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# Hemispheric Asymmetries in Categorical Facial Expression Perception

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Abstract

Although many sensory phenomena vary continuously, humans tend to divide them into discrete categories with facial expressions being divided into categories such as happy, sad, anger and fear. A critical effect of category use is categorical perception: same sized physical differences are better perceived if the difference occurs between two categories rather than within the same category. Here we investigate the lateralization of categorical perception of facial expressions. Categorical perception of facial expressions may be lateralized to the right hemisphere due to the intimacy of basic, possibly universal and innate, prototypical facial expression categories and face processing which is predominantly lateralized to the right hemisphere. Alternatively, facial expression categories may be a linguistic phenomenon and thus predominantly involve the left hemisphere. A visual half-field paradigm was used to assess categorical perception of morphed facial expressions running between happy-sad, and anger-fear. Across two experiments, the lateralization of categorical perception was found to be contingent upon previous exposure. Better between- than within-category discrimination of facial expressions was found in both visual half-fields when participants had previously been exposed to facial expression categories; but for naïve participants, categorical perception was restricted to the right visual hemifield, corresponding to the left cerebral hemisphere. Facial expressions presented to the right hemisphere are therefore not necessarily encoded in terms of their emotional expression category and such category-based encoding, when it does occur, may be due to the left hemisphere and so is likely to be subject to biases related to language.

*Keywords*: categorical perception; facial expression; hemispheric laterality; linguistic relativity

# Hemispheric Asymmetries in Categorical Facial Expression Perception

Despite the fundamental social importance of understanding emotional facial expressions, the role of each hemisphere in facial expression processing is unclear. The dominance of the right hemisphere for facial expression recognition is evident from the reduction in ability to make or recognize facial expressions following damage to the right hemisphere (Borod, Koff, Lorch, & Nicholas, 1986); the left half of faces being used more than the right when recognizing chimeric facial expressions in healthy participants (Bourne, 2010; Burt & Perrett, 1997; Campbell, 1978; Innes, Burt, Birch, & Hausmann, 2016); and the better recognition of facial expressions presented briefly in the left than the right visual field (Alves, Aznar-Casanova, & Fukusima, 2009; Najt, Bayer, & Hausmann, 2013). Such evidence has led to models of facial expression recognition in which the right hemisphere is dominant with some evidence suggesting that facial expressions are processed exclusively in the right cerebral hemisphere (Shobe, 2014). However, contrary evidence suggests a role for the left hemisphere either in facial expression recognition generally (Roberson, Damjanovic, & Kikutani, 2010) or depending upon the facial expression (Ahern & Schwartz, 1979; Harmon-Jones, 2004; Najt et al., 2013; Prete, Laeng, Fabri, Foschi, & Tommasi, 2015). Thus, both hemispheres may have specific roles in processing emotional facial expressions.

The left hemisphere’s role may be due its dominance in language processing, implying that the different adult facial expression categories are a linguistic phenomenon (Roberson et al., 2010) supported by concept knowledge (Fugate, 2013; Lindquist, Gendron, Barrett, & Dickerson, 2014; Roberson et al., 2010; Roberson & Davidoff, 2000). As such, the phenomenon of categorical perception, better discrimination of a same size physical difference between stimuli which differ in category than stimuli of the same category, might be expected to occur only for facial expressions presented to the left hemisphere. Such a finding would indicate a separation between facial expression categories in the left hemisphere and dominance for face processing more generally in the right hemisphere.

Although categorical perception has been demonstrated for facial expressions many times since it was initially documented (Calder, Young, Perrett, Etcoff, & Rowland, 1996; Etcoff & Magee, 1992), its laterality has not been assessed. In opposition to the notion of facial expression categories being linguistically based there has been a longstanding argument, since Darwin (1872/1934), that facial expressions are a basic, universal and innate part of human emotional communication (Ekman, Friesen, & Ellsworth, 1982; Izard, 2007). Within this, categorical perception of facial expressions has been interpreted as reflecting prototypical facial expression configurations related to the individual basic facial expressions (Calder et al., 1996; Young et al., 1997). These expression categories are thought not to depend upon language with infants showing differentiation of facial expression categories prior to language use (Kotsoni, de Haan, & Johnson, 2001; Leppanen, Richmond, Vogel-Farley, Moulson, & Nelson, 2009) and other primates categorising the facial expressions of conspecifics without specific training (Parr, Hopkins, & de Waal, 1998; Parr, Waller, & Heintz, 2008). The basic facial expressions prototypes underlying such facial expression recognition would be expected to be an integrated part of face processing which is predominantly represented in the right hemisphere, resulting in categorical perception only for facial expressions presented to the right hemisphere.

Although the lateralization of categorical perception of facial expressions has not been studied, the left hemisphere bias has been found for categorical perception of non-facial properties like colour and object shape (Drivonikou et al., 2007; Gilbert, Regier, Kay, & Ivry, 2006). Lateralized categorical perception was originally found for colour by Gilbert et al (2006) who presented squares of four different shades ranging from green to blue in even steps (green, greeny-blue, bluey-green, blue). Participants were generally faster at identifying odd squares presented to the left of fixation, reflecting the dominance of the right hemisphere in colour discrimination generally. However, when the difference between the shades crossed the categorical boundary between what a participant categorised as green and blue they were faster when the odd coloured square was on the right of fixation, implicating the left hemisphere. This was interpreted in terms of the left hemisphere being biased by the top-down information, such as an individual's language on perception (the Whorf hypothesis, Whorf, Carroll, Levinson, & Lee, 2012), affecting left hemisphere perceptual processing of colour. Subsequent studies have extended these findings beyond the domain of colour by using line drawings of animals (Gilbert, Regier, Kay, & Ivry, 2008) and silhouettes of novel objects (Holmes & Wolff, 2012). However, other researchers have failed to find a lateralized effect but have instead found similar between category speeding of reaction times in both visual fields (Suegami, Aminihajibashi, & Laeng, 2014; Witzel & Gegenfurtner, 2011).

Initially, we aimed to use a task based upon Gilbert et al.'s (2006, 2008) to assess lateralization of facial expression perception. Like Gilbert, we used four equidistant levels of gradation between our stimulus categories: 5%, 35%, 65%, 95% computer generated morphs from a happy to a sad face image or from an angry to a fearful face image. In Gilbert et al.'s task, 12 coloured swatches were arranged in a circle around a fixation cue with the measure being the reaction time to locate the position (on the left or right) of the odd coloured swatch. However, we found the differences between face stimuli (e.g. detecting the 'odd' 5% happy face from a crowd of 35% happy faces) were too subtle to be detected without the participant looking towards the individual stimuli even when only 6 face stimuli were presented. A method more similar to that used previously by Roberson et al (2010)  to investigate categorical perception of facial expression was used instead (Figure 1), where a single face was initially presented and participants were asked which of two subsequently presented faces (presented tachistoscopically (<200ms), one presented to the left and the other to the right) matched the initial face. As it has been proposed that individuals vary in the position of their category boundaries for facial expressions (Roberson et al., 2010), the position of each participant's categorical boundary for each morphed expression pair was separately calculated based upon their categorizing the same morphed face stimuli in a separate part of the experiment.

**[ Figure 1 near here ]**

Despite ostensibly similar methods some have repeatedly found lateralized categorical perception (Drivonikou et al., 2007; Gilbert et al., 2006, 2008; Holmes & Wolff, 2012) whereas other have repeatedly found categorical perception to be symmetrical (Suegami et al., 2014; Witzel & Gegenfurtner, 2011). As many previous studies of categorical perception have exposed participants to the categories prior to assessing lateralization, for example by labelling the colours before the lateralized task (Drivonikou et al., 2007; Gilbert et al., 2006); or explicitly by training the discrimination (Gilbert et al., 2008; Holmes & Wolff, 2012; Zhou et al., 2010), it was felt that prior exposure to the categories might affect the  lateralization of categorical perception.  So, in the current study, prior to the task of assessing categorical lateralization of facial expressions most participants were exposed to a quarter of the stimuli (by asking them to categorize the facial expressions in images morphed either between fear and anger, or sad and happy). Results of a pilot indicated that less exposure might lead to lateralized categorical perception. Hence, an additional condition in which some participants were kept naïve and not exposed by categorizing any facial expressions was added. A second experiment presented here attempted to replicate the finding of lateralized categorical perception found in the naïve participants in the first experiment.

The current study aims to fill a crucial gap in the literature: that despite the importance of facial expression perception generally, and categorical perception of facial expressions specifically, the lateralization of the categorical perception of facial expressions has not been determined. Models implicating language in facial expression categories predict a left hemisphere advantage whereas models in which facial expression categories reflect basic facial expression prototypes predict a right hemisphere advantage. Additionally, since recent prior exposure resulting from categorising stimuli was thought to be a possible explanation for variation in categorical lateralization found precious experiments, participants' prior degree of exposure to the stimulus categories was manipulated: some participants were kept fully naive of the categorical nature of the experiment were as the other participants were exposed by categorising a subset of the stimuli.

## Experiment 1

### *Participants*

Thirty participants (24 female, 6 male) aged between 17 and 20 years (M=19.38, SD=0.82) drawn from a student population completed the experiment. All participants had normal or corrected to normal vision. Ethical approval was given for both experiments by the authors' departmental ethics committee. Participants gave full consent for participating and were not paid.

### *Stimuli*

Image morphs of 5%, 35%, 65% and 95% were prepared running from happy to sad and from angry to fearful based upon the posed facial photographs of 4 individuals WF, PF, MO and EM (Ekman & Friesen, 1976). Areas outside of the face were then masked. The stimuli were based upon the Ekman and Friesen's set of images since these examples of facial expressions are widely used and well understood both within the literature related to categorical perception of facial expressions as well as more widely. The expression pairs of happy to sad and angry to fearful were used since these have been previously demonstrated to show categorical perception (Calder et al., 1996; Etcoff & Magee, 1992) and that these comparisons are still generally agreed to be universally discriminated (Jack, Blais, Scheepers, Schyns, & Caldara, 2009). Psychomorph (Tiddeman, Burt, & Perrett, 2001), an updated version of the software used by Young et al (1997), was used to ensure even spacing in terms of physical differences between pairs of image morphs. The faces of 4 individuals posing the facial expressions were used to increase the variation both to ensure that any results are generalizable across different instances of a facial expression and to reduce the likelihood that effects were the results of participants becoming highly practiced after being repeatedly exposed to the same face. Although blends of emotional expressions may seem artificial we note that blended expression are thought to occur with greater frequency than single emotional expression (Ekman, 1973).

### *Procedure*

Each participant completed the experiment on a computer in a laboratory supervised by the experimenter. The nature of the experiment was initially explained to participants in terms of face categorization with no reference being made to facial expressions. 'Exposed' participants categorized a subset of stimuli (Table 1) prior to the lateralization of categorical perception being assessed. The subset of stimuli categorized was varied in a counterbalanced manner (groups 1-4 in Table 2). 'Naïve' participants' lateralization of categorical perception was assessed prior to their categorizing any faces (counterbalancing groups 5-6 in Table 2). Each counterbalancing group contained 5 participants resulting in a total of 20 'exposed' participants and 10 'naïve' participants. Stimuli which were not categorized prior to assessing lateralization were categorized afterwards so that the boundaries between facial expressions could be calculated individually for each participant.

**[ Tables 1 then 2 near here ]**

Participants were asked to sit at a comfortable distance from the screen which they could maintain throughout the experiment and with the help of the experimenter measured the distance between their nose and the screen. This measurement was used to calculate the size and eccentricity of the stimuli so that for each participant the stimuli subtended the same visual angle. For a participant 500mm from the monitor the interpupillary distance of each face was 20mm (2.3° of visual angle) and, when two faces were shown simultaneously on screen the stimulus eccentricity (between the two face midlines) was 32.5mm (3.7°) with approximately 15mm (1.7°) separating the side of the face from the centre of the screen.

***Expression categorization task***

On each trial (Figure 1, left panel) a face was presented centrally for approximately 500ms after which the participant was asked to categorize the face as one of the two constituent emotional expressions. Each level of morph (5%, 35%, 65% and 95%) was presented four times in random order. Many previous studies of categorical perception of facial expressions (Calder et al., 1996; Etcoff & Magee, 1992) used 8 presentation. However, the discrimination being attempted by these studies was much more subtle and the aim to acertain whether categorical perception existed for a particular boundary between expressions. For example, attempting to discriminate the position of the categorical boundary between 11 different levels of expression morph and assess the extent to which this matched to an abrupt change from participants seeing the faces as predominantly one expression to predominantly the other, whereas here the position of the categorical boundary between 4 levels of morph was being determined between pairs of facial expressions between which categorical perception is well established (Calder et al., 1996; Etcoff & Magee, 1992).

***Categorical expression lateralization task***

A modified version of the discrimination task previously used to assess categorical perception of facial expressions (Etcoff & Magee, 1992; Roberson et al., 2010) was used. In this new task (Figure 1, left), the face to be matched was first presented centrally on screen for 2500ms ±250 before being replaced by a pair of face images which appeared for 166ms on either side of the original image's position. Participants were then asked to make a forced choice judgement using the 's' key if the image on the left matched the central image or the 'k' if the image on the right matched the central image.

Trials were composed of all combinations of two levels of facial expression pairings (happy-sad, anger-fear), three levels of adjacent intensities of facial expression morphs (5%-35%; 35%-65%, 65%-95%), two levels of presentation of higher intensity face in the left visual field and right visual field, two levels of matching face being on the left and on the right, and four different identities of individual posing the expression (WF, PF, MO, EF). Each trial was shown twice. This gave a total of 192 trials (2*3*2*2*4*2).

In addition 96 catch trials were included in which the initial face did not match either of the two laterally presented faces. This was done to rule out an attentional or strategic bias towards one side. In total there were 288 trials which were presented in a randomly ordered block.

The experiment was run in Internet Explorer on computers running Windows 7 and implemented in JavaScript. The requestAnimationFrame method, which is triggered when it is possible to draw onto the screen in preparation for the next screen refresh was used. The pair of face stimuli was presented on screen for 166ms (10 screen refreshes at 60Hz) to ensure that the occurrence of the pair of stimuli was less than 200ms. To assess the accuracy of this method the time between calls was measured (using the performance.now method). In total, there were six trials across the whole experiment in which the timing appeared off by more than 20ms. In all other trials assessment of the timing revealed that on all but two computers, the average timing between calls was 166.6ms (ranged from 166.4-167.4ms). On these two computers, the time averaged 172.7ms (range 171.3-172.0ms) and was traced back to monitors running at 70Hz rather than 60Hz.

***Calculation of the categorical boundary position***

The categorical boundary was defined as being between the pair of morphs in the sequence (5%, 35%, 65%, 95%) between which the predominant expression changed from being one expression to the other. Typically (68% of the time) the boundary was in the centre of the morph (between 35-65%), but 26% of the time it occurred off-centre (between the 5%-35% or 65%-95% morphs). Occasionally (6% of the time) the boundary could not be determined because all levels of morph were predominantly reported as one facial expression (4% of the time) or because there were multiple positions in the morph which fulfilled the criteria (2% of the time).

For every participant the boundary could be determined for 6 or more of the 8 morphs meaning that in the initial analysis presented in the results section between-category data points were the average of between 24 and 32 trials with each trial scored zero (incorrect) and one (correct). Between-category data points contained twice as much data since for each within-category trial there were two between-category trials.

**Results**

To assess the effect of being naïve as compared to having been exposed (via categorizing a subset of the faces), a 2×2×2 mixed ANOVA was performed on the proportion of correct matches with participant naivety (naïve, exposed) as a between subjects factor and visual field (correct stimulus in the left, correct stimulus in the right) and boundary (within category, between category) as within subjects factors[1]. As there was a significant three-way interaction between participant naivety, side, and boundary condition, $F(1,28)=5.173$, $p=.031$, $\eta_p^2=.156$, (Figure 2), the naïve and previously exposed participants were analysed separately.

**[ Figure 2 near here ]**

For the naïve participants, there was no significant effect of visual field, $F(1,9)=2.614$, $p=.140$, $\eta_p^2=.225$; no significant effect of boundary, $F(1,9)=4.461$, $p=.064$, $\eta_p^2=.331$; but there was an interaction between visual field and boundary, $F(1,9)=7.122$, $p=.031$, $\eta_p^2=.442$, which was related to a significant asymmetry in perception with between category advantage for stimuli

[1] Expression pair (happy-sad, anger-fear) was also initially entered into the analysis, but removed from the reported analysis since there were no significant effects.

presented to the right visual field, $F(1,9)=7.055$, $p=.026$, $\eta_p^2=.439$, but not in the left visual field, $F(1,9)=0.027$, $p=.873$, $\eta_p^2=.003$.

However, participants who had previously been exposed to the facial expression categories showed a different pattern with a significant effect of visual field, $F(1,19)=9.514$, $p=.006$, $\eta_p^2=.334$, reflecting better performance when the correct stimulus was presented to the left visual field than the right. In addition, a significant effect of boundary was found, reflecting better recognition between than within category, $F(1,19)=32.336$, $p<.001$, $\eta_p^2=.630$. The interaction was not significant, $F(1,19)=.010$, $p=.923$, $\eta_p^2=.001$. Within these exposed participants the ANOVA was performed again adding familiarity (stimuli same as categorized, stimuli with both different expression morph and identity than categorized) as a within subjects factor to assess whether the degree of exposure was important. However, no main effect of familiarity or interactions with familiarity were found ($F<1$).

In order to assess participants' performance in each condition, the proportion of correct matches was compared to chance (0.5). Performance in all conditions (both exposed, $t(19)>4.0$, $p<.01$, and naïve, $t(9)>4.3$, $p<.01$) was better than chance with the exception of the within category comparisons when the matching stimulus was presented in the right visual field, which did not differ significantly from chance (both exposed, $t(19)=2.16$, $p=.059$, and naïve, $t(9)=1.670$, $p=.111$).

To assess whether participants might have been selectively attending to one visual field, trials in which neither face matched the target were analysed. Neither exposed participants, $t(19)=1.126$, $p=.274$, nor naïve participants, $t(9)=0.231$, $p=.823$, were significantly biased to responding that the matching face was on the left or right on trials with no match.

To assess potential speed accuracy trade-offs, an ANOVA was run on log reaction time for correct trials with training (naïve, trained) as a between-subjects factor, and side and boundary condition as within-subjects factors. There was a significant effect of visual field, $F(1,28)=13.543$, $p<.001$, $\eta_p^2=.326$, with participants reacting faster to matching stimuli presented in the left visual field rather than the right. No other effects or interactions were found ($F<1$).

**Interim discussion**

The lateralization of categorical perception for emotional facial expressions was investigated. In line with studies which found lateralized categorical perception of colour, and with predictions based upon adult facial expression categories being a linguistic phenomenon (Roberson et al., 2010), lateralized categorical perception was found for emotional facial expressions in the right visual field, implicating the left hemisphere. However, this was restricted to naïve participants. Participants who had been exposed, by previously categorizing facial expressions, demonstrated categorical perception of facial expressions in both left and right visual fields - reminiscent of other findings of symmetrical categorical perception for colour (Suegami et al., 2014; Witzel & Gegenfurtner, 2011). Thus, it appears that the laterality of categorical perception of emotional facial expressions depends upon participants' experience to the experiment which presumably affected their strategy. These effects do not seem to be due to participants strategically focusing, and possibly fixating, on the faces on one side, as no bias was seen in catch trials in which neither the face on the left nor the face on the right matched, and with the exception of the within category comparisons when the matching stimulus was presented on the right, participants matched faces significantly above chance in all conditions.

Although, for colour, lateralized categorical perception has been replicated (Suegami et al., 2014; Witzel & Gegenfurtner, 2011), other researches, despite repeated attempts, have instead found categorical perception for stimuli presented to both visual half-fields (Witzel & Gegenfurtner, 2011). As such, it is imperative to replicate our analogous findings of lateralized categorical perception found in the naïve condition. In order to achieve this, a second experiment was performed which included a new and larger sample of naïve participants. In this experiment a greater number of individuals posing emotional facial expressions were included in order to test the generalizability of the effect.

## Experiment 2

### *Participants*

Thirty-two participants (23 female, 8 male, 1 choosing not to identify; 27 right handed, 5 left handed) aged between 17 and 20 years (M=19.38, SD=0.82) drawn from a student population completed the experiment. All participants had normal or corrected to normal vision. Participants gave full consent for participating and were not paid for their participation.

### *Stimuli*

The stimuli were produced in the same way as the previous experiment except that the morphs of faces of eight individuals (C, EM, JJ, MF, PE, PF, SW and WF) (4 females) (Ekman & Friesen, 1976) were used.

### *Categorical expression lateralization task*

The task was the same as used previously with the exceptions that the faces of eight individuals were used rather than four (Experiment 1) that each trial was shown once and no catch trials were included. Thus, 192 randomly ordered trials were used.

### *Determination of the categorical boundary*

The task and method used in Experiment 1 to determine the categorical boundary although each stimulus was presented 3 rather than 4 times. Similar to the previous experiment the categorical boundary was typically (62% of the time) in the centre of the morph, but 27% of the time it occurred off-centre. Occasionally (11% of the time) the boundary could not be determined because all levels of morph were predominantly reported as one facial expression (6% of the time) or because there were multiple positions in the morph which fulfilled the criteria (5% of the time).

***Procedure***

The experiment was the same as the previous experiment with the exceptions that all participants did the categorical expression lateralization task prior to categorizing the expressions of the morphed faces. Participants then completed the short form of the Edinburgh Handedness Inventory (Veale, 2014).

**Results**

**[ Figure 3 near here ]**

A 2×2 ANOVA was performed on the proportion of correct matches with visual field (correct stimulus in left, correct stimulus in right) and boundary (within-category, between-category) as within-subject factors (Figure 3). There was a significant effect of visual field, $F(1,31)=4.324$, $p=.046$, $\eta_p^2=.122$, with participants recognizing correct stimuli presented in the right more often than in the left visual field, and a significant effect of boundary, $F(1,31)=4.199$, $p=.049$, $\eta_p^2=.119$, with participants being better at recognizing stimuli which differed across the categorical boundary. However, and as expected given the finding for naïve participants in Experiment 1, there was a significant interaction between boundary and visual field, $F(1,31)=6.518$, $p=.016$, $\eta_p^2=.174$. To assess this interaction the data was split by side. When the correct stimulus was in the left visual field, there was no significant effect of boundary, $F(1,31)<0.001$, $p=.985$, $\eta_p^2<.001$, but when the correct stimulus was in the right visual field recognition was significantly better between-category than within-category, $F(1,31)=11.811$, $p=.002$, $\eta_p^2=.276$. Furthermore, when the 5 left-handed participants were removed from the analysis leaving only right handers, the same pattern remained with no significant effect of boundary when the correct stimulus was in the left visual field, $F(1,26)=0.003$, $p=.957$, $\eta_p^2<.001$, but a significant effect of boundary when the correct stimulus was in the right visual field, $F(1,26)=8.055$, $p=.009$, $\eta_p^2=.237$.

To assess potential speed accuracy trade-offs, the initial ANOVA was run but with log reaction time for correct trials side and boundary conditions as within-subjects factors. No effects or interactions approached significance (all $F<1$).

**General Discussion**

The lateralization of categorical perception of emotional facial expressions was investigated in two experiments. Lateralization was found to vary depending upon participant exposure with categorical perception being lateralized to the right visual field (implicating the left hemisphere) in naïve participants but being present in both visual fields in participants who had previously been exposed to the stimuli through categorizing their facial expressions. These findings imply a continuous role for the left hemisphere in categorising facial expressions, but that the right hemisphere, despite superior discrimination performance, does not necessarily encode faces in terms of emotional categories. The findings provide further evidence that emotional facial expression categories are subject to the effects of language processes (Gendron, Lindquist, Barsalou, & Barrett, 2012). The results also suggest that categorization may be a less important part of the perception of emotional facial expression than might be expected since discrimination of stimuli varying in facial expression can take place in the absence of categorical perception.

Contrary to models which suggest that the left hemisphere cannot independently process facial expressions (Shobe, 2014), the current results demonstrate that both hemispheres are able to process information related to facial expression. However, the finding that in the left visual field within-category discrimination did not differ from chance and only between-category discrimination was higher than chance, indicates that the information processed by the left hemisphere is coded predominantly in terms of category, in keeping with the notion of a left hemisphere categorical processing system (Roberson et al., 2010).

Roberson et al. (2010) suggest that the left hemisphere categorical processing system is in competition with the right hemisphere perceptual processing systems. In keeping with the right hemisphere having superior perceptual processing, we find that matching in the left visual field is consistently better than chance independent of the discrimination being within- or between-category. However, participants who were exposed to the nature of the underlying categories of facial expressions in Experiment 1 demonstrated categorical perception in both visual half-fields. This might be thought of as an experiential effect in which prior exposure to the differences between one pair of facial expressions accentuates the categorical distinction to the extent that the particular categorical distinction is used by both hemispheres. As such it would be expected that participants who had been exposed by categorising facial expressions would only show categorical perception in the left visual field (relate to the right hemisphere) for the facial expressions that they had categorised. Each exposed participant in Experiment 1 categorised one pair of facial expressions (either happy-sad or anger-fear) and lateralization of categorical perception was assessed for both pairs and instead found no difference in lateralization of categorical perception between the pair which the participant was exposed and the pair which they had not categorized. Thus, the manipulation in the current experiments which alters the laterality of categorical perception appears to work either through making all emotional categories more salient or making the strategy of categorization more salient and more likely to be used by participants.

A similar change in strategy may explain the variation in findings for categorical perception of colour (Gilbert et al., 2006, 2008; Suegami et al., 2014; Witzel & Gegenfurtner, 2011). For example, participants categorized colours prior to the lateralization being assessed both in experiments by Gilbert et al (2006), who found lateralized categorical perception, and by Witzel and Gegenfurtner (2011); who repeatedly found categorical perception in both hemifields. Such repeated differences in findings, despite the similar methods used, indicate another factor may be at play - an uncontrolled factor which caused participants to differ in strategy. Based upon our findings this factor may lead to the strategy of categorising colour being more or less used. In keeping with this, increasing the delay within a trial between initial stimulus presentation and response has been found to increase categorical perception (Maeshima, Yamashita, Fujimura, Okada, & Okanoya, 2015).

The simplest explanation for the our findings of categorical perception of emotional facial expressions in both visual half-fields found in exposed participants (Experiment 1) is that the underlying categories being used are the same in both hemispheres with the two hemispheres having different characteristic processing strategies. As such - and following from Gilbert et al's (2006) finding of disrupted of left hemisphere-lateralized categorical perception of colour by verbal suppression, and subsequent findings that left language areas are activated in between category colour perception (Siok et al., 2009) - left hemisphere-lateralized lexical coding would be responsible for the categorical distinctions reflecting the callosal-relay model (Zaidel, Clarke, & Suyenobu, 1990). Cross hemisphere access would be expected to result “in measureable loss of speed as well as loss of stimulus quality” (p. 303, Zaidel et al., 1990). As a result, the right hemisphere might be expected to show poorer specificity in categorical perception but this may be offset, if not reversed, by the right hemisphere’s well documented superiority in face processing generally. Better processing of faces, processing that is both faster and with greater veracity, by the right hemisphere may mean that cross-hemisphere access to categorical information in the left hemisphere is a stronger and more used pathway than the within-hemisphere pathway, resulting in individuals predominantly using information on the left side of the face (Bourne, 2010; Burt & Perrett, 1997; Campbell, 1978; Innes et al., 2016) and left visual field (Alves et al., 2009; Najt et al., 2013) when categorizing facial expressions.

Alternatively both hemispheres may separately process information categorically, following the direct-access model (Zaidel et al., 1990). Further supporting this, the right hemisphere has been found to support categorical perception in isolation as patients with left hemisphere damage - causing aphasia - show no between category advantage in the right visual field, but do show an advantage in the left. This might indicate a change in lexical organization favouring the right hemisphere (Paluy, Gilbert, Baldo, Dronkers, & Ivry, 2011) and infants of around 5 months show categorical perception of colour lateralized to the left visual field (Franklin et al., 2008). However, both of these studies suggest a right hemisphere ability in categorical perception which, rather than being general to typical adults, may be specific to individuals with aphasia or to a particular period of development. As such these studies demonstrate a capacity, but not that the capacity is actually used or available for use to typical adults. However, there is evidence that the two hemispheres of typical adults use different categories. For example, categorical perception of line orientation appears lateralized to the left visual field rather than the right visual field in adults (Franklin, Catherwood, Alvarez, & Axelsson, 2010). Furthermore, both hemispheres appear to have separate roles in the semantic processing of images of objects, with the right hemisphere having a greater role in weaker and more remote semantic relationships (Lovseth & Atchley, 2010). Thus, both hemispheres may code categorically, but these categories vary between hemispheres, with access to category information dependent upon participant strategy.

More specifically in terms of facial expressions - linguistic categories, although often aligned to categorically perceived categories (Etcoff & Magee, 1992) - do not seem to be necessary for categorical perception as both pre-linguistic infants (Kotsoni et al., 2001) and adults from cultures with absent emotional categories (Sauter, LeGuen, & Haun, 2011) show categorical perception of emotional expressions. Thus, the finding reported here that better between category discrimination can be found in both hemispheres may not be due to the facial expressions being linguistically coded, and despite indicating that information presented to both hemispheres can be categorically coded, may relate to different category encoding between the two hemispheres. For instance, the right hemisphere may instead code faces in terms of 'basic affect' (positive-neutral-negative) rather than emotional expression categories, as, for example, Lindquist et al (2014) found that individuals with semantic dementia (associated with the left hemisphere) spontaneously categorised faces varying in expression in terms of basic affect rather than the basic expressions used by controls. Additionally, it is unclear what is being encoded by the right hemisphere when no categorical perception is being found.

The relationship between the different emotional facial expression categories used by the two hemispheres is theoretically important. If they are independent then categorical perception of emotional facial expression in the right hemisphere may reflect the activation of prototypes related to basic emotional categories (Calder et al., 1996) (although it may be notable the left hemisphere damage in semantic dementia seems to reduce these categories, Lindquist et al., 2014). However, based upon Experiment 1, it appears that even if such right hemisphere categories exist, they are not always used, and so, are not a necessary stage of processing when an individual is confronted with the facial expressions of others. Instead, the effect of the emotional expressions of others in terms of categories may be interpreted via left hemisphere-based processing that is likely to relate to language and so subject to Whorf's hypothesis of biases in perception caused by variation between languages in a similar way to colour. Such left hemisphere linguistic encoding may facilitate the left hemisphere's role as the interpreter and categorizer of information but with the development of language being "at the cost of pre-existing perceptual systems" (Gazzaniga, 2000). This may be reflected not only in the left hemisphere's lack of ability in discriminating facial expression within-category found here, but also in the lack of ability of individuals with surgical section of the corpus callosum to match facial expressions presented to their left hemisphere unless explicitly primed to label the facial expression (Stone, Nisenson, Eliassen, & Gazzaniga, 1996).

The current study is limited in its assessment of handedness and that it did not attempt to assess the lateralization of categorical perception for all pairs of emotional expressions but was instead confined to two pairs of expressions which have previously been shown to demonstrate categorical perception. In addition to assessing the generalizability across different emotional expressions future work needs to quantify the causes for the variation in the lateralization of categorical perception found both within Experiment 1 and between previously published experiments which have investigated the lateralization of categorical perception of colour.

Although the first experiment presented here presents a method of producing variation in the lateralization of categorical perception the generalizability of this method and the mechanism behind this variation is not clear – for example, the effect may be caused by making facial expressions more salient, biasing participants to use categorical encoding or to attend to different aspects of the face. Furthermore, the relationship between the categories used by the two hemispheres is unclear – it may be that the right hemisphere accesses linguistically defined categories of the left hemisphere or may encode facial expressions unaided by the left hemisphere possibly based upon basic affect (Barrett, 2006; Lindquist et al., 2014) or a continuous approach to facial expressions which might encode subtitles including emotional intensity (Young et al., 1997). In addition, there may be variation between individuals in the manner that they process facial expression – for example gender effects which are not assessed here. Further experimentation to address these issues is warranted.

In summary, both left and right hemispheres are able to process facial expressions, but the encoding of information in the left hemisphere appears to be necessarily categorical in nature in terms of emotional facial expression, with the encoding in the right hemisphere being more detailed but with access to categorical information dependent upon strategy. The extent to which the encoding of emotional expression is similar or shared between the two hemispheres is unclear with some evidence from other domains suggesting that it may be separate. However, it is clear that categorization is not a necessary part of the processing of emotional faces by the right hemisphere. As such, emotional categories may be less important than generally thought or perception of others people’s facial expressions subject to biases induced by language and variations between languages.

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Table 1.

*Composition of the stimulus subsets (A to D)*

| | | Faces of individuals | |
|---|---|---|---|
| | | WF and PF | MO and EM |
| Expression pair | Happy-Sad | A | B |
| | Angry-Fearful | C | D |

Table 2.

*Running order of stimulus subsets used to counterbalance the 6 participant groups.*

| Participant group | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1. Training block (Categorisation) | A | B | C | D | - | - |
| 2. Main task | | | Lateralization task | | | |
| 3. Same expression Categorisation | B | A | D | C | AB | CD |
| 4. Other expression Categorisation | CD | CD | AB | AB | CD | AB |

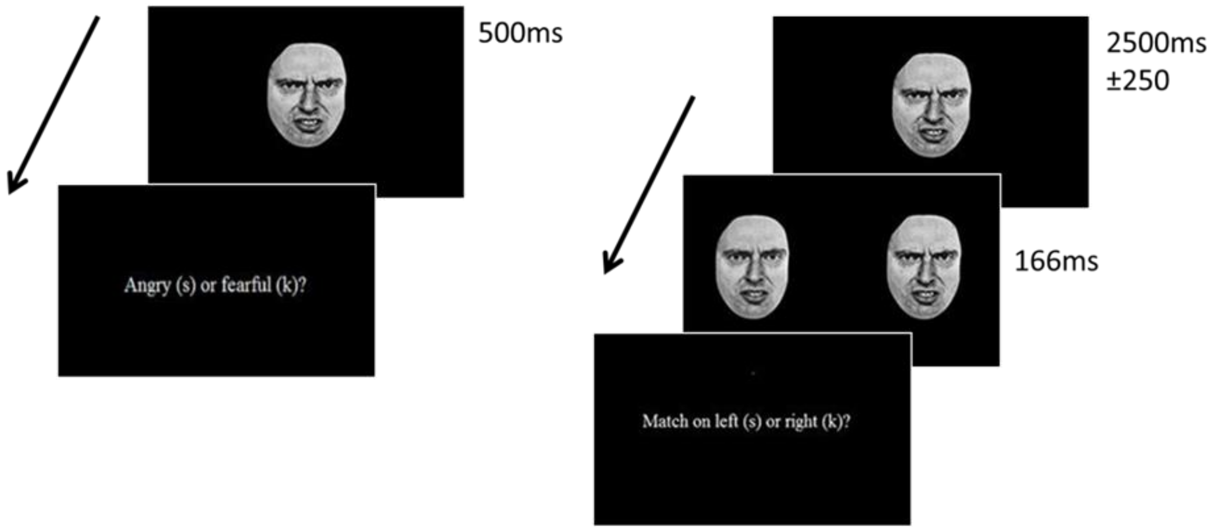


*Figure 1.* The categorization task (left) and lateralization task (right) used in the two experiments. All stimuli and stimulus pairs were presented centred on the screen.

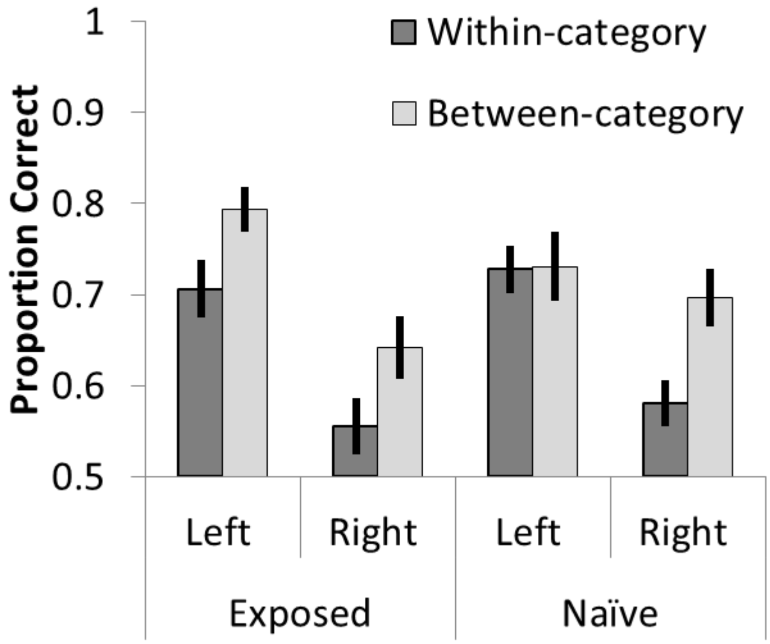


*Figure 2.* Mean proportion of correct discriminations (±SEM) for matching stimuli presented to the left and right visual fields for participants who had received exposure (had categorized some facial expressions) and naïve participants who had not.

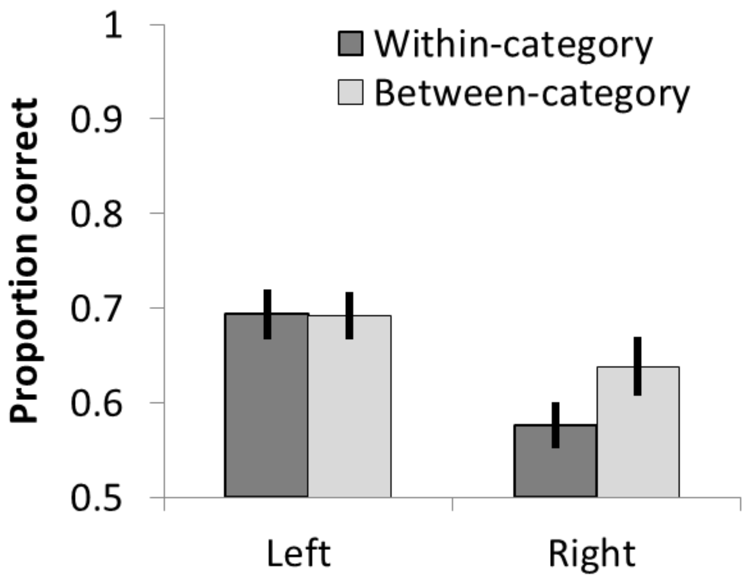


*Figure 3.* Mean proportion of correct discriminations (±SEM) for matching stimuli presented to the left and right visual fields for different levels of training with individual faces and expressions.