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Cerebral lateralisation for facial processing: Gender-related cognitive styles determined using Fourier analysis of mean cerebral blood flow velocity in the middle cerebral arteries

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Facial processing was studied in 16 (eight men and eight women) right-handed healthy participants using a new functional transcranial Doppler technique called functional transcranial Doppler spectroscopy (*f*TCDS). MFV was recorded simultaneously in both right and left middle cerebral arteries in dark condition and during visual processing of object and facial tasks. *f*TCDS used Fourier analysis of mean flow velocity (MFV) time series to derive spectral density estimates that correlate with expected mental activity. Men were right lateralised for object and facial perception, while women were left lateralised for facial tasks but showed a right tendency or no lateralisation for object perception. For facial perception, men used a category-specific process-mapping system for right cognitive style, but women used same for the left.

The neuroanatomical correlates of facial perception have been fairly well studied. Most authors agree that during the perception of faces, major activations occur in the extrastriate areas bilaterally, particularly in the fusiform gyri and in the inferior temporal gyri (Andreasen et al., 1996; Haxby et al., 1991; Haxby, Horwitz, Ungerleider, Maisog, Pietrini, & Grady, 1994; Haxby, Ungerleider, Horwitz, Maisog, Rapoport, & Grady, 1996; Kanwisher, McDermott, & Chun, 1997; Puce, Allison, Asgari, Gore, & McCarthy, 1996; Puce, Allison, Gore, & McCarthy, 1995; Sergent, Ohta, & MacDonald, 1992). Others have shown that the fusiform gyri are preferentially responsive to faces, whereas the parahippocampal/lingual gyri are responsive to buildings (Gorno-Tempini & Price, 2001). Ishai and colleagues have proposed the object form topology hypothesis, which

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posits that there is a topological organisation of neural substrates for object and facial processing (Ishai, Ungerleider, Martin, Schouten, & Haxby, 1999). However, Gauthier disagrees and suggests that the category-specific and process-map models could accommodate most other proposed models for the neural underpinnings of facial processing (Gauthier, 2000). It is not known at this time how gender-related differences affect the preferred processing model.

Electrophysiological studies have demonstrated gender-related differences during a face recognition memory (FRM) task and a facial affect identification task (FAIT). Boys used a right, while girls used a left, hemisphere neural activation system in the processing of faces and facial affect (Everhart, Shucard, Quatrin, & Shucard, 2001). Moreover, in face recognition there was no association to estimated intelligence, suggesting that face recognition performance in women is unrelated to several basic cognitive processes (Herlitz & Yonker, 2002; Lewin & Herlitz, 2002). Gender-related differences (Smith, 2000) may suggest a role for sex hormones. In women there may be variability for psychological functions (Voyer, Voyer, & Bryden, 1995) related to differences in hormonal levels during different phases of the menstrual cycle (Hausmann, 2005).

Data obtained in norm and in pathology support asymmetric face processing (De Renzi, 1986; De Renzi, Perani, Carlesimo, Silveri, & Fazio, 1994; Mattson, Levin, & Grafman, 2000). The left inferior frontal cortex and the bilateral occipitotemporal junction respond equally to all face conditions (Gorno-Tempini et al., 2001). Others contend that both the left inferior frontal cortex (Brodman area 47) and the occipitotemporal junction are implicated in facial memory (Barton & Cherkasova, 2003; Sprengelmeyer, Rausch, Eysel, & Przuntek, 1998; Verstichel, 2001). The right inferior temporal/fusiform gyrus responds selectively to faces but not to non-faces. The right temporal pole is activated during the discrimination of familiar faces and scenes from unfamiliar ones (Nakamura et al., 2000). Right asymmetry in the mid temporal lobe for faces has also been demonstrated using ^{133}-Xenon measured cerebral blood flow (CBF) (Gur et al., 1993). Others have observed right lateralisation for facial recognition in previous electrophysiological and imaging studies (Ojemann, Ojemann, & Lettich, 1992; Sergent et al., 1992; Allison et al., 1994b; Puce et al., 1996; Kanwisher et al., 1997). One implication of the asymmetry for facial perception would be that different hemispheric strategies would be implemented. The right hemisphere would be expected to employ a holistic strategy, and the left an analytic strategy (Bogen, 1969, 1975; Bradshaw & Nettleton, 1981; Galin, 1974).

Functional transcranial Doppler (*f*TCD) has been implemented in the study of cerebral lateralisation (Knecht et al., 2000; Njemanze, 1991, 1996, 2004, 2005; Stroobant & Vingerhoets, 2000). Moreover, most established neuroanatomical substrates for facial processing are perfused by the middle cerebral artery (MCA). During facial recognition tasks, greater changes in the right middle cerebral artery (RMCA) than the left (LMCA) have been observed (Droste, Harders, & Rastogi, 1989; Harders, Laborde, Droste, & Rastogi, 1989). More recently, it was demonstrated that men were right lateralised and women left lateralised during facial processing tasks (Njemanze, 2004). Similar gender-related reversed asymmetry has been observed for performance implicating general intelligence in ultrasound, functional magnetic resonance imaging (*f*MRI), and magnetic resonance spectroscopy (MRS) studies (Jung et al., 2005; Njemanze, 2005; Tranel, Damasio, Denburg, & Bechara, 2005). The *f*TCD technique has the appropriate temporal and regional spatial resolutions for this type of cognitive study.

However, conventional *f*TCD may not differentiate the lateralising effects due to stimulus characteristics from those due to light responsiveness. Furthermore, *f*TCD does not distinguish between flow signals emanating from cortical and subcortical branches of the cerebral arteries of the circle of Willis. Each principal artery of the circle of Willis gives origin to two different systems of secondary vessels. One of these is named the ganglionic system, and the vessels belonging to it supply the thalami and corpora striata; the other is the cortical system, and its vessels ramify in the pia mater and supply the cortex and subjacent brain substance. The cortical branches are divisible into two classes: long and short. The long or medullary arteries pass through the grey substance and penetrate the subjacent white substance to the depth of three or four centimetres. The short vessels are confined to the cortex. The cortical and ganglionic systems do not communicate at any point in their peripheral distribution, but are entirely independent of each other, and there is, between the parts supplied by the two systems, a borderline of diminished nutritive activity (Gray & Clemente, 1984). The vessels of the cortical arterial system are not so strictly "terminal" as those of the ganglionic system. Blood flow in these two systems in the MCA territory supplies 80% of both hemispheres (Toole, 1990), including most neural substrates implicated in facial processing at cortical and subcortical structures. Therefore, measurements of mean blood flow velocity (MFV) in the MCA main stem could potentially provide information about downstream changes at cortical and subcortical sites within the MCA territory. To achieve this goal, each distal arm of the MCA vascular system could be separated into "near" and "far" distal reflection sites for the cortical and ganglionic (subcortical) systems, respectively.

One method is to apply Fourier analysis to the periodic time series of MFV acquired during stimulations. Fourier analysis would yield peaks representing pulsatile energy from reflection sites at various harmonics, which are multiples of the fundamental frequency (McDonald, 1974;

Njemanze, Beck, Gomez, & Horenstein, 1991). It is known from pressure/flow oscillations in the peripheral circulation that the first five harmonics usually contain 90% of the entire pulsatile energy within the system (McDonald, 1974). This assumes that each arm of the vascular system represents a single viscoelastic tube terminated by impedance, creating a single reflection site (Campbell, Lee, Frasch, & Noordergraaf, 1989; McDonald, 1974, Njemanze et al., 1991). Vasomotor activity at each terminal site sets up a standing sinusoidal wave oscillation, comprising a summation of waves due to effects of incident, reflected, and re-reflected waves from distal to proximal point of measurement.

In the present work it was hypothesised that there are gender-related differences in facial processing due to reversed hemispheric asymmetry of neural substrates for processing faces but not non-faces. Furthermore, men employ a right hemisphere cognitive style, but women a left hemisphere cognitive style, during facial processing (Njemanze, 2004). The right hemisphere is expected to implement a holistic processing strategy, and the left an analytic processing strategy. More specifically, the present work analysed responses to object and facial tasks in the RMCA and LMCA, respectively. Fourier-derived spectral density estimates were used for subtractive analysis of light responsiveness compared to stimulus main effects, as well as to discern cortical from subcortical neuronal activity. It would be expected that cortical rather than subcortical peaks would be associated with facial perception. The aim is to determine models of cognitive styles for men and women, respectively.

METHOD

Participants

The population consisted of 16 right-handed participants (mean ± *SD* age = 24.8 ± 2.7 years): eight men were age matched to eight women. The preferred hand was determined using a questionnaire (Peters, 1998). Participants were matched by anthropometric variables, body mass index, and waist–hip ratio. All participants had normal blood pressure and normal visual acuity. None reported any history of neurologic, cardiovascular, or respiratory diseases. Participants were not under any medication, including contraceptive pills for women. All were non-smokers, and there was no report of alcohol abuse in participants and their immediate families. None ingested caffeine at least 24 hours prior to the study. All had 16 to 18 years of schooling. All participants signed informed consent according to the Declaration of Helsinki, and the Institutional Review Board approved the study protocol.

Scanning procedure

All *f*TCD procedures were performed using examination techniques previously described for cognitive studies (Knecht et al., 2000; Njemanze, 1991, 1996, 2004, 2005; Njemanze, Gomez, & Horenstein, 1992; Stroobant & Vingerhoets, 2000). The *f*TCD scanning was performed using bilateral simultaneous *f*TCD instrument (Multi-Dop T, DWL, Sipplingen, Germany). All participants were briefed on the protocol for the entire experiment, and all questions and practice sessions on what was required for the facial paradigm were explained prior to the start of the experimental data acquisition.

*f*TCD studies were performed as follows: first, the participant was placed in a supine posture with their head up at 30 degrees. The probe holder headgear—LAM-RAK (DWL, Sipplingen, Germany)—was used with a base support on two earplugs and on the nasal ridge. Two 2-MHz probes were affixed in the probe holder and insonation was performed to determine the optimal position for continuous monitoring of both MCA main stems at 50 mm depth from the surface of the probe. All gain and power settings were kept constant for both MCAs in all participants. Comfort of the participant within the headgear was assured prior to start of recording. Participants were instructed to remain mute and not to move throughout the data acquisition time duration, and were informed that they would be debriefed of all mental activities after the experimental data acquisition session. All participants were requested to refrain from internal or external verbalisation and informed of the deleterious effects it might have on the data acquired. Environmental luminance was kept constant for all participants. Sound shielding of the experimental room was provided, and the participant wore earplugs that reduced environmental noise levels. However, no participant was completely sensory deprived. Electrocardiographic monitoring of pulse and respiratory rates was recorded. Self-perceived anxiety levels were monitored with a state-trait anxiety inventory (STAI) in pre-test and post-test conditions. The STAI has been tested and validated (Bowling, 2001; Spielberger, Ritterband, Sydeman, Reheiser, & Unger, 1995).

Post-experimental debriefing focused on what participants were “thinking” during task performance. Participants were encouraged to provide full disclosure of their thoughts during the experimental data acquisition. No threat of penalty was made for non-compliance. Pre-experimental test runs in a different but selected group of participants provided insights into how participants handled the stimulus used in the present study (Njemanze, 2004). The latter was taken into account in the task design. Baseline vital signs were recorded in full consciousness under normal resting conditions.

Dark recordings

A continuous train of velocity waveform envelopes was recorded at rest with the participant mute, still, and attention-focused, in a dark visual field within a dark enclosed space with no mental or manual tasks to perform. This had a similar effect to eye closure, but did not require eye muscle contractions that could elicit motion artefacts. Dark recording was obtained prior to stimuli administration for 60 seconds, and was used as reference for light stimulation conditions.

Stimulation recordings

Paradigm 1: Checkerboard square (object perception). The black and white chequered square paradigm (Figure 1a) comprised a square of alternating black and white square dots. This was a nonverbal passive viewing task of an object foveally presented from a slide projector onto a screen placed in front of the participant, which was inclined at 30 degrees from the horizontal plane at a distance of 80 cm from the nasal ridge. A continuous train of velocity waveform envelopes was recorded with the participant mute, still, with fixed gaze, and attention focused on the object. There were no mental or manual tasks to perform while viewing the object. MFV measurements were made for 60 seconds.

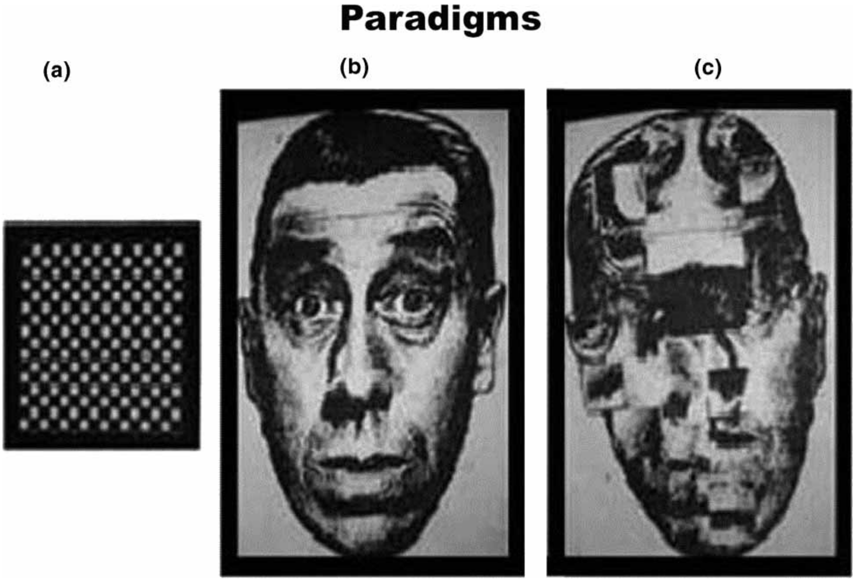

Figure 1. The stimuli used as (a) paradigm 1, (b) paradigm 2, and (c) paradigm 3.

Paradigm 2: Face encoding task (whole neutral face). A novel whole male face expressing a neutral emotion (Figure 1b) was presented. The participant was instructed to commit the face to memory and told that their memory would be tested later. The MFV was recorded for 60 seconds while the participant viewed the face.

Paradigm 3: Facial elements sorting task. This facial task comprised sorting elements of a disarranged face (Figure 1c). Participants were asked to sort the elements of the face and arrange them into a whole face, one element at a time, for 60 seconds. The task required a sophisticated perceptual mechanism capable of extraction of components of a face; analysis of their width and height, distances between these elements, angles, contours, illumination, expression, hairline, hair style and so on; and constantly spatially fitting the puzzle by matching each element with that stored in memory and then proceeding to form the picture of the whole face. In other words, far more iterations were required to accomplish the recognition task. Moreover, it has been suggested that facial processing comprises several stages (Kim et al., 1999; Sinha & Poggio, 1996). However, on presentation of a face, all stages of processing occur almost simultaneously (Allison et al., 1994a). Therefore this task was designed to break down the processes into several iterative steps, and to exclude verbalisable features that may cause extraneous compounding effects (Njemanze, 2004). The MFV was recorded for 60 seconds during the performance of the task.

The task design excluded performance ratings by any observer and any competitive indices to minimise any role of anxiety. Positively and negatively valenced pictures, culturally familiar faces, as well as female faces, were also not used in the present study. Pretest runs suggested that the latter factors could cause emotional activation both subliminally and supraliminally, with compounding effects on autonomic responses (Jonsson & Sonnby-Borgstrom, 2003). Other design rationales for this pedigree of paradigms have been described in detail elsewhere (Njemanze, 2004). Participants were later debriefed on the sequence of task execution and the climax attained. Other post-test debriefings focused on “what participants were thinking” at each stage of the task, difficulties, distractions, and any confounding experiences or thoughts. They described in detail the sequence and strategy used for each task execution, and how they resolved internal conflicts that arose during task performance. Their self-rating of performance on a 4-point scale (from poor to best performance) was also assessed relative to self-attained target performance for the same task during pretest runs. Motion artefacts such as eye movements and voluntary and involuntary movements were monitored by an observer who documented time of occurrence on the MFV train for later analysis.

Calculations

Prior to data analysis, marked artefacts during recording were removed. Data averaging comprised 10-second segments of the train of velocity waveform envelopes for the dark task and each of the paradigms (1–3), respectively. For baseline and each stimulus, 60 seconds of recording resulted in six MFV values for dark and each task, respectively. These values were used for further calculations. Cerebral lateralisation was assessed using laterality index (LI) expressed as:

$$\mathrm{LI} = \left(\frac{\mathrm{RMCA\ MFV_{10s}} - \mathrm{LMCA\ MFV_{10s}}}{\mathrm{RMCA\ MFV_{10s}} + \mathrm{LMCA\ MFV_{10s}}}\right) \times 100$$

The actual magnitude of lateralisation (LI) for each 10-second segment for each paradigm was calculated as the difference between LI values measured during the 10-second segment of the task and the corresponding 10-second segment of dark (onset of dark corresponds with onset of visual paradigm within the 60 seconds segment):

$$\mathrm{LI} = \mathrm{LI\ paradigm\ 10\ s} - \mathrm{LI\ dark\ 10\ s.}$$

In general, positive LI values suggest right lateralisation, while negative LI values suggest left lateralisation from the dark condition. Zero LI values showed no lateralisation from the dark condition or possible bilateral response.

Fourier analysis

Fourier transform algorithm was applied using standard software (Time series and forecasting module, Statistica for Macintosh, StatSoft, OK, USA). The standard and most efficient Fourier algorithm requires that the length of the input series is equal to a power of 2. If this is not the case, additional computations have to be performed. To obtain the required time series, the data were averaged in 10-second segments for 1-minute duration for each stimulus; yielding 6 data points for each participant and a total of 48 data points for all eight men and women, respectively. Smoothing the periodogram values was accomplished using a weighted moving average transformation. Hamming window was applied as a smoother (Bloomfield, 1976; Brigham, 1974). The spectral density estimates, derived from single series Fourier analysis, were plotted, and the frequency regions with the highest estimates were marked as peaks.

Other statistics

All analyses were performed using the software package Statistica for Macintosh (StatSoft, OK, USA). Results were given as mean ± *SD* and plots represented as mean/SE/1.96*SE where applicable. Analysis of LI was recomputed after excluding outliers. Analysis of variance (ANOVA) was applied to spectral density estimates between two minima including the peak (as maxima) to examine the effects of paradigms on cortical and subcortical responses. The latter was followed by planned contrasts to examine luminance effect (dark versus Paradigm 1), discrimination of face from non-face or category-specific face effect (Paradigm 1 versus Paradigm 2), and face-processing strategy effect (Paradigm 2 versus Paradigm 3). The level of significance was at $p < .05$.

RESULTS

To examine the effects of the different paradigms on MFV, an ANOVA with repeated measures was performed with $2 \times 4 \times 2$ design: two levels of GENDER (men and women), four levels of STIMULATION (dark and Paradigms 1–3), and two levels of ARTERY (RMCA and LMCA). The MFV was analysed as the dependent variable. There was a main effect of GENDER, $F(1, 94) = 42$, $MSE = 37919.6$, $p < .0001$. There was a main effect of STIMULATION, $F(3, 282) = 11.4$, $MSE = 277.9$, $p < .0001$. There was a main effect of ARTERY $F(1, 94) = 7.7$, $MSE = 801.4$, $p < .01$. There was a STIMULATION × ARTERY interaction, $F(3, 282) = 5.3$, $MSE = 11.7$, $p < .01$. There was a GENDER × STIMULATION × ARTERY interaction, $F(3, 282) = 6.6$, $MSE = 14.7$, $p < .001$. Planned contrasts for GENDER main effect revealed that women (77.4 cm/s) had higher MFV than men (63.4 cm/s), $p < .0001$. Planned contrasts for STIMULATION main effect revealed that the luminance effect involved diminution of MFV from levels at dark (71.3 cm/s) compared to that during Paradigm 1 (68.8 cm/s), $p < .0001$. Conversely, the category-specific face effect was marked by increase in MFV from levels during Paradigm 1 (68.8 cm/s) to that during Paradigm 2 (70.1 cm/s), $p < .05$. Similarly, the face-processing strategy effect accentuated MFV from levels during Paradigm 2 (70.1 cm/s) to that during Paradigm 3 (71.3 cm/s), $p < .05$. Planned contrasts for ARTERY main effect revealed that MFV in the RMCA (71.4 cm/s) was higher than in the LMCA (69.4 cm/s), $p < .01$. Figure 2A–B show the box and whiskers plot of mean/SE/1.96*SE of MFV (in cm/s), for both RMCA and LMCA for men (Figure 2A) and women (Figure 2B), during all measurement conditions (dark, Paradigms 1–3), respectively.

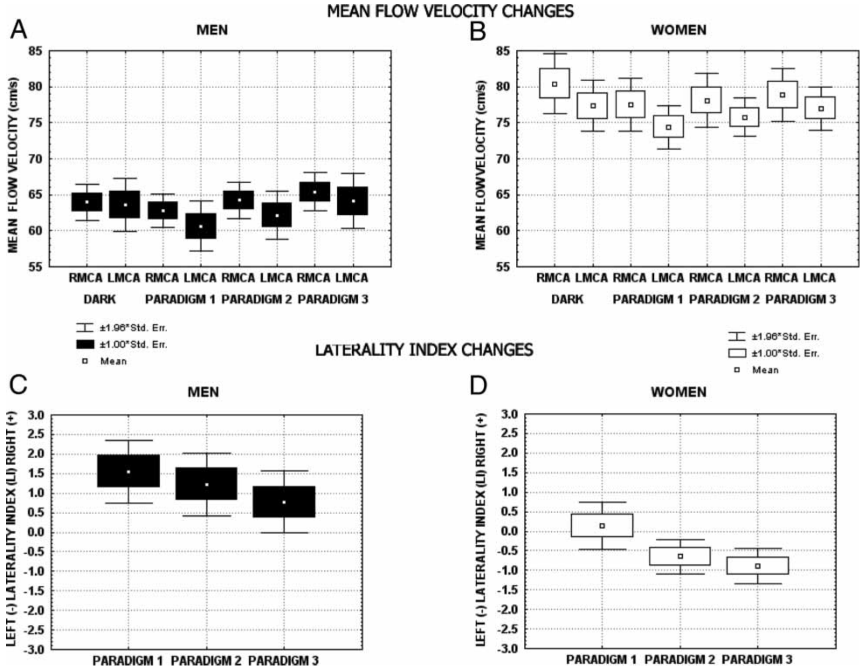

Figure 2. The box and whiskers plots of mean flow velocity in (A) men and (B) women, respectively; and laterality index in (C) men and (D) women during each study condition, respectively.

LI calculations were used to examine the effects of the different paradigms on cerebral lateralisation relative to dark. The LI was analysed as the dependent variable. An ANOVA with repeated measures was performed with 2 × 3 design: two levels of GENDER (men and women), three levels of STIMULATION (Paradigms 1–3). There was a main effect of GENDER, $F(1, 94) = 17.5$, $MSE = 196.4$, $p < .0001$. There was a main effect of STIMULATION, $F(2, 188) = 7$, $MSE = 19.9$, $p < .01$. There was no GENDER × STIMULATION interaction, *ns*. Figure 2 C–D show the box and whiskers plot of mean/SE/1.96*SE of LI for men (Figure 2C) and women (Figure 2D) during stimulation conditions (Paradigms 1–3), respectively. Overall, men were right lateralised for facial Paradigms 2 and 3 as well as non-face object Paradigm 1. On the other hand, women were left lateralised for both facial Paradigms 2 and 3, but right lateralised for object Paradigm 1. However, on exclusion of outliers, women showed no lateralisation with zero LI value or bilateral activation.

Figure 3 A–D show the spectral density plots for each artery during all study conditions in men (Figure 3 A–B) and women (Figure 3 C–D),

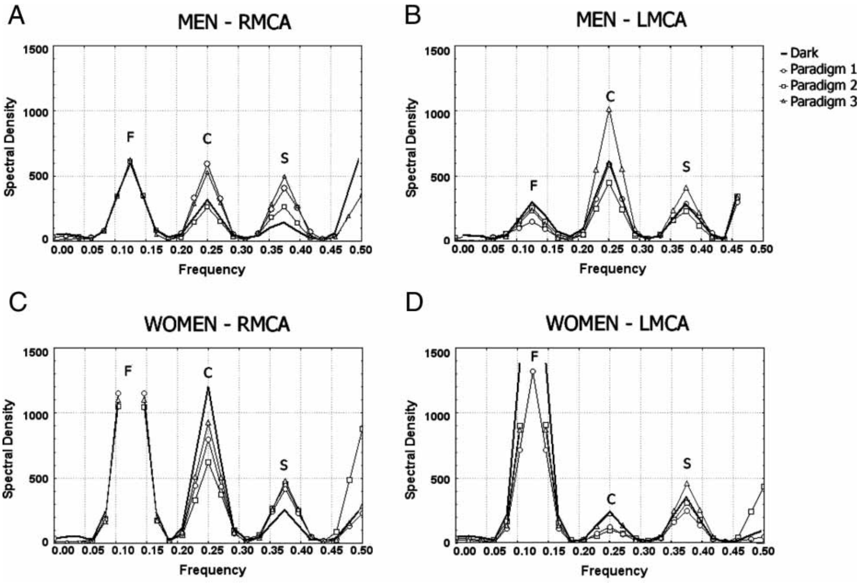

Figure 3. Overlaid plots of spectral density estimates in the RMCA in (A) men, and (C) women, respectively; and in the LMCA in (B) men and (D) women, respectively.

respectively. In general, for all stimulations in both men and women there were three peaks designated as F-, C-, and S-peaks, representing the fundamental, cortical, and subcortical peaks, which occurred at regular frequency intervals of 0.125, 0.25, and 0.375, respectively. The spectral density peaks were analysed for each gender separately to examine the effect of dark and stimulations at C- and S-peaks for the RMCA and LMCA, respectively. A one-way ANOVA with repeated measures for all four levels of STIMULATION (dark, Paradigms 1–3) was used. This was followed by planned contrasts. In men, in the RMCA at C-peaks, there was a main effect of STIMULATION, $F(3, 18) = 4.2$, $MSE = 16804.3$, $p < .05$. Planned contrast revealed a category-specific face effect, $p < .05$, (Figure 3A). However, at the S-peaks there was only a marginal tendency for luminance effect. In men, in the LMCA at C-peaks, there was a main effect of STIMULATION, $F(3, 18) = 4.4$, $MSE = 39947$, $p < .05$. Planned contrast revealed a facial processing strategy effect, $p < .05$, (Figure 3B). However, at S-peaks there was no main effect of STIMULATION. In women, in the RMCA at C-peaks, there was a main effect of STIMULATION, $F(3, 18) = 4.2$, $MSE = 38441.9$, $p < .05$. Planned contrast revealed a luminance effect, $p < .05$ (Figure 3C). Similarly, at the S-peaks there was a marginal tendency for luminance effect. In women, in the LMCA at

C-peaks, there was a main effect of STIMULATION, $F(3, 18) = 3.2$, $MSE = 2791.4$, $p < .05$. Planned contrast revealed a facial processing strategy effect, $p < .05$ (Figure 3D). However, at S-peaks there was no main effect of STIMULATION.

The confounding effects of cardiovascular measures were assessed using one-way analysis of variance (ANOVA). In men the heart rate during Paradigm 1 (71.9 ± 10.6 bpm), Paradigm 2 (69.6 ± 11 bpm), and Paradigm 3 (70.5 ± 5 bpm) did not differ from resting baseline (67.5 ± 9 bpm), ($p > .05$). Similarly, in women the heart rate during Paradigm 1 (76.9 ± 9.8 bpm), Paradigm 2 (78.9 ± 12 bpm), and Paradigm 3 (79.3 ± 13.8 bpm) did not differ from resting baseline (76.9 ± 9.6 bpm), ($p > .05$). In men the respiratory rate during Paradigm 1 (17.3 ± 3.5 per minute), Paradigm 2 (19.9 ± 5.7 per minute), and Paradigm 3 (16.9 ± 3.7 per minute) did not differ from resting baseline (17.9 ± 2.5 per minute), ($p > .05$). Similarly, in women the respiratory rate during Paradigm 1 (19 ± 4.5 per minute), Paradigm 2 (21 ± 5 per minute), and Paradigm 3 (21 ± 6 per minute) did not differ from resting baseline (19.3 ± 6.4 per minute), ($p > .05$). The overall mean heart rate was 74 bpm and respiratory rate was 19 per minute. There was no significant difference between pre-test and post-test blood pressure, ($p > .05$). Similarly, there were no significant differences between the stimuli for heart rate, respiratory rate, and anxiety scores ($p > .05$). In other words, there were no changes in cardiovascular parameters and anxiety scores during the study.

In post-test debriefings, participants described their initial condition as “blank”, unaware of subtle emotional state, as they tried to focus attention on the imagery spot within the dark visual field. Women described the paradigms in greater detail than men. For example, on first prompt for description, most men described Paradigm 1 simply as a draught board or chess board, while most women described it as alternating black and white squares within a cube. For execution of Paradigm 3, both men and women reported sorting one part of the face at a time into place before proceeding to the next part—in other words, all followed a step-by-step approach. All rated themselves as not being anxious, and assessed themselves as having good performance, with no difficulty with task execution.

DISCUSSION

Overall, there was a gender-related difference in facial processing. Facial perception occurred in the cortical region of the right hemisphere in men, but in the left in women. The results are similar to previous observations using transcranial Doppler (Njemanze, 2004), and agree with those made using electrophysiological techniques (Everhart et al., 2001). Similar gender-related hemisphere differences have been observed at the amygdala for emotionally related stimuli (Cahill, Uncapher, Kilpatrick, Alkire, & Turner, 2004), and for performance-related processing (Njemanze, 2005; Tranel et al., 2005; Jung et al., 2005). Men showed a right lateralisation during object processing, but women showed a right tendency or bilateral activation. The observed category-specific face effect was consistent with the concept of category-specific model, which posits a neural module for face category as distinct from non-face (Allison et al., 1994b; Clark, Keil, Maisog, Courtney, Ungerleider, & Haxby, 1996; Haxby, Ungerleider, Clarke, Schouten, Hoffman, & Martin, 1999; Puce et al., 1996). However, others have advocated the existence of alternative models (Gauthier, 2000; Ishai et al., 1999).

One presumption would be that, if neuronal assemblies processing light information share analogous topological organisation as their blood flow supply, then dark would elicit the least effect, followed by Paradigm 1, Paradigm 2, and Paradigm 3. This type of summation of responses related to stimulus complexity could be presumed as evidence for topological organisation of these cortical areas in men. It may suggest that the latter extends from the area implicated in object perception to a much greater area involved in facial perception. This agrees with the object form topology hypothesis proposed by Ishai and colleagues (Ishai et al., 1999). However, the relatedness of object and facial perception was process based, and appears to be associated with their common holistic processing strategy in the right hemisphere. Moreover, when the same men were presented with facial Paradigm 3 requiring analytic processing, the left hemisphere was activated. This agrees in principle with the suggestion made by Gauthier that the extrastriate cortex contains areas that are best suited for different computations, and described as the process-map model (Gauthier, 2000). Therefore, the proposed models are not mutually exclusive, and this underscores the fact that facial processing does not impose any new constraints on the brain other than those used for other stimuli. It may be suggested that each stimulus was mapped by category into face or non-face, and by process into holistic or analytic. Therefore, a unified category-specific process-mapping system was implemented for either right or left cognitive styles.

Another profound difference between men and women was their responsiveness to the dark condition. Studies in the dark condition were included to measure the effects of non-spectral stimuli, since it is known that some of these can actually result in the production of colour experience (Bartley, 1959). The tendency towards right lateralisation in women but no lateralisation in men in dark condition was difficult to interpret, and similar observations have been made in previous studies (Njemanze et al., 1992). It has been suggested that scotopic visual information was processed in the right hemisphere (Njemanze et al., 1992). However, in women data from spectral density estimates showed accentuation for dark responsiveness at C-peaks over those of light conditions. The latter may suggest that greater neuronal assemblies were implicated in processing scotopic vision in women compared to men. Furthermore, in women the neuronal assemblies may not have the same orderly topological arrangement as in men; rather the neurons involved in processing cone and rod vision were segregated within the right hemisphere cortical region. Hence, in women the right hemisphere responded to luminance effect and object perception, but showed no category-specific face effect. The latter arrangement explains the observed right lateralisation for non-face Paradigm 1, but left lateralisation for facial Paradigms 2 and 3. In other words, similar to men, women employed the holistic mechanism for processing object stimulus in the right hemisphere, but preferred the analytic mechanism for facial perception in the left. Therefore, one major observed gender-related difference was that, while men employed a category-specific process-mapping system for facial perception in the right hemisphere, women used same in the left hemisphere.

Another gender-related difference is the higher MFV in women than men, similar to the observations made by others (Marinoni, Ginanneschi, Inzitari, Mugnai, & Amaducci, 1998). However, side differences appear to be related to cognitive changes rather than anatomic differences (Muller, Brunholz, Radu, & Buser, 1991). To cancel the effects of these initial variations in MFV, laterality index calculations were used. However, if women differed from men in dark responsiveness, then LI calculations relative to dark would be expected to produce differences due to initial variations. In contrast, Fourier-derived spectral density estimates assessed the periodicity during each stimulus condition independently, and lacked the properties of the original MFV signals. In other words, absolute differences in MFV values would not affect the periodicity of the time series, hence the Fourier transform would be equally sensitive for both men and women.

The origins of the peaks are of interest in order to determine the reliability of the present technique. The F-, C-, and S-peaks occurred at regular frequency intervals of 0.125, 0.25, and 0.375, respectively. These frequencies could be converted to cycles per second (Hz), assuming that the fundamental frequency of cardiac oscillation was the mean heart rate. The fundamental frequency f of the first harmonic was determined by the mean heart rate per second of 74 bpm/60 seconds = 1.23 Hz. In other words, the F-, C-, and S-peaks occurred at multiples of the first harmonic, at second and third harmonics, respectively. Thus, the distance of the reflection site for F-peak could be presumed to emanate from a site at $D_1 = \frac{1}{4}\lambda$ or $c/4f$, or 6.15 $(\text{ms}^{-1})/(4*1.23\ \text{Hz}) = 125$ cm; where c is the assumed wave propagation velocity of the peripheral arterial tree (McDonald, 1974). Taking into account vascular tortuosity, the estimated distance approximates that from the measurement site in the MCA main stem, to an imaginary site of summed reflections from the aorto-iliac junction (McDonald, 1974) and the upper extremities, close to the finger tips when stretched sideways (Njemanze, unpublished). The C-peak occurred at the second harmonic, such that the estimated arterial length (using common carotid $c = 5.5\ \mathrm{ms}^{-1}$) (Meinders, Kornet, Brands & Hoeks, 2001) was given by $D_2 = 1/8\lambda$ or $c/8 \times 2f$, or 28 cm; and a frequency f_2 of 2.46 Hz. This length approximates the visible arterial length from the main stem of the MCA, through vascular tortuosity and around the cerebral convexity, to the end vessels at distal cortical sites such as the occipito-temporal junction on carotid angiograms of adults (Njemanze, unpublished). The S-peak occurred at the third harmonic, and may have arisen from an estimated site at $D_3 = 1/16\lambda$ or $c/16 \times 3f$, or 9.3 cm; and a frequency f_3 of 3.69 Hz. The latter approximates the visible arterial length of the lenticulostriate vessels from the main stem of the MCA on carotid angiograms (Kang, Han, Kwon, Kwon, Kim, & Chang, 2005). Although not displayed, the fourth harmonic would be expected to arise from the MCA bifurcation in closest proximity to the measurement site in the main stem of the MCA. The pre-bifurcation length from the measurement point would be given by $D_4 = 1/32\lambda$ or $c/32 \times 4f$, or 3.5 cm; and a frequency f_4 of 4.92 Hz. The calculated length approximates that of the segment of MCA main stem just after the carotid bifurcation, where probably the ultrasound sample volume was placed, to the MCA bifurcation or trifurcation, as the case may be. Thus it is plausible that these estimates approximate actual lengths. However, it has been suggested that the estimated distances may not correlate exactly with known morphometric dimensions of the arterial tree (Campbell et al., 1989).

The method described in the present study for the first time in medical literature, was referred to as functional transcranial Doppler spectroscopy (*f*TCDS). *f*TCDS examines spectral density estimates of periodic processes induced during mental tasks, and hence offers a much more comprehensive picture of changes related to effects of a given mental stimulus. The spectral density estimates would be least affected by artefacts that lack periodicity, and filtering would reduce the effect of noise. Interestingly, cardiovascular parameters were not altered in the present study. This may be related to differences in the facial stimuli used, compared to the emotionally valenced pictures under different levels of consciousness used in other studies (Critchley, Rotshtein, Nagai, O'Doherty, Mathias, & Dolan, 2005; Jonsson & Sonnby-Borgstrom, 2003). Regardless of these advantages of *f*TCDS, there are potential problems with the present study. The small sample size may create greater influence of outliers. However, statistical analysis did not reveal any extreme outliers in the present data set and exclusion of outliers did not alter the lateralisation patterns. The choice of eight men and eight women with a total of 48 points in each data set was ideal for Fourier analysis. In conclusion, it could be said that men and women use different hemispheres with complimentary mechanisms to perceive the essence of facial expressions that we come across in our daily life.

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