

Hemispheric assymetries in the visual processing of spatial frequencies of facial emotional expressions

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This paper examines two aspects of the lateralisation of cognitive function. A same-different reaction time paradigms was used to characterise perceptual processing in each visual field. Images were degraded using low-pass filtering to exclude ranges of high frequencies. In this experiment, psychophysical procedures used facial expression images as a carrier for spatial frequency information. Observers had to judge whether two sequentially presented images showed the same emotion, irrespective of identity, gender and spatial frequency content. Reaction time and accuracy measures showed that lower frequency information was processed better in the left visual field (right hemisphere). When higher frequency cues were available, both hemispheres processed stimuli equally well. In addition, some expressions were processed more rapidly or more accurately in a particular visual field.

The perception and recognition of faces and other learned objects involves many similar processes. The observed similarity between faces and other visual objects in terms of the functional organisation of semantic access and name retrieval is important for two reasons. Firstly, it demonstrates that the same organising principles appear to hold for the recognition of faces and other visual objects, even though there may be grounds for supposing that face recognition

has a specialised mechanism devoted to it. So, although there may be face-specific processes there may not necessarily be unique processes involved in face perception and recognition. Secondly, faces provide a very important class of visual objects in which their physical and semantic properties vary enormously. The particular identity of a face cannot be known just from its configuration and, in this respect, familiar faces are more like words than other vi-

sual object yet they are processed more like objects than like words (Humphreys & Bruce, 1989).

It seems possible that face recognition may be organised in a similar way to the module (or modules) used to recognise other categories of visual objects. (Bruce & Young, 1986). The model suggests that identification proceeds in parallel with expression analysis and lip-reading ("facial speech"). Identification itself involves stages of perceptual classification (via the "face recognition units"), semantic classification (at the "person identity nodes") and name retrieval. The face recognition units allow the classification of a novel view of a known face as familiar, and are thought (possibly) to contain access to view-specific representations of each known face. The person identity nodes, unlike the face recognition units, are domain-independent; they can be accessed by faces, voices, names and so forth, and they provide access to identity-specific semantic information, but are distinct from name retrieval. Another component in the model is "directed visual processing", which includes task-specific references to facial processing.

It is well known that the two cerebral hemispheres of the human brain are not identical in function. Each side of the brain has been shown to differ in its capacity to handle different stimuli and/or in the manner in which information is processed. There are also indications that the hemispheres differ in their involvement with regulation of emotions and related behaviour (Burton & Levy, 1989).

A description of the incoming information, and of its cortical representations in terms of spatial frequency (SF), may offer the possibility to examine the localisation of hemispheric function. Sergent (1985) demonstrated the relatively greater capacity of the right hemisphere, to operate on the low frequency (≤ 2 cpd) contents

of faces. This differential sensitivity to SF may be one of the factors contributing to the familiar right hemisphere superiority when the viewing conditions prevent the extraction of higher frequencies or when performance does not benefit from processing these frequencies.

The experiment was designed to extend the findings of Sergent (1982, 1985) in a reaction time paradigm. A number of predictions were made:

1. Images of the same spatial frequency will be matched with the same accuracy.
2. Low spatial frequency images presented in the left visual field, processed first by the right hemisphere, will be responded to more quickly compared with presentations in the right visual field. The right visual field (RVF-LH) will be more sensitive to higher spatial frequencies.
3. Asymmetries arise at a level when cognitive processes are performed beyond the sensory areas.

Any differences due to response time may be accompanied by a speed/accuracy trade-off (faster but less accurate responses). Such findings are not uncommon in speed tasks (e.g. Benson & Perrett, 1991). In this experiment, relatively poor performance accuracy was anticipated because of the necessarily brief presentation times required to show hemispheric differences.

Methods

Participants. Three male observers and one female observer participated voluntarily (mean age = 33). All had normal, or corrected to normal vision.

Material. Images were taken from Ekman and Friesen (1978). Images of 6 males and 8 females displaying seven facial expressions (angry, disgust, fear, happiness, neutral, sadness and surprise) were used in the experiment (Figure 1).

None of the faces wore glasses, beards, or moustaches. Stimuli were created by low-pass filtering the original portraits with frequencies 0.5, 0.7, 1, 1.4, 2, 2.8, 4, 8 and 11.3 cycles/deg (cpd). Images were 239×360 pixels (11.4 x 17.1 degrees, when viewed at a distance of 57 cm). All stimuli were masked with an elliptical aperture to exclude external features (hair, ears, etc).

Procedure. The experiment began when subject pressed the “Enter” key after instructions had been presented on the stimulus monitor. Subjects were required to fixate a small point at the center of the display 0.25 deg diameter. The distance between subject and screen was 57 cm. Before starting up images, subject heard a 350 Hz tone lasting 150 ms. After an initial 2000 ms delay, an unfiltered target image was presented centrally for 50 ms. After 750 ms, a filtered probe image was presented for 50 ms 3 deg laterally into either the left or right visual field. Subjects then had to make a response as quickly as possible – to push indicated key, if the facial expressions were the same or the different. Subjects were instructed to respond as quickly and as accurately as possible. The next trial followed the subject’s response. The inter-trial interval was 1000 ms. Use of different keys for same and for different responses were counter balanced. Presentation of stimuli (expression, visual field, spatial frequency) was fully randomised. Response reaction time (in milliseconds) and performance accuracy were collected. Between 50–100 practice trials were given (excluded from analyses). Stimuli were fully randomised, and then selected in blocks of ~120 trials to minimise fatigue.

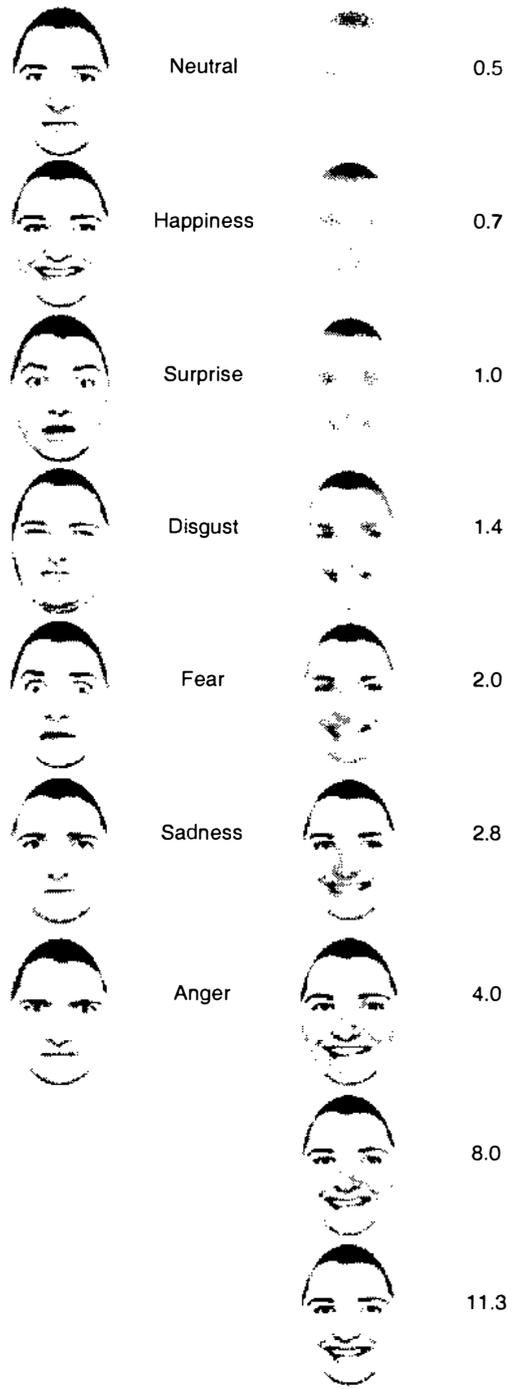


FIG. 1 Examples of facial stimuli used in experiments and filtered images of one emotional expressions

Results

Reaction Time

Reaction time data were analysed by ANOVA (using SPSS software). Incorrect responses and faces with neutral expression were not included. Reaction times greater than ± 1.96 sd of the mean were excluded from analysis to minimise the effect of outliers. There were four factors – Match (same and different), Visual Field (VF, right and left), Spatial Frequency (SF, 9 levels – 0.5, 0.7, 1, 1.4, 2, 2.8, 4, 8 and 11.3 cpd), Facial Expression (6 emotion categories – anger, disgust, fear, happiness, sadness and surprise). A general factorial analysis of reaction time showed that all factors (Match, VF, SF and Expressions) reached significance ($p < 0.05$).

There was a main effect of Match ($F(1,3054) = 21.08, p < 0.001$), VF ($F(1,3054) = 10.79, p = 0.001$), SF ($F(8,3054) = 26.34, p < 0.001$), Expression ($F(5,3054) = 5.87, p < 0.001$). There was a significant interaction between Match x SF ($F(1,3054) = 7.02, p < 0.001$; Figure 2); subjects performed differently to Same and Different expressions depending on which SFs were available. The VF x SF was also significant ($F(8,3054) = 3.32, p = 0.001$; Figure 3); the LVF-RH and RVF-LH were differently sensitive to SF upholding the important laterality hypothesis. Match x Expression ($F(5,3054) = 6.61, p < 0.001$; Figure

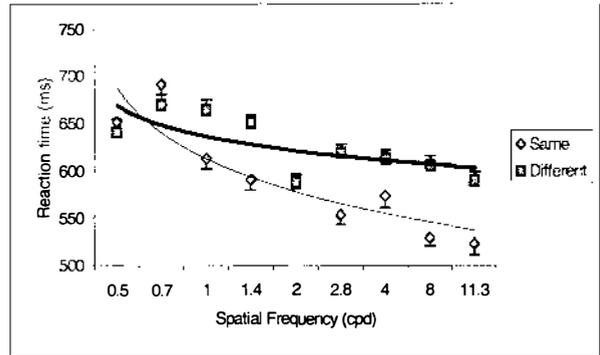


FIG.2 Reaction Time for Same/Different (Match) by Spatial Frequency

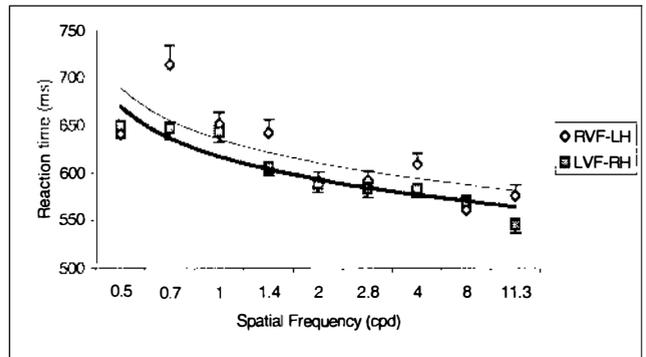


FIG.3 Reaction Time for each Visual Field by Spatial Frequency

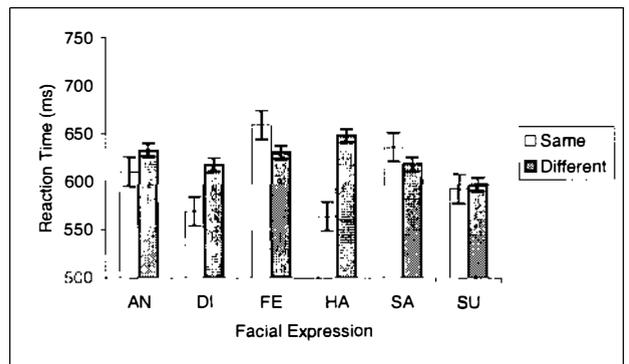


FIG.4 Reaction Time for each Match condition by Facial Expression. Expressions are denoted by their respective labels: ANger, DIsgust, FEar, HAppiness, SAdness and SUrprise

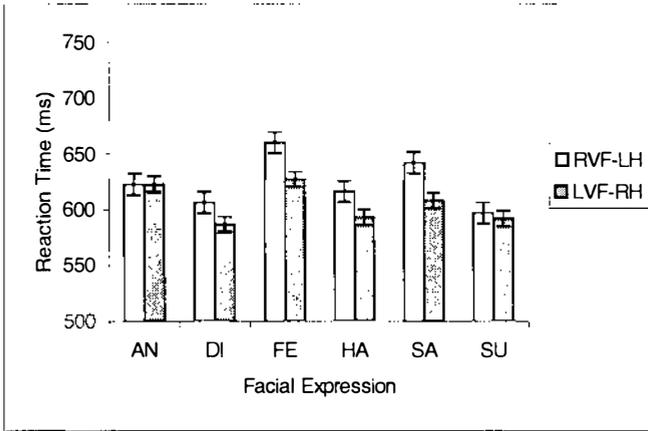


FIG.5 Reaction Time for both Visual Fields By Facial Expression. Labels are the same as in FIG.4

re 4), SF x Expression ($F(40,3054) = 2.71$, $p < 0.001$) and Match x SF x Expression ($F(40,3054) = 1.64$, $p = 0.01$) interactions were all significant. Same expressions were discriminated more easily than others and at different spatial frequencies, confirming the utility of particular features.

Subjects gave faster answer when the sequentially presented expressions were the “same”, than the “different”. Reaction time was generally quicker when images were presented in the LVF-RH, than in the RVF-LH. Recognition time was the shortest for the 11.3 cpd images (560 ± 124 ms) when the most information was available. Figure

3 shows the dependence of reaction time for each VF on SF. In the analysis of expressions, reaction time for disgust was the fastest (591 ± 154 ms). Although the interaction of VF and Expression did not reach significance ($F(5,3054) = 1.38$, $p = 0.23$), the LVF-RH showed greater sensitivity for the recognition of facial expression than the RVF-LH (Figure 5).

Detailed Analysis of SF Effect

A more detailed analysis of SF was done using Scheffé *post hoc* tests (SPSS). Table 1 shows summary of results. There were no significant differences between images filtered with 0.5 and 1 cpd, 0.5 and 1.4 cpd, 8 and 11.3 cpd, and between in the interval [2–4] cpd. The images filtered with 0.5 cpd were very blurred and recognition accuracy was low (50% chance performance). Thus, the SF scale could be divided into three intervals: [0.5–1.4], [2–4] and between 8 and 11.3 cpd. The SFs in the interval [2–4] might represent the threshold for different sensitivity to SF between LVF-RH and RVF-LH.

Table 1. Significant Differences of Reaction Time across Spatial Frequencies

SF (cpd)	0.5	0.7	1	1.4	2	2.8	4	8
0.4	<0.001							
1		<0.001						
1.4	0.05	<0.001	0.03					
2	<0.001	<0.001	<0.001	<0.001				
2.8	<0.001	<0.001	<0.001	<0.001				
4	<0.001	<0.001	<0.001	0.01				
8	<0.001	<0.001	<0.001	<0.001	0.02	0.04	0.01	
11.3	<0.001	<0.001	<0.001	<0.001	0.01	0.02	<0.001	

Separate post hoc analyses of reaction time were performed for each SF with Match, VF and Facial Expression as factors. There was a main effect of Match, when images were filtered with frequencies 0.7 cpd ($p = 0.03$), 1 cpd ($p = 0.01$), 1.4 cpd ($p < 0.001$), 2.8 cpd ($p < 0.001$), 4 cpd ($p = 0.03$), 8 cpd ($p < 0.001$) and 11.3 cpd ($p < 0.001$). In general, responses were faster to the “same” task than “different” except for faces blurred with 0.7 cpd which might indicate that discrimination was based on a different strategy using only gross features shapes.

For VF, the significant spatial frequencies were 0.7 cpd ($p < 0.001$), 4 cpd ($p = 0.02$) and 11.3 cpd ($p = 0.03$), and responses were faster for LVF-RH stimuli.

For Expression, different emotions were degraded to different degrees at 0.7 cpd ($p = 0.02$), 1 cpd ($p < 0.001$), 8 cpd ($p = 0.01$) and 11.3 cpd ($p < 0.001$). The shortest reaction time was to negative emotions (disgust and fear) when these images were filtered at 8 and 11.3 cpd. Lower spatial frequencies (0.7 and 1 cpd) were important for surprise and happiness.

The interaction Match x VF was significant only for stimuli filtered at 1.4 cpd ($p = 0.01$). There was a further interaction of Match x Expression for images blurred at 0.7 cpd ($p = 0.01$), 1.4 cpd ($p = 0.01$), 2 cpd ($p = 0.01$) and 2.8 cpd ($p = 0.03$). This was probably again due to the appearance of displays containing salient features degraded by low-pass filtering.

Additional Effects due to Expression

Separate analyses of reaction time were performed for each Expression with Match, VF and SF as factors. The main effect of Match was significant for disgust ($p = 0.01$), happiness ($p < 0.001$) and surprise ($p = 0.02$). Responses were faster to the “same” condition. Although, in

general factorial analysis, there was no significant overall interaction between VF x Expression ($p = 0.23$), there was an interaction between VF for fear ($p = 0.01$). Fear was recognized faster in the LVF-RH (647 ± 184 ms).

Analysis of the interaction SF x Expression showed that blurring over the range (0.5 – 11.3 cpd) was detrimental to speeded responses for all expressions ($p < 0.001$), except surprise. Responses were faster for higher SFs (8 and 11.3 cpd), but reaction times for sadness were the shortest when images was blurred at 2 cpd.

The interaction between Match x SF was significant for anger ($p < 0.001$), fear ($p = 0.02$) and happiness ($p = 0.01$). This effect might be evoked by facial features such as interbrow furrow, chin lines and nose wrinkle for angry, crow’s-feet and chin lines for fear and crow’s-feet, nasolabial lines and chin lines for happiness (Benson, 1999).

Accuracy

Accuracy (for correct responses) was analysed by Mann-Whitney U-test (using SPSS and Microsoft Excel). Data for neutral expressions were not included. Accuracy expected by chance performance alone was 50%. There were four factors, as before – Match, VF, SF, Facial Expression.

Spatial Frequency

General analysis showed that accuracy was no different across VFs or the Match condition. Separate analyses of accuracy were conducted for each SF with Match and VF. Performance accuracy was unaffected by presentations to RVF-LH and LVF-RH (Figure 6). The trend was for increasing accuracy with increasing SF; at 8 and 11.3 cpd accuracy was optimal.

A more detail analysis of Match condition at various SFs showed significant differences bet-

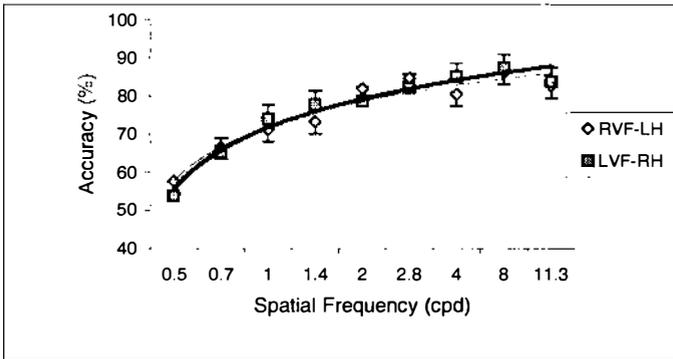


FIG. 6 Performance Accuracy in each Visual Field influenced by Spatial Frequency

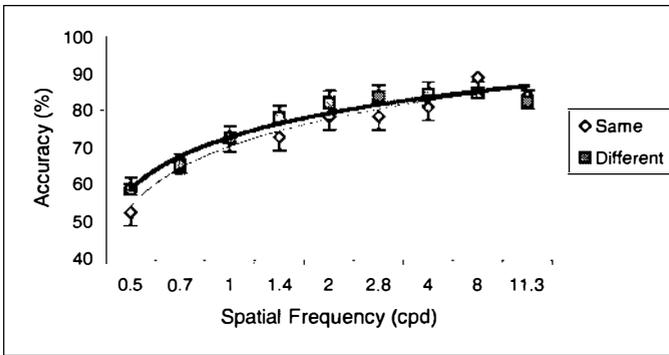


FIG. 7 Accuracy for Same/Different (Match) by Spatial Frequency

ween response types – “same” and “different” for images filtered at 2 ($p = 0.01$), 2.8 ($p = 0.02$) and 4 cpd ($p = 0.02$). Responses were more accurate for “different” task at this interval (Figure 7).

Accuracy was not affected by SF, as expected. There were no significant differences between images filtered in the intervals 1–1.4 cpd, [2; 4], 2–11.3, 2.8–11.3 and [4; 11.3] cpd. In general, accuracy increased with increasing SF. SFs in the interval [2; 4] could represent a threshold for performance differences between low SFs and poor performance, and higher SFs and well above chance discrimination.

Facial Expressions

A detailed analysis of Expression matching performance showed significant differences

between anger and disgust ($p = 0.01$), anger and happiness ($p < 0.001$), anger and surprise ($p < 0.001$), disgust and fear ($p < 0.001$), disgust and sadness ($p = 0.01$), fear and happiness ($p < 0.001$), fear and surprise ($p < 0.001$), happiness and sadness ($p < 0.001$), sadness and surprise ($p < 0.001$). Disgust, happiness and surprise were matched more accurately than anger, fear and sadness. This effect might be evoked by small expression details, such as forehead lines for surprise and nose wrinkles etc., as was the case when reaction time was the dependent variable.

Separate analyses of accuracy were performed for each Expression with Match, VF and SF as factors. The main effect of Match was significant only for anger ($p = 0.04$) and sadness ($p < 0.001$). Responses were more accurate to the “different” conditions. Although, Mann-Whitney tests did not show a general effect of VF on Expression processing, disgust and happiness were recognized more accurately in the RVF-LH than in the LVF-RH. Anger, fear, sadness and surprise were responded to more accurately when presented in the LVF-RH.

The general relationship between SF filtering an expression matching performance was for an increase in accuracy with increasing availability of high frequency information.

Discussion

The role of viewing conditions was illustrated in this experiment. Several variables were identified as determining visual field asymmetries, and it is suggested that the emergence of hemispheric superiority in an experiment can be determined by many factors, none of which are themselves sufficient to account for the findings. Sergent's (1983) findings agree with this.

Reaction Time and Spatial Frequency

Two dependent variables are commonly used in research on cognitive information processing: reaction time and accuracy. Each address different aspects of visual processing. Response latency measures in this experiment indicated that matching the "same" and "different" expressions led to significantly different performance in each visual field due to the effects of low-pass filtering and the availability of high spatial frequencies. Responses were faster when expressions were the same, indicating that observers performed well in providing speeded responses and when, in general, stimuli were presented in the LVF-RH. Expression matching was fastest of all when the expressions were the same and shown with high spatial frequencies present. With low frequencies only, reaction times were surprisingly different in each visual field when the spatial resolution was between 0.5 and 0.7 cpd. In particular, responses to 0.7 cpd stimuli presented in the RVF-LH were approximately 60 ms slower than when presented in the LVF-RH. This finding alone was immediately suggestive of asymmetric processing of low spatial frequency information in the matching task.

Many interactions arose as a result of these two main effects (Match, VF). Each can be explained by the resolution of particular important facial features. Some features are more im-

portant than others for the discrimination of each of the 6 expressions. In addition, the results of Match analysis were complicated, because faster responses were made to "same" facial expressions, but these were generally less accurate. A similar speed/accuracy trade-off is not uncommon in speeded recognition or matching experiments (e.g. Benson and Perrett, 1991). Accuracy was better for "different" judgements. This can be explained by the fact that it is almost always easier to tell when 2 objects are different, than it is when they are the same or identical. In terms of categorical judgements, it is easier to tell that 2 facial displays belong to different categories of emotion expression than it is to make a within-category judgement (which is instead likely to be a question of similarity).

Accuracy and Spatial Frequency

Performance accuracy was no different across visual field. Responses were, however, more accurate when expressions did not match; the reasons for this have already been suggested above. In this experiment, accuracy was not a major concern provided that it did not radically affect the outcome of the main finding.

Some expressions were matched more accurately than others, but there was no particularly obvious pattern that would suggest that this measure could be a reliable indicator of hemispheric asymmetry. Instead, reaction time provided this information.

Lateralisation of Expression Processing

Although many studies have showed that the RH is dominant for the perception of emotion, there is a real lack of convincing evidence supporting this idea from reaction time experiments. There are other data, however, that suggests that both hemispheres process emotionally related behaviors, but do so for different types of emotions.

Commonly, the LVF-RH is implicated in the regulation of negative affects, while the RVF-LH is associated more with positive emotions (Silberman & Weingartner, 1986; Davidson, 1992). The study of Morris et al. (1998) showed that a significant neural response was elicited in the right amygdala after presentation of angry faces. In this experiment, a similar result for anger was found. In general, there was no significant difference between accuracy in VF due to Expression category, anger, fear, sadness and surprise elicited more accurate responses in the LVF-RH, and disgust and happiness benefited from presentation in the RVF-LH. Fear was recognised faster in the LVF-RH than in the RVF-LH.

Hemispheric Asymmetry and Related Studies

Advantage of visual field shifts caused by variations in stimulus energy may be understood if one considers the effects of these variations on the information available for processing. Since stimulus energy determines the characteristics of the incoming information extracted and integrated by the visual system in terms of SF components, reversal in hemispheric superiority may then reveal a preferential sensitivity of the hemispheres to particular ranges of SF. This sensitivity may provide each hemisphere with predispositions and limitations in developing its specific competence, and may allow the hemispheres to operate together by processing different aspects of the same information (Sergent, 1983). A variety of studies in both unimpaired and brain-lesioned subjects have suggested that the right hemisphere is specialised for processing emotional aspects of information (Silberman & Weingarter, 1986). Although, analysis of accuracy did not show significant differences between the VFs (a similar investigation using

gratings was found by Kitterle, Christman and Conesa in 1993), reaction time was faster in the LVF-RH, than in the RVF-LH.

Significant differences of the reaction time speed were evoked by images filtered at 0.5, 4 and 11.3 cpd. Kitterle (1979) made a direct comparison of low and high frequency components by requesting subjects to respond to the onset of gratings at varying spatial frequencies in a reaction time experiment. A significant LVF-RH superiority with low frequency gratings was found, as well as a non-significant RVF-LH effect with high frequency gratings that were responded to more slowly than low frequency gratings.

These results thus provide support for the view that the two hemispheres may not be equally sensitive to different spatial frequency bandwidths. Sergent (1982) expanded this theory that the LVF-RH displays greater efficiency than the RVF-LH in processing early available low-spatial-frequency contents of visual images. However, our experimental data showed that higher frequency cues were utilised by both hemispheres with equal efficiency. This is contrast with finding of Sergent (1982), that the RVF-LH is better equipped than the LVF-RH.

Conclusions

Reaction time measures in the expression matching task succeeded in demonstrating important hemispheric differences due to spatial frequency content. The LVF-RH processed low SFs more ably than the RVF-LH. Higher frequency cues were utilised by both hemispheres with equal efficiency. Accuracy data helped defend the hypothesis that asymmetries in visual processing could be due to post-sensory processing.

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VEIDO EMOCINIŲ IŠRAIŠKŲ ERDVINIŲ DAŽNIŲ APDOROJIMO SMEGENŲ PUSRUTULIUOSE SKIRTUMAI

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Santrauka

Šio darbo tikslas – ištirti erdvinių dažnių įtaką veido emocinių išraiškų atpažinimo skirtinguose pusrutuliuose greičiui ir tikslumui. Reakcijos laiku buvo bandyta įvertinti veido emocinių išraiškų atpažinimo proceso skirtumus abiejuose smegenų pusrutuliuose. Eksperimentui buvo naudojamos septynios emocijas išreiškiančios veido išraiškos, nufiltruotos žemais erdviniais dažniais. Tiriamojo užduotis – kuo greičiau ir tiksliau atpažinti dvi paciliui rodomas veido išraiškas nepriklausomai nuo veidų individualumo, lyties ir

erdvinių dažnių. Reakcijos laiko ir tikslumo matavimai parodė, kad žemesnių erdvinių dažnių vaizdai greičiau atpažįstami dešiniajame pusrutulyje, tuo tarpu aukštesnių erdvinių dažnių vaizdai vienodai tiksliai ir greitai atpažįstami abiejuose pusrutuliuose. Be to, skirtingos emocinės veido išraiškos atpažįstamos skirtingu greičiu ir tikslumu abiejuose pusrutuliuose: pykčio, baimės, lįūdesio ir nuostabos išraiškos greičiau ir tiksliau atpažįstamos dešiniajame pusrutulyje.

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