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BRIEF REPORT

How are emotions lateralised in the brain? Contrasting existing hypotheses using the Chimeric Faces Test

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There are two contrasting hypotheses that attempt to explain how emotion perception might be organised in the brain. One suggests that all emotions are lateralised to the right hemisphere whereas the other suggests that emotions may be differently lateralised according to valence. Here these two theories are contrasted, in addition to considering the role of emotional intensity in explaining possible differences in strength of lateralisation across emotions. Participants completed a Chimeric Faces Test for each of the six basic emotions: anger, disgust, fear, happiness, sadness and surprise. All emotions showed significant lateralisation to the right hemisphere, however, differences in strength of lateralisation within the right hemisphere were found. Stronger patterns of right hemisphere lateralisation were found for positive emotions and for emotions of higher intensity. The results support the right-hemisphere hypothesis, but suggest that there may be variability in organisation within the right hemisphere across different types of emotion.

Keywords: Emotional expression; Emotional valence; Emotional intensity; Hemispheric specialisations.

INTRODUCTION

A growing amount of research has attempted to describe how emotion processing is lateralised in the human brain. There are a number of vastly contrasting hypotheses, which either claim that all emotion processing is lateralised to the right hemisphere or that emotion processing is lateralised across the hemispheres. How the emotions might be grouped and bilaterally distributed is also a matter of debate. In this paper the Chimeric Faces Test is used, with all six of the basic emotions (anger, disgust, fear, happiness,

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sadness and surprise; Ekman, 1993) in an attempt to contrast these hypotheses.

The Chimeric Faces Test has been increasingly used over the past few years to enable behavioural estimates of lateralisation for processing facial emotion to be estimated. In this task participants are presented with pairs of vertically split chimeric faces comprising one neutral half face and one emotive half face. One of the pair shows the expression in the left half face, and hence left visual field, while the other shows the expression in the right half face, and hence the right visual field. Participants are then asked which of the two faces is most emotive. Most individuals are biased towards selecting the face with the emotion expressed in the left visual field. This is explained in terms of right-hemisphere dominance for processing facial stimuli as this information is initially presented to and processed by the right hemisphere. By giving participants a number of trials it is possible to work out which hemisphere is dominant for processing facial emotion and the strength of lateralisation.

Chimeric face stimuli were first used with split-brain patients (Levy, Trevarthen, & Sperry, 1972). When shown chimeric faces in which each half represented a different learned face, they found that responses were biased towards the identity shown in the left half face. This provides validation for the bias found using the Chimeric Faces Test reflecting hemispheric processing and has also been supported in more recent studies using patients with unilateral right-hemisphere lesions (Bava, Ballantyne, May, & Trauner, 2005; Kucharska-Pietura & David, 2003).

The Chimeric Faces Test in its most common form, in which two chimeric faces are presented and the participant has to decide which is more emotive, was introduced by Levy, Heller, Banich, and Burton (1983) who first demonstrated the left visual field, right-hemisphere bias in non-clinical participants. This test has now become a popular behavioural measure of emotion lateralisation with the left visual-field bias being reported in a large number of papers (e.g., Bourne, 2005, 2008; Compton, Fisher, Koenig, McKeown, & Munoz, 2003; Heath, Rouhana, & Ghanem, 2005). However, one limitation of many of these studies is that only happy chimeric faces were used. Consequently more recent studies have tended to use multiple emotive chimeras in an attempt to examine whether the reported right-hemisphere dominance is consistent across all emotions, or whether there are systematic differences between emotions. Such studies have shown somewhat mixed results with varying patterns of lateralisation across different emotions being reported. These results are typically discussed in terms of the varying theories of emotion lateralisation that are under examination in this study.

The simplest proposal is that all emotions are lateralised to the right hemisphere; much evidence has provided support for this theory. For example Kucharska-Pietura and David (2003) found that patients with

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unilateral right-hemisphere lesions showed a reduced left visual-field (right-hemisphere) bias for processing both positive and negative emotions on a Chimeric Faces Test. In contrast non-clinical participants and patients with unilateral left-hemisphere damage both showed a left visual field (right-hemisphere) bias. The right-hemisphere hypothesis has also been supported in a number of studies using the Chimeric Faces Test with non-clinical participants. For example, a left visual-field bias has been reported for both happy and angry chimeras (Ashwin, Wheelwright, & Baron-Cohen, 2005), happy, surprised, sad and angry chimeras (Christman & Hackworth, 1993), chimeras expressing positive and negative affect (Drebing, Federman, Edington, & Terzian, 1997) and both prosocial and antisocial chimeras (Workman, Peters, & Taylor, 2000). A left visual-field bias has also been reported when presenting emotional faces to either visual field (Natale, Gur, & Gur, 1983). Right-hemisphere dominance when processing emotion has also been shown using functional neuroimaging with non-clinical participants when using both facial stimuli (Nakamura et al., 1999) and linguistic stimuli in which participants had to make judgements based on intonation (Wildgruber et al., 2005). The right-hemisphere hypothesis has also been supported by evidence examining asymmetry in the expression of emotion (both positive and negative) which has shown that emotions are more intensely expressed on the left side of the face than on the right side of the face (Indersmitten & Gur, 2003; Sackeim & Gur, 1978; Sackeim, Gur, & Saucy, 1978).

Alternative theories suggest that emotions are differently lateralised across the two hemispheres. The most frequently examined of these separates the emotions according to valence, suggesting that the left hemisphere is dominant for processing positive emotion and that the right hemisphere is dominant for processing negative emotion (Davidson, 1992). Support for this hypothesis has also been shown using chimeric face stimuli, finding a left visual-field (right-hemisphere) bias for the processing of negative facial emotion and a right visual-field (left-hemisphere) bias for the processing of positive facial emotion (Adolphs, Jansari, & Tranel, 2001; Jansari, Tranel, & Adolphs, 2000). This pattern was also found by Rodway, Wright, and Hardie (2003), although only in female participants. Although the valence hypothesis has received some support, there is also evidence suggesting the opposite pattern. Borod et al. (2000) examined the processing of verbal pragmatics in patients with unilateral brain lesions and found that patients with right-hemisphere damage were impaired when processing positive affect and patients with left-hemisphere damage were impaired when processing negative affect. This pattern has not been shown using chimeric face stimuli.

It is also possible that clustering emotions into subgroups may not be the best method of classification, and consequently not provide the best way in which to examine lateralisation of emotion. It may be that the emotions are

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more validly considered as existing on a single continuum, rather than in discrete categories. An alternative solution may be to rank the emotions in terms of intensity. Such rank scores are available from the work conducted by Palermo and Coltheart (2004), who asked participants to rate the intensity of emotional expression for faces expressing the six basic emotions. On the basis of this study it is possible to order the emotions from low intensity to high intensity in the following way: sadness, disgust, anger, surprise, fear and happiness. While no work has explicitly considered patterns of lateralisation for emotions of differing intensity, it is quite possible that differences might be found, either in terms of a spread across the two hemispheres or within one hemisphere.

It seems that it is still unclear how emotion processing is lateralised in the brain. While some evidence supports right-hemisphere dominance across all emotions, other evidence suggests that emotions may be differently lateralised. This possibility can be examined in two ways: first by considering categories of emotions, such as positive or negative valence; second by considering the emotions ranked on a continuum, such as in terms of increasing intensity. Both the right-hemisphere and the valence hypotheses have received a fair amount of attention in the previous research, therefore the data collected here primarily reflect a replication of previous studies. However, the comparison of these contrasting hypotheses has not been considered before. Additionally, the possible relationship between emotional intensity and lateralisation has not been considered in previous work and this provides a novel approach to the area. In this study strength of emotion lateralisation was measured for all six of the basic emotions using the Chimeric Faces Test. These were then analysed in various ways to enable the contrasting hypotheses to be compared within the same data set.

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METHODS

Participants

Eighty-three (47 female) participants with a mean age of 24 years ($SD = 6.5$, range 18–49) were tested. Participants were all undergraduate students and had not seen the stimuli previously. All were right handed by self-report and handedness was confirmed with a handedness questionnaire (adapted from Dorthe, Blumenthal, Jason, & Lantz, 1995). All participants were pre-screened using a questionnaire that asked about possible factors that may have influence their handedness, whether they had a head injury or psychiatric diagnosis. None reported changing their handedness or any events that may have influenced their handedness and none reported any previous neurological damage or psychiatric disorder. Vision was either normal or corrected to normal in all participants.

Chimeric Faces Test

The chimeric face stimuli were created using the Ekman emotional faces (half male and half female) for each of the six basic emotions: anger, disgust, fear, happiness, sadness and surprise. The stimuli were the same as used by Workman, Chilvers, Yeomans, and Taylor (2006; see Figure 1). All faces were presented in greyscale, showing a static frontal image of the face. Faces were shown with a mixture of open and closed mouths. Faces were vertically split and emotional hemifaces were attached to neutral hemifaces. Two copies of a face were presented in each trial, one above the other. One of the faces showed the emotional expression in the left hemiface and the other showed the emotional expression in the right hemiface. Faces were presented on a white background and each individual face subtended approximately 4.5° horizontally and 7° vertically at a viewing distance of 52 cm. The placement of the stimuli was counterbalanced. Participants completed 24 trials for each emotion in a blocked design. In each trial faces were presented centrally on a computer screen and participants had to decide which face was more emotive (i.e., angry, disgusted, fearful, happy, sad or surprised). If they thought the top face was more emotive then they had to press any left button on the response pad. If they thought the bottom face was more emotive then they had to press any right button on the response pad. Faces remained on screen until a response was made. Stimuli presentation was controlled and randomised using Superlab version 4. For each emotion a laterality quotient (see Bourne, 2008, for details) was calculated which provided a score ranging from -1 through to $+1$. Positive values represent

Figure 1. Example chimeric face stimuli. From left to right the emotions expressed are: anger, disgust, fear, happiness, sadness and surprise. For all faces, the top face is showing emotion in the viewers left visual field and the bottom face is showing emotion in the viewers right visual field.

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a left visual-field (right-hemisphere) bias whereas negative values represent a right visual-field (left-hemisphere) bias.

Contrasting the hypotheses

In order to test each of the hypotheses, mean laterality quotients were calculated according to the various proposed groupings of emotions. To test the right-hemisphere hypothesis a mean laterality quotient was calculated that included all six emotions. To test the valence hypothesis mean laterality quotients were calculated for positive (happiness and surprise) and negative (anger, disgust, fear, sadness) emotions separately. Surprise was included as a positive emotion as the stimuli were taken from the Ekman stimuli, in which positive surprise is expressed in all of the images. For each of these hypotheses the crucial analyses were one sample *t*-tests comparing the laterality quotients to 0 (i.e., no bias). For the valence hypothesis a repeated-measures *t*-test also compared the two calculated laterality quotients. To test the intensity hypothesis the emotions were placed in order of intensity, from low to high, on the basis of the ratings acquired by Palermo and Coltheart (2004): sadness, disgust, anger, surprise, fear and happiness. In their study participants were shown faces from the Ekman set of stimuli (i.e., the same as used in this study) expressing each of the six emotions. For each face participants had to rate the intensity of the emotion expressed on a 7-point Likert scale. A one-way repeated measures analysis of variance (ANOVA) with trend analysis was conducted to see whether laterality quotients differed according to emotion and whether strength of lateralisation changed as a linear function of increasing intensity.

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RESULTS

The mean laterality quotient for all of the emotions combined was $+0.21$ ($SD = 0.47$) indicating a left visual-field (right-hemisphere) bias. This value was significantly different from 0, $t(82) = 4.1$, $p < .001$, indicating a significant right-hemisphere bias and supporting the right-hemisphere hypothesis of emotion lateralisation. Laterality quotients on all six emotions were positively correlated (all ps $< .001$). There were no sex differences across the six emotions (see Table 1).

Mean laterality quotients also indicated left visual-field (right-hemisphere) bias for the positive ($M = +0.25$, $SD = 0.58$) and negative ($M = +0.19$, $SD = 0.43$) emotion groupings. Both of these were significantly different from 0, positive: $t(82) = 4.0$, $p < .001$; negative: $t(82) = 4.0$, $p < .001$, suggesting a right-hemisphere dominance for the processing of both positive and negative emotions. The repeated measures *t*-test showed that the processing of positive

TABLE 1

Descriptive statistics of laterality quotients for males and females separately across all six emotions. Analysis of sex differences are also presented ($df = 81$ for all)

	Males ($N = 47$)		Females ($N = 47$)			
	Mean	*SD*	*Mean*	*SD*	*t*	*p*
Anger	0.26	0.56	0.18	0.54	0.671	.504
Disgust	0.17	0.53	0.06	0.53	0.944	.348
Fear	0.32	0.61	0.25	0.57	0.539	.591
Happiness	0.25	0.61	0.22	0.57	0.277	.782
Sadness	0.17	0.36	0.14	0.26	0.404	.687
Surprise	0.37	0.58	0.21	0.62	1.221	.226

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emotions is more strongly lateralised than the processing of negative emotions, $t(82) = 2.1$, $p = .042$).

When looking at the six emotions separately, in order of increasing intensity, all showed a significant left visual-field (right-hemisphere) bias, sadness: $t(82) = 4.6$, $p < .001$; disgust: $t(82) = 1.8$, $p = .035$; anger: $t(82) = 3.5$, $p < .001$; surprise: $t(82) = 4.2$, $p < .001$; fear: $t(82) = 4.4$, $p < .001$; happiness: $t(82) = 3.6$, $p < .001$. The repeated-measures ANOVA showed a significant main effect of Emotion, $F(5, 78) = 5.3$, $p < .001$, partial $\eta^2 = .254$, which was best described in terms of a linear trend, $F(1, 82) = 10.7$, $p = .002$, partial $\eta^2 = .115$. Inspection of Figure 2 shows an overall increase in strength of lateralisation with increasing intensity of emotion, although the pattern is not exactly as predicted as sadness is more strongly lateralised than disgust and happiness is less strongly lateralised than both fear and surprise.

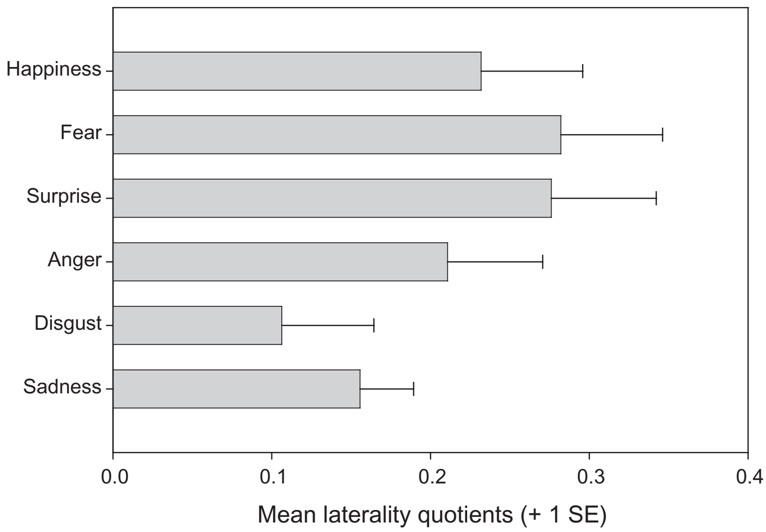

Figure 2. Graph showing mean laterality quotients (+1 *SE*) for each of the six emotions in order of intensity from low to high. Positive laterality quotients indicate right-hemisphere bias.

On the basis of these analyses it seems that the different emotions are all lateralised to the right hemisphere, but there may be variability across the different emotions in terms of strength of right-hemisphere lateralisation. It is unclear how this variability may be clustered as differences in strength of lateralisation were found according to positive/negative grouping and increasing intensity. In order to see whether there is any natural grouping of the emotions within the right hemisphere a factor analysis was conducted on the six emotion laterality quotients. All of the emotions loaded onto one factor, which had an eigenvalue of 4.7 and explained a total of 77.5% of the variability in lateralisation for emotion processing. The factor loadings for the emotions were: anger = .828, disgust = .886, fear = .938, happiness = .926, sadness = .770, and surprise = .922. Given that only one factor was extracted, a rotated solution was not possible. This suggests that all emotions are lateralised to the same hemisphere and that subdivision of the emotions is not necessary.

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DISCUSSION

The findings of this study support the right-hemisphere hypothesis in that all six emotions showed a left visual-field (right-hemisphere) bias. However, it does suggest that not all emotions are lateralised to the same extent within the right hemisphere. Different strengths of right-hemisphere lateralisation were found across the emotions either when categorising the emotions according to valence or when ranking them in terms of intensity.

While these analyses suggest that all emotions are lateralised to the right hemisphere, it is important to consider the effect that the choice of stimuli and task may have had on the results. The Chimeric Faces Test is a test of lateralised biases for the processing of facial emotion. It is possible that the use of facial stimuli may have influenced performance. While it is generally accepted that both hemispheres are involved in face processing to at least some extent (e.g., Sagiv & Bentin, 2001) evidence from both prosopagnosic patients and non-clinical participants using behavioural and functional neuroimaging techniques suggests that the right hemisphere is dominant, or more involved, than the left hemisphere (e.g., Bentin & Deouell, 2000; Bourne & Hole, 2006; Marotta, McKeeff, & Behrmann, 2002). It is therefore possible that the left visual-field (right-hemisphere) dominance found across all six emotions may be explained in terms of a face lateralisation effect rather than an emotion-specific effect. While this is possible, this explanation does not seem to provide a complete explanation for the findings as differences were found between different emotions. If the right-hemisphere bias were purely due to the use of facial stimuli, no differences between emotions would be predicted.

In order to consider whether this may provide an explanation of the present findings it is important to examine research on the lateralisation of emotion processing using non-face stimuli such as linguistic stimuli. If emotion is lateralised to the right hemisphere then right-hemisphere dominance should be found regardless of the type of stimuli used. Alternatively, if emotion lateralisation is influenced by the type of stimuli used, left-hemisphere dominance for emotion processing may be predicted with language-based stimuli. Smith and Bulman-Fleming (2006) reported right-hemisphere dominance for processing negative words but no lateralised bias for the processing of positive words. A more detailed study used fMRI to examine the distinction between a phonetic and an emotional decision when listening to spoken stimuli expressed in five different emotions (Wildgruber et al., 2005). They found left-hemisphere activation when making a phonetic decision and right-hemisphere activation when making an emotive decision. The findings from these two studies suggest that right-hemisphere lateralisation for emotion processing can be found with stimuli other than faces.

It seems that there is a fair amount of evidence in support of emotion processing being lateralised to the right hemisphere. However, the various analyses conducted within this paper suggested that the strength of lateralisation within the right hemisphere may vary across the different emotions and the different ways of categorising the emotions. A possible explanation is that the processing of emotion is lateralised within the right hemisphere, but that different emotions or groups of emotions are lateralised to different areas. This possibility is supported by a meta-analysis conducted by Wager, Phan, Liberzon, and Taylor (2003), who found that positive emotions were reported to elicit activity on the basal ganglia whereas negative emotions elicited activity in the insula and the cerebellum. However, Wager et al. concluded that findings with regard to the lateralisation and localisation of emotions on the basis of positive/negative classification were inconsistent across the studies included in their meta-analysis.

It is also interesting to consider whether the participant's mood, or possible depression, may have influenced their functional lateralisation when processing facial emotion. None of the participants reported any psychiatric diagnoses; however it is likely that there were some quite significant differences in mood across participants. Reduced right-hemisphere biases on the Chimeric Faces Test has been reported in patients with clinical depression (e.g., Bruder et al., 2002; Kucharska-Pietura & David, 2003), although a comparable relationship between right-hemisphere bias and self-reported mood in a non-clinical sample has been more elusive (David, 1989; Ennis & McConville, 2007; Harris & Snyder, 1992). This issue is particularly important given recent evidence showing that arousal may mediate the extent to which hemispheric asymmetries in emotion lateralisation are evident (Alfano & Cimino, 2008).

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This study provides the first direct comparison between the differing theories of emotion lateralisation using the Chimeric Faces Test across all six of the basic emotions. The findings support the right-hemisphere hypothesis of lateralisation, showing this pattern of lateralisation across all six of the basic emotions. However, there is some evidence for differences in strength of lateralisation within the right hemisphere across different emotions. It is unclear whether this variability may be best explained in terms of valence, intensity or perhaps another method of classification.

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