This was to reduce effects of repeated testing on these cognitive variables. Participants also completed the empathy questionnaires at Time 1. Participants completed the EmoStroop and emotion perception tasks at Time 2, as well as the HADS.

Statistical Analyses

Statistical analyses were performed in SPSS. Significance level was $\alpha = .05$.

Group differences on general cognitive functioning, emotion perception and empathy. We used t-tests to determined whether the groups differed on general cognitive functioning, self-reported emotional empathy and on emotion recognition accuracy.

EmoStroop. To investigate whether the EmoStroop effect differed across groups, we conducted mixed 2 (Group: TBI, Control) by 3 (Congruency: Congruent, Neutral, Incongruent) ANOVA with latency as the dependent variable. We also conducted follow-up mixed ANOVA's to determine whether the two groups had different pattern of latencies across positive and negative emotions. For the congruent trials, we conducted a mixed 3 (Condition: Happy, Angry, Sad) by 2 (Group: TBI, Control) ANOVA. Similarly, for the

neutral trials, we conducted a mixed 3 (Condition: Happy, Angry, Sad) by 2 (Group: TBI, Control) ANOVA. For the incongruent trials, there were too many individual word/face combinations to examine each as a separate condition. Thus we divided the incongruent trials into three conditions: 1. Negative words on positive faces (i.e. angry or sad word on a happy face), 2. Positive words on negative faces (i.e. happy word on sad or angry face) and 3. Negative words on negative faces (e.g. sad word on angry face or angry word on sad face). The first two conditions are incongruent along valence lines and the third condition is incongruent with respect to specific emotion.

Mimicry. Due to excessive movement artefact, 1 control participants and 2 participants with TBI were excluded from the mimicry analysis, leaving a remaining sample of 29 controls and 24 participants with TBI. For analysis, trials on which an incorrect response was made were removed. Artefact rejection led to 6.4% of trials in the control group and 8.2% of trials in the TBI group being removed for analysis.

First, to investigate zygomaticus mimicry to emotional words, we conducted a mixed 3 (Word: Happy, Sad, Angry) by 2 (Group: TBI, Control) ANOVA. Next, to investigate the effect of congruent versus incongruent background faces on the mimicry of happy words, we conducted a mixed 3 (Condition: Happy word on happy face, Happy word on angry face, Happy word on sad face) by 2 (Group: TBI, Control) ANOVA. To investigate zygomaticus mimicry to background faces, we conducted a mixed 4 (Face: Happy, Angry, Sad, Neutral) by 2 (Group: TBI, Control).

Then, to investigate corrugator mimicry to emotional words, we conducted a mixed 3 (Word: Happy, Sad, Angry) by 2 (Group: TBI, Control) ANOVA. Next, to investigate the effect of congruent versus incongruent background faces on the mimicry of sad and angry words, we conducted a mixed 3 (Condition: Sad word on sad face, Sad word on angry face,

Sad word on happy face) by 2 (Group: TBI, Control) ANOVA and a mixed 3 (Condition: Angry word on angry face, Angry word on sad face, Angry word on happy face) by 2 (Group: TBI, Control) ANOVA. Finally, to investigate corrugator mimicry to faces, we conducted a mixed 4 (Emotion: Happy, Sad, Angry, Neutral) by 2 (Group: TBI, Control) ANOVA.

Correlations. Primarily, we were interested in correlations between the EmoStroop task and emotion recognition and self-reported empathy on the BEES. First, we calculated an EmoStroop difference score by subtracting the mean latency for congruent trials from the mean latency for incongruent trials for each participant. Six controls and six people with TBI did not demonstrate the EmoStroop effect (i.e. did not show slower latencies for incongruent compared to congruent). We then correlated this difference score with emotion recognition accuracy scores and with self-reported empathy scores.

Secondly, we were interested in whether the EmoStroop difference score, Emostroop latency, Emostroop accuracy or emotion recognition accuracy correlated with general cognitive function. We calculated three general cognitive functioning scores. The working memory score was the standard score for the WAIS-IV digit span task. The processing speed composite score was an average of Z scores for TMT A, WAIS-IV Coding and WAIS-IV Symbol Search. Use of this composite measure was justified, since all three measures were significantly correlated (all r's >.667, all p's <.001). The executive function composite score was an average of Z scores for TMT B and the standard score for the Hayling's sentence completion task. Use of this composite measure was justified, the two measures were correlated (r=-.432, all p=.001). All Z scores were calculated using the control group mean and standard deviations, which can be found in Table 1. All correlations presented in Table 2 were conducted on the whole sample (people with TBI and controls combined). Finally, we conducted correlations between the mimicry scores and self-reported empathy on the BEES.

Results

General cognitive functioning, empathy and emotion perception

Participants with TBI were not significantly different from controls on their premorbid ability, estimated by Shipley-2 Vocabulary, $t(54)=-1.58$, $p=.119$. Participants with TBI did differ from controls on a range of neuropsychological tests measuring working memory ($p=.041$), processing speed ($p<.001$ for both measures), and executive functions ($p<.01$ for all measures). See Table 1 for details. Participants with TBI had significantly lower self-reported emotional empathy scores on the BEES, $t(54)=-2.14$, $p=.037$, and had significantly lower emotion recognition accuracy scores, $t(54)=-3.41$), $p=.001$. Because our TBI sample varied greatly with respect to time since injury, and because differences between groups on years of education and self-reported depression approached significance, we checked whether any of these variables were related to our key Emostroop variables. Neither time since injury, years of education, nor HADS depression score was related to any of the Emostroop variables (Emostroop effect size, average latency or number of errors).

EmoStroop

Control participants made on average 3.7 errors ($SD=7.17$), while participants with a TBI made on average 8.3 errors ($SD=13.36$), which was not significantly different, $t(54)=1.65$, $p=.104$. The groups also did not differ on the number of errors made on congruent, incongruent or neutral trials, or on the number of happy, sad or angry trials (p's all >.05). We excluded a total of 217 trials in the TBI group and 111 trials in the control group on the basis of errors in word classification. Further, we excluded a total of 12 trials in the TBI group and 21 trials in the control group on the basis of latency exceeding 4 SDs above the participant's average.

The mixed 2 (Group: TBI, Control) by 3 (Condition: Congruent, Neutral, Incongruent) ANOVA revealed a significant main effect of group, $F(1,54)=10.52$, $p=.002$, $\eta^2=.16$, such that latencies were slower in the TBI group compared to the control group. There was also a significant main effect of congruency, $F(2,108)=10.83$, $p<.001$, $\eta^2=.17$. Post-hoc pairwise comparisons with a Bonferroni adjustment revealed that latencies on congruent trials were faster than latencies on neutral trials ($p=.038$), which were faster than latencies on incongruent trials ($p=.022$). There was no group by congruency interaction effect ($p=.557$), indicating that the EmoStroop effect did not differ between groups. These results are shown in Figure 2. Because gender has been identified as an important variable in a range of emotional processing measures, we re-ran our analysis on only the male participants in our sample, but this did not change the results.

Figure 2 about here

We also conducted follow-up ANOVA's to examine differences between trial types within the congruent, incongruent and neutral conditions. For the congruent trials, the mixed 3 (Condition: Happy, Angry, Sad) by 2 (Group: TBI, Control) revealed was a main effect of condition, $F(2,106)=37.564$, $p<.001$, $\eta^2=.415$, a main effect of group, $F(1,53)=8.633$, $p<.005$, $\eta^2=.140$, and a group by condition interaction, $F(2,106)=5.115$, $p=.008$, $\eta^2=.088$. Overall, participants categorised negative words slower than positive words (Happy: $M=1051$, $SD=39.582$, Sad: $M=1298.220$, $SD=55.826$, Angry: $M=1324.877$, $SD=66.321$). This effect was larger for the TBI group compared to the control group. Means and standard deviations are shown in Figure 3.

For the neutral trials, the mixed 3 (Condition: Happy, Angry, Sad) by 2 (Group: TBI, Control) revealed a main effect of condition, $F(2,106)=27.533$, $p<.001$, $\eta^2=.342$, a main effect of group, $F(1,53)=9.701$, $p=.003$, $\eta^2=.155$, and a group by condition interaction,

$F(2,106)=5.994$, $p=.003$, $\eta^2=.102$. Overall, participants had slower latencies for categorising negative words compared to positive words (Happy: $M=1103.464$, $SD=42.099$, Angry: $M=1338.073$, $SD=64.134$, Sad: $M=1314.654$, $SD=54.405$). This effect was larger for the TBI group compared to the control group. Means and standard deviations are shown in Figure 3.

Finally, for the incongruent trials, the mixed 3 (Condition: Negative words on negative face, Negative word on positive face and Positive word on negative face) by 2 (Group: Control, TBI) revealed a main effect of condition, $F(2,106)=31.191$, $p<.001$, $\eta^2=.370$, a main effect of group, $F(1,53)=8.707$, $p=.005$, $\eta^2=.141$, and a condition by group interaction, $F(2,106)=8.303$, $p<.001$, $\eta^2=.135$. Overall, participants had longer latencies when categorising negative words compared to positive words (Positive words on negative face: $M=1142.942$, $SD=45.887$, Negative word on negative face: $M=1372.670$, $SD=63.135$, Negative word on a positive face: $M=1387.716$, $SD=716$). This effect was larger for the TBI group compared to the control group. Means and standard deviations are shown in Figure 3.

Figure 3 about here.

Mimicry

Zygomaticus. First, to investigate zygomaticus mimicry to emotional words, we conducted a mixed 3 (Word: Happy, Sad, Angry) by 2 (Group: TBI, Control) ANOVA. There was a main effect of emotion, $F(2,102)=3.20$, $p=.045$, $\eta^2=.06$, whereby mimicry to happy words ($M=.212$, $SE=.09$) was greater than to angry words ($M=.035$, $SE=.06$; $p=.046$) and to sad words ($M=.038$, $SE=.06$; $p=.058$). There was no difference between zygomaticus mimicry to sad and angry words ($p=.964$). There was no main effect of group, $F(1,51)=.29$, $p=.591$, and no group by emotion interaction, $F(2,102)=1.15$, $p=.322$. Next, to investigate the effect of congruent versus incongruent background faces on the mimicry of happy words, we conducted a mixed 3 (Condition: Happy word on happy face, Happy word on angry face,

Happy word on sad face) by 2 (Group: TBI, Control) ANOVA. There were no main effect of condition, $F(2,102)=.55$, $p=.581$, no effect of group, $F(1,51)=.94$, $p=.338$, and no interaction effect, $F(2,102)=.63$, $p=.537$, showing that congruence of the background face did not affect mimicry of happy words. Finally, to investigate zygomaticus mimicry to background faces, we conducted a mixed 4 (Face: Happy, Angry, Sad, Neutral) by 2 (Group: TBI, Control). There was no main effect of condition, $F(3,153)=1.21$, $p=.310$, no effect of group, $F(1,51)=.29$, $p=.591$, and no interaction effect, $F(3,153)=.51$, $p=.675$.

Corrugator. First, to investigate corrugator mimicry to emotional words, we conducted a mixed 3 (Word: Happy, Sad, Angry) by 2 (Group: TBI, Control) ANOVA. There was an emotion by group interaction, $F(2,102)=3.31$, $p=.041$, $\eta^2=.06$, no main effect of emotion, $F(2,102)=.51$, $p=.604$ and no main effect of group, $F(1,51)=.04$, $p=.836$. We conducted two separate univariate ANOVAs comparing the emotional words in each group. There was no effect of emotion for controls, $F(2,56)=1.67$, $p=.197$, but there was a trend towards an effect of emotion in the TBI group, $F(2,46)=2.73$, $p=.076$. Post-hoc pairwise comparisons with a Bonferroni adjustment showed a trend towards greater corrugator mimicry to sad ($M=.025$, $SE=.10$) compared to happy words ($M=-.114$, $SE=.13$) in the TBI group, $p=.064$. Next, to investigate the effect of congruent versus incongruent background faces on the mimicry of sad words, we conducted a mixed 3 (Condition: Sad word on sad face, Sad word on angry face, Sad word on happy face) by 2 (Group: TBI, Control) ANOVA. There was a main effect of condition, $F(2,102)=4.36$, $p=.015$, such that sad words on congruent faces ($M=.204$, $SE=.16$) were mimicked more than sad words on happy faces ($M=-.070$, $SE=.18$; $p=.033$) and sad words on angry faces ($M=-.236$, $SE=.17$; $p=.010$). To investigate the effect of congruent versus incongruent background faces on the mimicry of angry words, we conducted a mixed 3 (Condition: Angry word on angry face, Angry word on happy face, Angry word on sad face) by 2 (Group: TBI, Control) ANOVA. There was no

main effect of emotion, $F(2,102)=2.07$, $p=.132$, no effect of group, $F(1,51)=.27$, $p=.608$, and no interaction effect, $F(2,102)=.57$, $p=.575$. Finally, to investigate corrugator mimicry to faces, we conducted a mixed 4 (Face: Happy, Sad, Angry, Neutral) by 2 (Group: TBI, Control) ANOVA. There was a main effect of emotion, $F(3,153)=4.19$, $p=.007$, $\eta^2=.08$, such that there was more corrugator mimicry to sad faces ($M=.114$, $SE=.15$) compared with happy ($M=-.063$, $SE=.14$; $p=.008$) and angry faces ($M=-.155$, $SE=.15$, $p=.004$). There was no effect of group, $F(1,51)=.04$, $p=.836$, and no interaction effect, $F(3,153)=1.59$, $p=.195$. All mimicry results are shown in Figure 4.

*** Figure 4 about here***

Correlations

Primarily, we were interested in whether the EmoStroop effect, indexed by the difference in mean latency between the congruent and incongruent condition of the EmoStroop task, correlated with self-reported emotional empathy on the BEES or with emotion recognition accuracy. Bonferroni correction (adjusted $\alpha = .05/2 = .025$) was used for multiple comparisons. The size of the EmoStroop effect was not related to either the BEES ($r=.008$, $p=.955$) or to emotion recognition accuracy ($r=-.119$, $p=.383$) across the whole sample. These correlations remained non-significant when examining the two groups separately.

Secondly, we investigated whether the EmoStroop effect, EmoStroop latency, Emostroop accuracy or emotion recognition accuracy were related to general cognitive functioning. Bonferroni correction (adjusted $\alpha = .05/15 = .003$) was used for multiple comparisons. The EmoStroop effect was not related to any of the general cognitive functioning variables (working memory: $r=-.134$, $p=.326$, processing speed: $r=-.046$, $p=.737$, executive function: $r=-.027$, $p=.843$). These correlations remained non-significant when

examining the two groups separately. However, EmoStroop average latency was significantly correlated with all cognitive variables (working memory: r=-.505, p<.001, processing speed: r=-.632, p<.001, executive function: r=-.664, p<.001, and emotion recognition, r=-.512, p<.001). Similarly, the Emostroop accuracy score was related to all cognitive variables (working memory: r=-.364, p=.006, processing speed: r=-.516, p<.001, executive function: r=-.748, p<.001, and emotion recognition, r=-.320, p=.016). Finally, the emotion recognition accuracy score was also related to all cognitive functioning variables (working memory: r=.429, p=.001, processing speed: r=.453, p<.001, executive function: r=.486, p<.001). Examining each group separately revealed that these correlations with general cognitive functioning were driven largely by the TBI group, which had greater variability in cognitive scores. Correlations across both groups are shown in Table 2.

Table 2 about here

Finally, we investigated whether the EMG responses were correlated with the BEES. The BEES score did not correlate with the zygomaticus response to happy words (r=.016, p=.910) or happy faces (r=-.036, p=.798) or with corrugator response to sad words (r=-.064, p=.648), angry words (r=.020, p=.888), sad words (r=.003, p=.984) or sad faces (r=-.064, p=.650) in the whole sample. No significant correlations emerged when the groups were examined separately.

Discussion

In this study, we investigated whether people with TBI have reduced capacity for the rapid conceptual processing of emotional facial expressions compared with controls on the EmoStroop task. Before proceeding to our discussion of the group analysis, though, it is worth noting that we were able to reproduce the Emostroop effect which was first presented by Preston and Stanfield (2008) with different stimuli and in a smaller sample. This speaks to

the robustness of the Emostroop effect, and provides further evidence for the assertion that faces are indeed very rapidly processed at a conceptual (semantic) level.

Due to well-documented problems in emotional processing after TBI, we expected to see altered performance on the Emostroop task in our participants with TBI. Contrary to our hypotheses, though, participants with TBI demonstrated an EmoStroop effect which was similar to that observed in controls. That is, both healthy controls and participants with TBI experienced interference from incongruent background faces and facilitation from congruent background faces while categorising emotional words. This intact conceptual processing of the emotional faces was despite significantly reduced cognitive funcitoning in the participants with TBI compared to controls in the domains of working memory, processing speed and executive functions. Indeed, the EmoStroop effect was not correlated with any of these cognitive measures. Despite an intact EmoStroop effect, response latencies in the EmoStroop task were substantially slowed in participants with TBI compared to controls. This slowed responding was correlated with all cognitive functioning measures. Our results, then, suggest that the rapid conceptual processing of emotional faces is often preserved after TBI, despite being slowed overall in keeping with broader deficits in processing speed and other cognitive functions.

Secondly, we investigated the role of rapid conceptual processing of emotional faces in emotion recognition and emotional empathy after TBI. We found that participants with TBI had reduced emotional empathy and emotion recognition accuracy compared to controls, despite demonstrating normal conceptual processing of emotional faces. Further, the size of the EmoStroop effect (the extent to which background emotional faces interfered with word categorisation) was not related to emotional empathy or emotion recognition. The perception-action model (PAM) of empathy posits that damage leading to diminished empathy can come at any stage along a chain of information processing stages, the first of which is conceptual

encoding. Thus, our study suggests that reduced empathy after TBI are not a result of impairment at this initial processing step, but may be due to changes in downstream stages. For instance, even if a person is able to rapidly encode emotions initially, executive problems interfere with their ability to attend to emotional states in complex environments and to consider others emotions in a goal-directed manner. Indeed, Hofelich and Preston (2012) have previously found that trait empathy was related to tasks which involve attention to emotional material, but not to initial emotion encoding. Thus, although we found no correlations between trait empathy and any other study variables, there are a myriad of neuropsychological changes after TBI that may contribute to reduced empathy. Further research should aim to explicitly test the relationship between empathy in people with TBI and processes downstream of initial emotional encoding.

We also found no relationship between conceptual processing of emotional faces on the EmoStroop task and accuracy on the emotion recognition task, which was perhaps more surprising. Given that the emotion recognition task involved ascribing verbal (i.e. semantic) labels to the very same emotional faces that participants encountered in the EmoStroop task, we expected that performance on these two tasks would be related. Our findings suggest that the rapid, automatic processing of facial expressions does not have a simple, direct relationship with performance on emotion recognition tasks. In contrast, emotion recognition was significantly related to working memory, processing speed and executive function, in line with past research (Rosenberg et al., 2015). It may be that more controlled, higher-order processes play a larger role in performance on emotion recognition tasks than fast, automatic processing of emotion. This may particularly be the case for emotion recognition tasks in which stimuli are presented for unlimited periods and where participants have time to consider responses, such as in this study. Thus, in people with TBI, compromised higher-order cognitive processes may interfere with accurate judgements about emotions, despite

normal rapid and automatic conceptual processing of the stimuli. In light of this, our finding of preserved rapid conceptual processing of emotional faces after TBI raises an interesting question about whether recognition of rapidly presented facial emotions would also be preserved.

Next, we conducted some follow-up analyses to explore latencies in categorising the different emotional words in the congruent, neutral and incongruent conditions. In line with Preston and Stansfield (2008), we found that participants across both groups and in all conditions were significantly slower to correctly categorise negative emotional words (i.e. 'angry' or 'sad') than they were to correctly categorise 'happy'. This is likely because correct 'happy' categorisations could be done purely at a valence level (i.e. all positive words could correctly be categorised as happy). On the other hand, distinguishing 'angry' from 'sad' words requires emotion-specific processing of the word meaning. Interestingly, the speed advantage for categorising happy compared to angry and sad words was greater in TBI participants compared to controls. This suggests that emotion-specific processing of words may be more affected by a TBI than is valence processing. This should be examined in further studies. Finally, we wanted to compare negative word trials which were incongruent with regards to specific emotion (i.e. angry word on a sad face) with trials which were incongruent with regards to valence of emotion (i.e. angry word on a happy face). Preston and Stansfield (2008) showed that when categorising angry and sad words, an incongruent negative background face does slow down processing, but a happy background face slows processing even more. That is, while emotion specific processing of the background face does interfere with responding, valence level processing of the background face interferes to a greater degree. By contrast, we found that across both groups, participants had similar latencies for categorising angry and sad words on happy background faces compared to categorising words which were incongruent with regards to specific emotion. Overall,

though, our results show that the rapid conceptual processing of the background faces do occur at an emotion specific level, rather than merely at a valence level, in line with past research (Preston & Stansfield, 2008).

Finally, we measured mimicry responses to the EmoStroop stimuli to determine whether the faces or the words were mimicked. We partially replicated Hofelich and Preston's (2012) EMG results, which showed greater mimicry to emotional words compared to emotional faces. Specifically, we found zygomaticus mimicry to happy words, but not to happy faces. Further, we found the congruency of the background face did not affect mimicry to happy words. These results show that while the happy background faces were rapidly processed at a conceptual level, they were not mimicked, supporting Hofelich and Preston's conclusion that mimicry is not required for the rapid conceptual processing of (happy) faces. Instead, participants mimicked the happy words, which was the stimulus they were directing their attention towards. This result is consistent with work showing that mimicry is predicted by the degree of visual processing and attention (Achaibou, Pourtois, Schwartz, & Vuilleumier, 2008), is sensitive to information-processing goals, and facilitates recognition accuracy of emotional concepts (Niedenthal, Winkielman, Mondillon, & Vermeulen, 2009).

However, our results diverge from Hofelich and Preston's with regards to the corrugator responses to sad and angry stimuli. In this case, we found more evidence for corrugator mimicry to sad faces than to sad words, suggesting that participants did mimic (and conceptually process) sad faces despite not paying explicit attention to them. We failed to show any corrugator mimicry to angry words or faces which was unexpected given the corrugator is usually activated by observing angry expressions. The disconnect between mimicry to words (but not faces) for the happy emotion and faces (but not words) for the sad emotion is interesting. Our prior work with people with TBI found that mimicry to negative facial expressions is differentially reduced relative to positive (de Sousa et al., 2011;

McDonald et al., 2011) suggesting that negative emotional expressions may engage unique brain processes. Although we found no impairment of mimicry in the TBI group on this occasion, the differential mimicry of sad but not happy faces reinforces the notion that negative emotions are processed differently.

Finally, we investigated the relationship between mimicry and emotional empathy reported on the BEES. Hofelich and Preston (2012) previously found that high empathy participants had more mimicry in the Emostroop task than low empathy participants. Research from our own lab has also found a correlation between self-reported emotional empathy on the BEES and mimicry to emotional faces (De Sousa et al., 2011). However, we found no such relationship in the current study. The lack of differences between participants with TBI and controls in mimicry, and the lack of relationship between mimicry and empathy, possibly reflects that we are looking for small effects in a relatively small, heterogeneous sample. A large-scale study or meta-analysis would be useful to determine the overall effect size of mimicry impairments in TBI and how frequently these impairments occur in the population. Replication in a larger sample of healthy controls would be useful to clarify these effects. Further, our ability to find relationships between trait emotional empathy and any other variables in the study may have been hampered by the use of a self-report measure (the BEES), which may not accurately reflect empathy after TBI due to poor self-awareness. Although empathy is very difficult to measure in other ways, the use of more objective measures may be helpful for future research looking at processes contributing to diminished empathy in this population.

In conclusion, found that rapid conceptual processing of emotional faces was preserved in people with TBI, despite diminished neuropsychological performance, emotion recognition, emotional empathy and slowed responding compared to controls.We conclude that in people with TBI, reduced empathy may be explained by processes downstream of the

initial rapid conceptual processing of emotional information, such as in higher-order abilities to flexibly attend to and respond to this information in a goal-directed manner in complex environments. In the future, it will be important to continue to map how each of these processes contributes to empathy after TBI, in order to determine suitable remediation targets. Due to the highly heterogeneous sample, our study is unable to speak to the neural underpinnings of the impairments exhibited by our sample, and this could be a focus of future research. Critically, our results also replicated a number of key findings of the original authors of the Emostroop task in different laboratory using new stimuli and substantially fewer trials. Thus our findings provide further support for important claims of perception-action model (PAM) of empathy, namely that emotional faces are processed rapidly at a conceptual level and in an emotion-specific (rather than valence-dependent) manner. This effect provides evidence emotional expressions are not simply reflexively mimicked (as suggested by the emotional contagion hypothesis), but rather that emotional expressions spontaneously activate representations in the observers' mind which facilitate *true understanding* of the emotional state.

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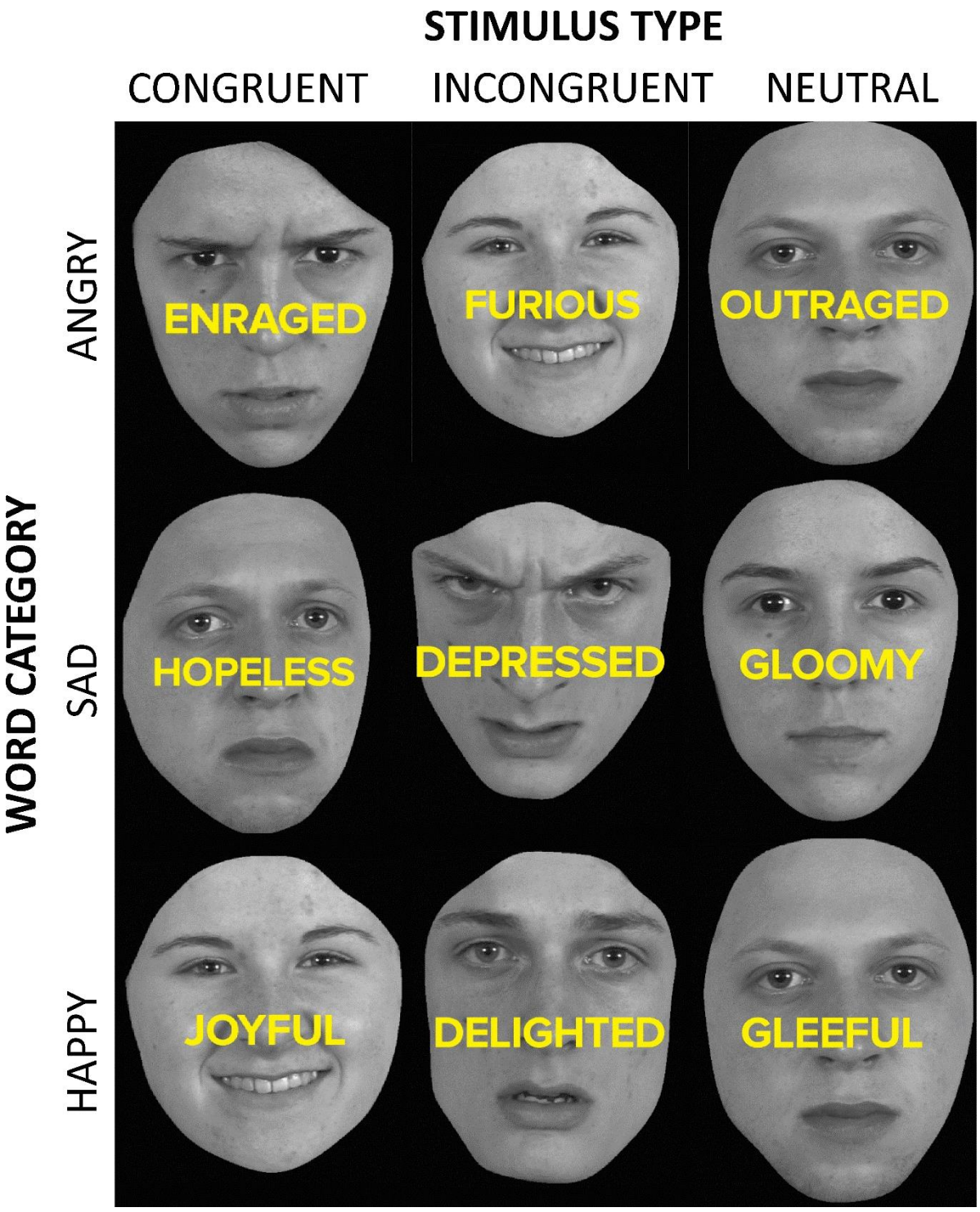

Figure 1. Example stimuli for the EmoStroop task

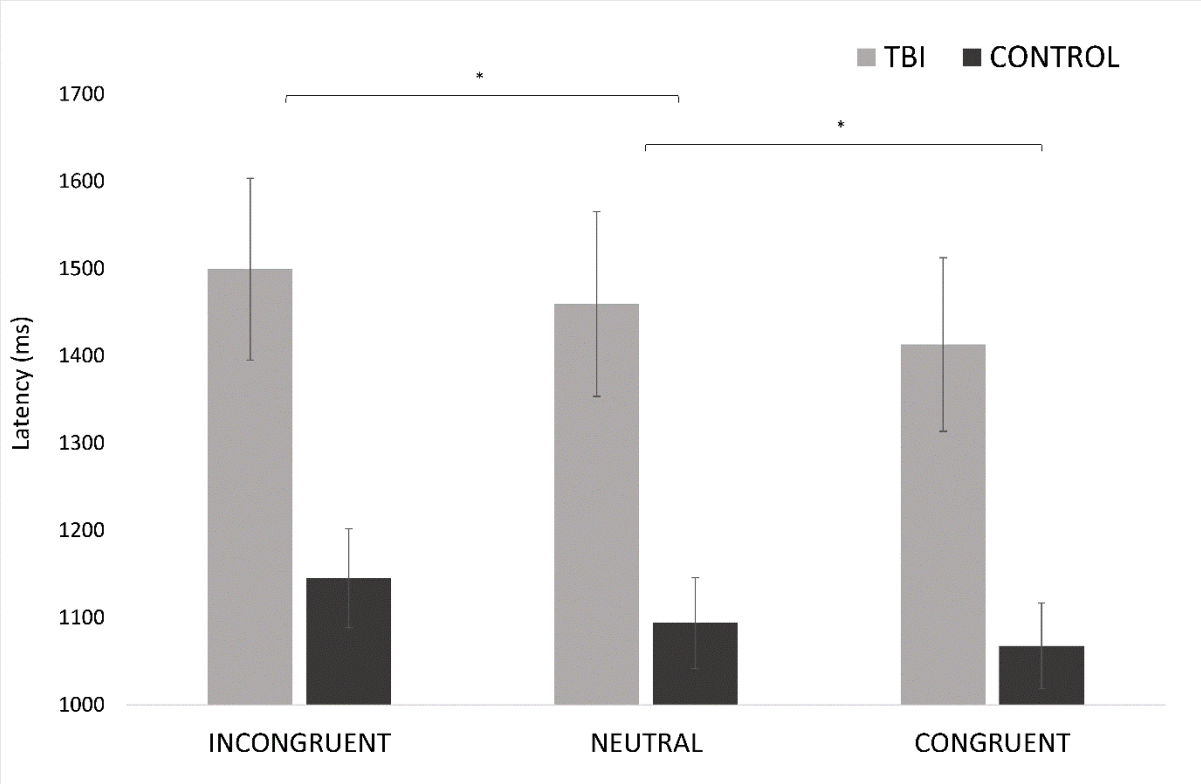

Figure 2. Mean latencies in the incongruent, neutral and congruent conditions for the TBI and control group

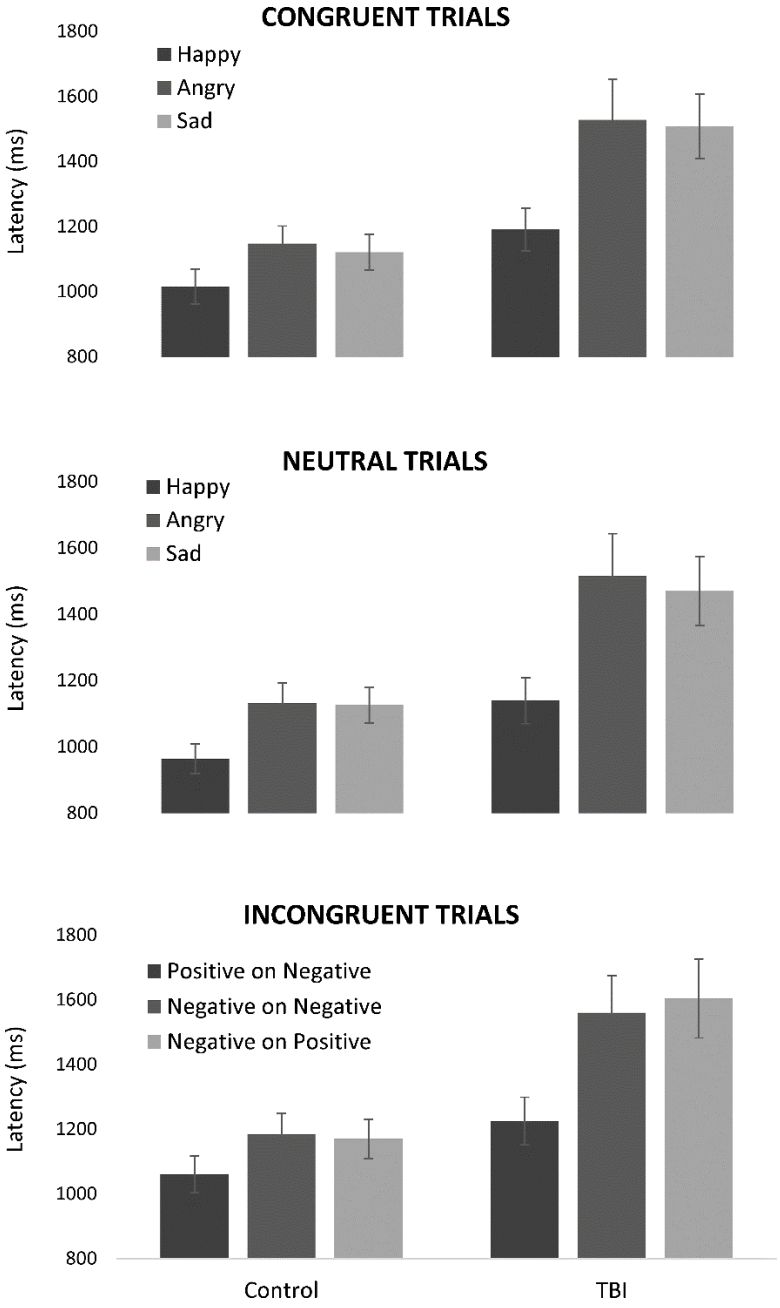

Figure 3. Top panel: Mean latencies to categorise happy, angry and sad words on congruent background faces in the TBI and control groups. Middle panel: Mean latencies to categorise happy, angry and sad words on neutral background faces in the TBI and control groups. Lower panel: Mean latencies to categorise positive (happy) words on negative (angry or sad) background faces, negative words on negative background faces, and negative words on positive background faces in the TBI and control groups.

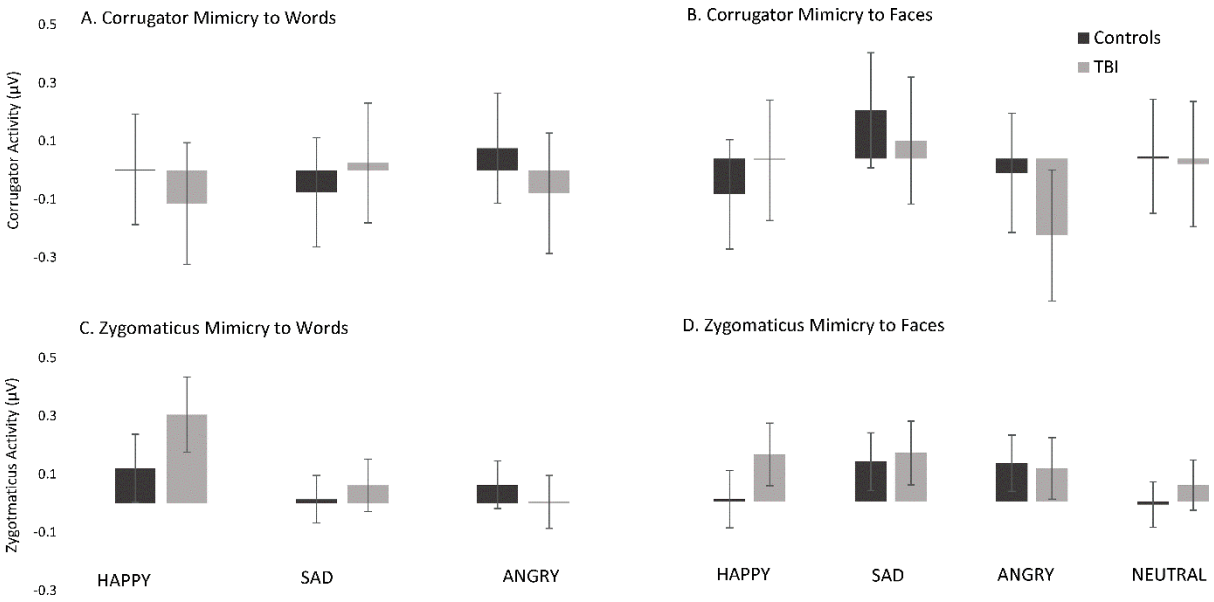

Figure 4. Panel A: Mean corrugator activity (μV) was greater to sad compared to happy words for the TBI group. Panel B: Mean corrugator activity (μV) was greater to sad compared to happy, angry and neutral faces. No group differences observed. Panel C: Mean zygomaticus activity (μV) was increased for happy words compared to sad and angry words. No group differences observed. Panel D: Mean zygomaticus activity (μV) did not differentiate between emotional face categories or between groups.

Table 1

Means, standard deviations and results of group comparisons on demographic, cognitive and emotional functioning variables for the TBI and control groups

	Mean (SD)		
	TBI (*N*=26)	Control (*N*=30)	Diff (*p*)
Demographics			
PTA (days)	53.48 (50.43)		
Time since injury (years)	14.65 (13.79)		
Age (years)	45.73 (14.35)	41.70 (14.97)	.310
Years of education	13.69 (2.90)	15.00 (2.68)	.085
Pre-injury Occupation			
Unskilled trade/unemployed	6	4	.899
Skilled trade	3	3	
Business owner	2	3	
Prof/managerial	8	10	
Student	7	10	
Cognitive Functioning			
Premorbid ability			
Shipley-2 Vocab	100.31 (13.84)	105.53 (10.83)	.119
Working memory			
WAIS-IV Digit Span	10.31 (3.69)	12.10 (2.71)	**.041**
Processing speed			
WAIS-IV Digit Symbol Coding	7.92 (2.64)	11.97 (2.39)	**<.001**
WAIS-IV Symbol Search	7.27 (2.65)	10.17 (2.41)	**<.001**
Trail Making A	-1.36 (2.34)	.52 (.85)	**<.001**
Executive Functions			
Hayling Overall score	4.65 (1.96)	5.77 (.82)	**.006**
Trail Making B	-2.01 (3.58)	.23 (1.49)	**.001**
Emotional Functioning			
HADS Anxiety	5.88 (3.95)	5.10 (3.29)	.421
HADS Depression	5.08 (4.00)	3.23 (2.88)	.051
Emotional Empathy			
BEES total	33.81 (28.81)	48.93 (25.13)	**.037**

Emotion Perception			
Emotion Recognition Accuracy	9.04 (2.99)	11.40 (2.18)	**.001**

Note: Shipley-2 Vocab score is a standard score. WAIS-IV scores are scaled scores. Trail making scores are z-scores calculated using norms from Tombaugh (2004). Hayling Overall Score is the scaled score calculated from raw scores on parts A and B. All other scores are raw scores.

Table 2

Correlations between Emostroop variables, emotion recognition accuracy, emotional empathy and general cognitive functioning

Variable	Emostroop effect	Emostroop latency	Emostroop accuracy	Emotion recognition	Emotional empathy	Working memory	Processing speed	Executive function
Emostroop effect	-	.221	-.165	-.119	.008	-.134	-.046	-.027
Emostroop latency		-	**-.595****	**-.512****	-.250	**-.505****	**-.632****	**-.664****
Emostroop accuracy			-	**.320***	.176	**.364***	**.516****	**.748****
Emotion recognition				-	.099	**.429****	**.453****	**.486****
Emotional empathy					-	.095	.116	.193
Working memory						-	**.428****	**.458****
Processing speed							-	**.800****
Executive function								-

Note. Emostroop effect is the difference in latency between the congruent condition and the incongruent condition, Emostroop latency is the average latency across the three conditions, emotional empathy is the self-reported BEEs score, working memory is the standard score for WAIS-IV Digit Span, processing speed is a composite of TMT A, WAIS-IV Coding and WAIS-IV Symbol Search and executive function is a composite of Hayling standard score and TMT B. * p <.05, ** p <.001.