SHORT COMMUNICATION

Asymmetry in Cerebral Blood Flow Velocity with Processing of Facial Images During Head-Down Rest

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NJEMANZE PC. *Asymmetry in cerebral blood flow velocity with processing of facial images during head-down rest.* **Aviat Space Environ Med 2004; 75:800–5.**

Introduction: Ability to interpret facial expression is crucial for nonverbal communication among humans, and could be affected by changes in cerebral circulation during exposure to microgravity or its simulation. ***Methods***: There were 16 subjects (8 men and 8 women) who were exposed to 24 h of −6° head-down rest (HDR). Transcranial Doppler ultrasonography was used to monitor mean blood flow velocity (MBFV) in the middle cerebral arteries bilaterally during processing of facial images before, at 6 and 24 h of HDR, and after HDR (Pre-, 6H-, 24H-, and Post-HDR, respectively). The laterality index was assessed as side-to-side differences in MBFV relative to Pre-HDR for each condition. ***Results***: For Pre-HDR, both objects and faces were right lateralized in men ($p < 0.001$) and showed a left lateralization tendency in women ($p > 0.05$). At 6H-HDR, both object and faces were left lateralized in men ($p < 0.05$), but right lateralized in women ($p < 0.001$). At 24H-HDR, both men and women were left lateralized ($p < 0.05$). For Post-HDR, both remained left lateralized for all tasks ($p < 0.05$). ***Discussion***: HDR alters cerebral lateralization for object and facial stimuli, with opposing tendencies in men and women. The gender differences may reflect peculiarities in processing strategy for object and faces between men and women. Men use a right hemisphere processing strategy for faces and women a left hemisphere strategy. The superiority of processing of faces by women compared with men has been attributed to left hemisphere based strategy. HDR alters lateralization patterns and may thus alter processing strategies for faces.

Keywords: cognition, cerebral dominance, space, ultrasound, mental performance, memory, perception.

FACIAL EXPRESSION is crucial for subtle communication among humans, particularly as a means of understanding what others are thinking. “Theory of Mind” teaches that humans observe behavior, including facial expressions and words spoken by others, and then build a model of the abstraction called a “person” (11). Furthermore, the mental machinery for doing this turns inward to build a model of the abstraction called a “Self” (13).

For crews in isolated environments, the universal expressional content of faces could become even more relevant than language for forming interpersonal relationships, reducing tension, forming cohesion, and providing leadership support. This is especially true when isolated crews are composed of people from different countries, ethnic backgrounds, languages, or cultures. Moreover, the need for tracking performance decrements during spaceflights has been emphasized (6).

Studies of the hemispheric lateralization of the cerebral processing of facial images are important to understanding human psychophysiology. This lateralization could be altered in space by changes in cognitive function associated with cerebral circulatory changes in microgravity.

Like language, facial processing is one of the higher cortical functions to undergo hemispheric specialization in ontophylogenetic development. The precise nature of hemispheric functional asymmetry for faces is not completely understood. Previous studies in recumbent subjects have used imaging and electrophysiological data to document right lateralization during facial recognition (1,5). The implicated brain regions are supplied by the middle cerebral arteries (MCAs), and increase in mean blood flow velocity (MBFV) in the right MCA (R-MCA), but not on the left (L-MCA), has been documented during facial recognition tasks (2).

Recent experiments suggest a left shift in lateralization of MBFV during head down rest (HDR) (8). The latter has been linked to observations that humans are slower in perceptual-motor performance in space, although central cognitive operations are unaffected (4). It was, therefore, postulated that processing of objects and faces, which has been associated with right hemisphere bias (1,5), may be altered in microgravity. The purpose of this study was to examine cerebral lateralization for object and facial tasks using bilateral measurements of MBFV before, during, and after a 24-h period of HDR.

METHODS

The study involved 16 subjects, 8 men and 8 women, all 100% right-handed as determined using the Edin-

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This manuscript was received for review in October 2003. It was accepted for publication in July 2004.

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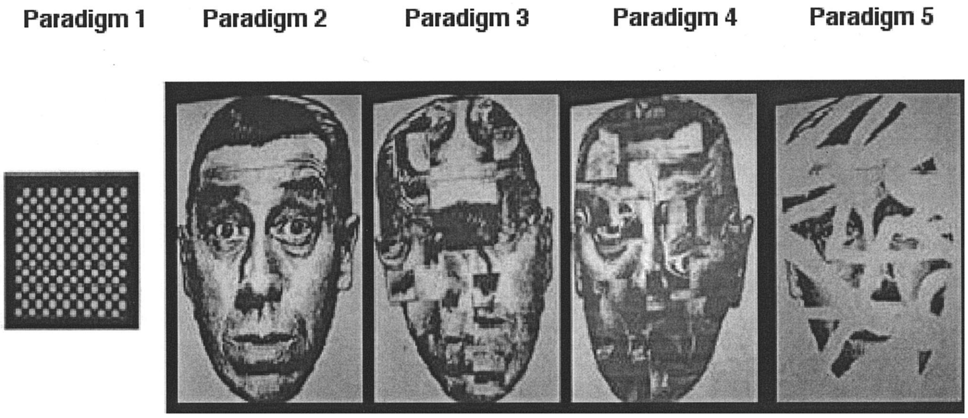

Fig. 1. Paradigms for object and facial recognition.

burgh handedness inventory (10). Men and women were matched for age at 24.8 ± 2.7 yr. Their characteristics were as follows (mean ± SD for men and women): body mass index 23 ± 2 $kg \cdot m^{-2}$ and 23 ± 5 $kg \cdot m^{-2}$; waist-hip ratio 0.85 ± 0.03 and 0.80 ± 0.05; systolic BP 110 ± 6 mmHg and 107 ± 5 mmHg; diastolic BP 70 ± 6 mmHg and 70 ± 9 mmHg. All subjects had normal visual acuity, and color vision. None reported any history of neurologic, cardiovascular, or respiratory diseases. Subjects were not taking any medication or recreational drugs, including contraceptive pills for women. All were non-smokers and there was no report of alcohol abuse in subjects and their immediate families. None ingested caffeine for at least 24 h prior to the study. All have had 16–18 yr of schooling. The study was approved by the Institutional Review Board and all subjects signed informed consent according to the Declaration of Helsinki.

The MBFV for Pre-HDR was recorded with the subject lying supine with head and trunk elevated at 30°. The subject was then placed on a bed set with a head-down angle of −6°. He or she rested on the bed for the duration of the 24 h of HDR. Subjects consumed regular light meals as prescribed by a dietician. A bedpan was used for toileting. On completion of 24 h bed rest, subjects were returned to conditions similar to Pre-HDR with head and trunk elevated at 30°, and Post-HDR recording began after 10 min of rest.

Scanning Procedure

The MBFV was measured using transcranial Doppler (TCD) ultrasonography as previously described (7,8) using two 2-MHz probes of a bilateral simultaneous TCD instrument (Multi-Dop T, DWL, Singen, Germany), with sample volume placed in each MCA main stem at 50 mm depth from the surface of the probe. All gain and power settings were kept constant for all subjects. Subjects were briefed on the protocol and instructed to remain mute and not to move throughout data acquisition. All subjects were requested to refrain from internal or external verbalization and were informed that such activity would have deleterious effects on the data. All environmental noise including sound from the TCD instrument was excluded, and environmental illumination was kept constant. Subjects were monitored for pulse rate and respiratory rate as well as self-perceived anxiety levels.

Task Paradigms

The facial tasks were designed by the author and associates, and have been used in our laboratory, showing consistency and reliability in cognitive studies with TCD ultrasonography. Memory for faces is composed of several stages, including the formation of a precept originating from the face, matching the precept to pre-existing stored information, and a contextual non-verbal and/or verbal evocation (5). However, on presentation of faces, all stages of recognition occur almost simultaneously (5). The tasks were designed to break facial processing into several iterative steps without verbalizable features; correct performance of the tasks was confirmed during debriefing of subjects. Facial recognition occurred when the subject reported matching newly presented images to previously stored information (5). Facial working memory implied that the perceived spatial arrangements of facial elements were used in a step-by-step comparison with previously stored information. The facial-working-memory task differed from facial recognition, because the latter did not require perceiving the spatial arrangement of facial elements (12).

For each condition, a continuous train of velocity waveform envelopes was recorded for 60 s from the R-MCA and L-MCA, respectively. The Pre-HDR baseline condition was dark, with the subject mute, still, and attention focused on the dark visual field with no mental or manual tasks to perform. The same conditions were maintained at onset of data acquisition (onset run MBFV in dark condition) in HDR and post-HDR positions. Similar conditions were also maintained for data acquisition during visual presentation of the five paradigms.

Paradigm 1. checkerboard square: The black and white checkered square paradigm (**Fig. 1**, Paradigm 1) comprised a square of alternating black and white square dots. This was a nonverbal passive viewing task of a foveally presented object, from a slide projector onto a screen placed in front of the subject and inclined at 30° 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 subject mute, still, with fixed gaze, and attention focused on the object. There were no mental or manual tasks to perform while viewing the object.

Paradigm 2. Face encoding task (whole neutral face): This was a face encoding task. A novel whole neutral face (Fig. 1, Paradigm 2) was presented. The face was 'novel' or unfamiliar, 'whole' or intact, and 'neutral' or expressionless, so as to exclude any extraneous processing. The subject was instructed to commit the face to memory and told that their memory will be tested later.

Paradigm 3. Facial working memory task: This facial task comprised sorting elements of a disarranged face (Fig. 1, Paradigm 3). Subjects were asked to sort the elements of the face and arrange them into a whole face as seen before, one element at a time. 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. This facial paradigm was in effect a facial working memory task, and appears to require more activities in the visual associative cortex than just facial recognition.

Paradigm 4. Facial recognition task: This facial recognition task comprised disarranged facial elements with a part of the face left in place as a clue (Fig. 1, Paradigm 4). Subjects were asked to recognize the face. The clue was intended to introduce some measure of "automaticity" in the recognition process. In other words, the clue reduced the number of iterations required to accomplish the task.

Paradigm 5. Facial recognition task: This facial recognition task comprised a degraded face with missing elements but the contour and some elements were preserved in place (Fig. 1, Paradigm 5). The subject was required to recognize the face.

Calculations

During analysis, recording artifacts were marked and removed. Velocity waveform envelopes for the relevant 60-s intervals were first averaged in 10-s segments to produce six values for dark condition and each of the five paradigms, respectively, and were used for computations of laterality index (LI'). Further averaging into a single value was used for MBFV step plots.

Cerebral lateralization was assessed using LI' expressed as:

$$LI' = \frac{(\text{R-MCA MBFV10-s} - \text{L-MCA MBFV10-s}) \times 100.}{(\text{R-MCA MBFV10-s} + \text{L-MCA MBFV10-s})}$$

The actual magnitude of lateralization (LI) for each 10-s segment for each paradigm was calculated as the difference between LI' values measured during the 10-s segment of the task and the corresponding 10-s segment of baseline dark condition (onset of resting baseline corresponds with onset of visual paradigm within the 60-s segment):

$$LI = LI'\ \text{paradigm10-s} - LI'\ \text{baseline10-s}$$

In general, positive LI' values suggest right lateralization, while negative LI' values suggest left lateralization. Zero LI' values showed no lateralization from baseline or possible bilateral response. The LI values were calculated for each 10-s segment of the MBFV envelope.

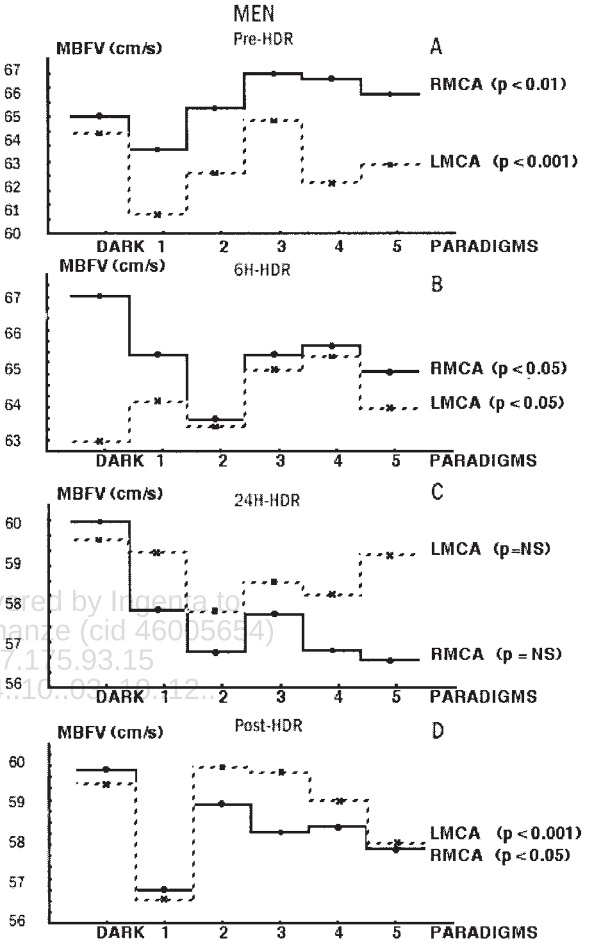

Fig. 2. A. Mean blood flow velocity (MBFV in cm · s^{-2}) step plots in both right (R-MCA) and left (L-MCA) middle cerebral arteries for men (n = 8). The p-values refer to differences in MBFV between paradigms.

Statistics

Results were given as mean ± SD and/or mean ± SE where applicable. A one-way analysis of covariance (ANCOVA) for repeated measures was performed. The covariates were MBFV at baseline dark condition for R-MCA and L-MCA, respectively. The effect of each stimulus was assessed independently, and in comparison with others. This was then followed by a planned contrast analysis comparing the LI for Paradigm 2 (whole neutral face) vs. Paradigm 3 (facial working memory). Task induced variations in MBFV were displayed in step plots of mean variations for R-MCA and L-MCA, respectively. All statistical calculations were performed using a statistical software package (Statistica, StatSoft, Tulsa, OK).

RESULTS

MBFV and LI for male subjects appear in **Fig. 2 and Fig. 3**, respectively. For Pre-HDR, baseline MBFV in dark condition did not differ between R-MCA and L-

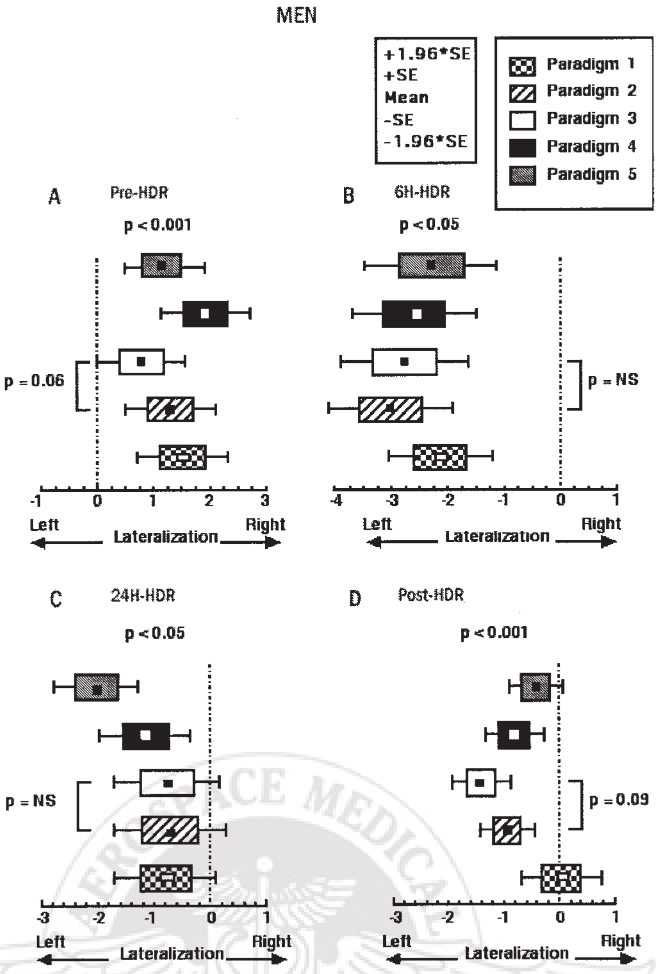

Fig. 3. Lateralization patterns showing laterality index (LI′) (x-axis) for each paradigm in men (n = 8). The p-values refer to differences in LI between paradigms.

MCA. Paradigms 1–5 induced significant variation in MBFV in the R-MCA ($p < 0.01$) and L-MCA ($p < 0.001$) (Fig. 2, panel A). This resulted in right lateralization for all tasks (Fig. 3, panel A). There was a marginal difference between Paradigm 2 and Paradigm 3 ($p = 0.06$), due to more pronounced activation in the L-MCA ($p < 0.01$) than R-MCA ($p = 0.053$) (Fig. 2, panel A) during Paradigm 3. Overall, tasks were right lateralized ($p < 0.001$), showing stimulus-specific effect in lateralization. At 6H-HDR (Fig. 2, panel B), during onset run dark condition, there was a significant difference in MBFV between R-MCA and L-MCA ($p < 0.01$). Paradigms 1–5 reduced MBFV on the right but increased it on the left (Fig. 2, panel B). As a result there was a left lateralization of MBFV for all tasks at 6H-HDR (Fig. 3, panel B). Paradigm 2 did not differ from Paradigm 3 in LI, however, for all tasks, there was at least categorical (object vs. faces) stimulus-specific effect in lateralization ($p < 0.05$). At 24H-HDR (Fig. 2, panel C), onset run MBFV in dark condition did not differ between R-MCA and L-MCA. However, Paradigms 1–5 induced diminution of MBFV more in the R-MCA than L-MCA for all tasks; as a result, there was a left lateralization for Paradigms 1–5, but a differential left lateralization mainly due to Paradigms 4 and 5 ($p < 0.05$) (Fig. 3, panel C). In other words, categorical stimulus-specific effect in lateralization was lost at 24H-HDR. At Post-HDR (Fig. 2, panel D), onset run MBFV in dark condition did not differ between R-MCA and L-MCA. However, there remained a task-specific MBFV activation in the L-MCA ($p < 0.001$), but attenuation in the R-MCA ($p < 0.05$). As a result there was a left lateralization with overall stimulus-specific effect ($p < 0.001$), with particular tendency for Paradigm 2 to differ from Paradigm 3 ($p = 0.09$) (Fig. 3, panel D) as in Pre-HDR.

MBFV and LI for female subjects appear in **Fig. 4** and **Fig. 5**, respectively. At Pre-HDR (Fig. 4, panel A), baseline MBFV in dark condition was higher in L-MCA than R-MCA, and Paradigms 1–5 induced significantly greater attenuation of MBFV in the R-MCA ($p < 0.05$) than in the L-MCA ($p < 0.001$). As a result, there was left lateralization for all tasks for Pre-HDR (Fig. 5, panel A). There was no difference between Paradigm 2 and Paradigm 3. In other words, in women, stimulus-specific effects did not yield lateralization of MBFV. At 6H-HDR (Fig. 4, panel B), onset run MBFV in dark condition was higher on the left than on the right, and Paradigms 1–5 induced greater diminution of MBFV on

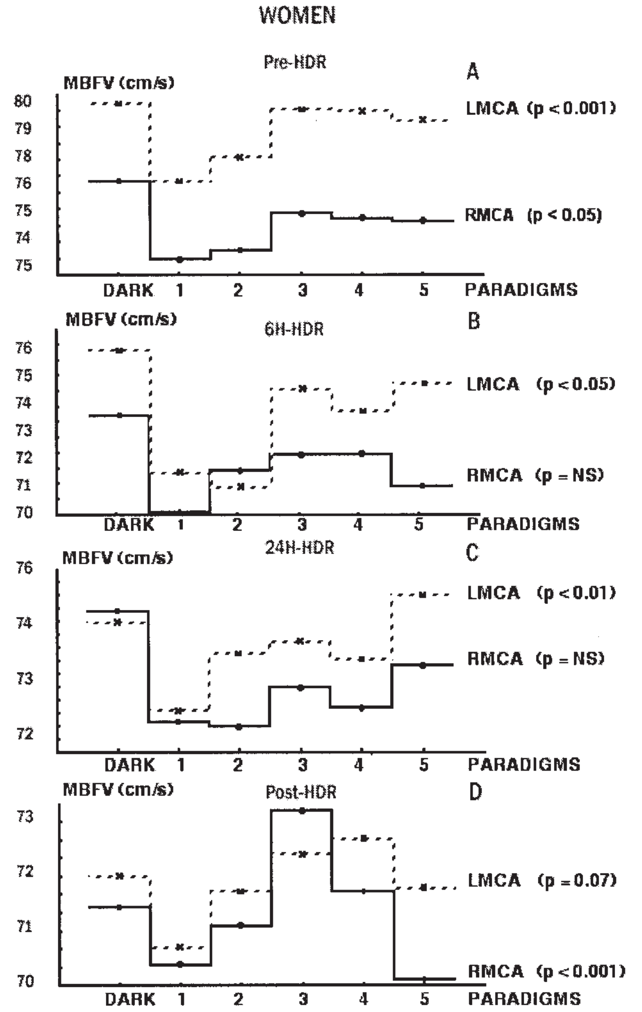

Fig. 4. Mean blood flow velocity (MBFV in $cm \cdot s^{-2}$) step plots in right (R-MCA) and left (L-MCA) middle cerebral arteries for women (n = 8). The p-values refer to differences in MBFV between paradigms.

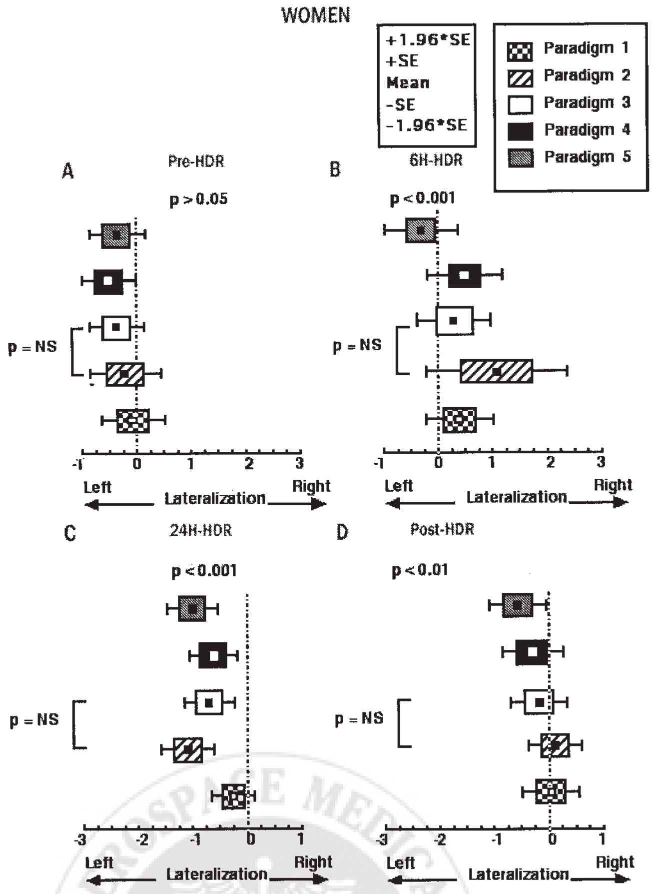

Fig. 5. Lateralization patterns showing laterality index (LI′) (x-axis) for each paradigm in women (n = 8). The p-values refer to differences in LI between paradigms.

the left than on the right. As a result, there was right lateralization for Paradigms 1–4, but not Paradigm 5, at 6H-HDR (Fig. 5, panel B). Paradigm 2 did not differ from Paradigm 3 in LI, however, for all tasks, there was stimulus-specific lateralization ($p < 0.001$). At 24H-HDR (Fig. 4, panel C), onset run MBFV in dark condition did not differ between sides. However, Paradigms 1–5 induced greater diminution of MBFV on the right than on the left for all tasks. As a result, there was left lateralization for all tasks ($p < 0.001$) (Fig. 5, panel C). However, Paradigm 2 did not differ from Paradigm 3. There was stimulus-specific effect of lateralization at 24H-HDR. At Post-HDR (Fig. 4, panel D), onset run MBFV in dark condition did not differ between R-MCA and L-MCA. There was task-induced MBFV change in the R-MCA ($p < 0.001$) but marginal variations in the L-MCA ($p = 0.07$). There was a resultant left lateralization pattern similar to that seen at Pre-HDR, however, with stimulus-specific effect of lateralization ($p < 0.01$). There was no difference between Paradigm 2 and Paradigm 3 (Fig. 5, panel D).

DISCUSSION

Four important observations were made in this study: 1) HDR induced changes in lateralization during processing of object and facial tasks; 2) these changes were gender related; 3) there was dynamic variation of lateralization with duration of HDR; and 4) changes in lateralization in Post-HDR appeared to show a tendency toward recovery to Pre-HDT values.

This study demonstrated that right lateralization for objects and faces in Pre-HDR was altered by HDR in men. This may implicate other right lateralized visuospatial tasks as well as discerning another person's facial expression. These functions are processed within the extrastriate cortex and neighboring temporo-parietal junction, respectively, and are within the R-MCA supply territory (11).

Findings in women were opposite to those in men. Prior studies conducted in normal recumbent subjects using event-related potential amplitude during face recognition tasks indicated greater right bias for men and left bias for women (3). Recent application of cross-spectrum analysis to uncover the correlation between MBFV in the R-MCA and L-MCA at different frequencies demonstrated that women use left hemispheric frequency-dependent modulation for facial processing (Njemanze PC. Unpublished, 2004.). In contrast, despite right bias in spectral density estimates, men's responses showed bi-hemispheric cortico-cortical dynamic synchronization phenomena (Njemanze PC. Unpublished, 2004.). The present observation that women tended toward right lateralization at 6H- HDR but made a left shift at 24H-HDR, reflects the changing strategy for facial processing with time under conditions of HDR. Although 24 h was used as an endpoint, further changes may occur later.

These observations are potentially striking and require further studies. In a more recent study, the author demonstrated that actual performance on the Raven Progressive Matrices test of general intelligence correlated with cerebral lateralization and that performance decrements were associated with no lateralization (9). These findings, if confirmed and reproduced during spaceflight, would raise the possibility of relevance to future aerospace operations.

In conclusion, HDR alters cerebral lateralization for object and facial stimuli, with women showing tendencies opposite to men. Further studies of cerebral lateralization in microgravity should be of interest.

REFERENCES

1. Allison T, Ginter H, McCarthy G, et al. Face recognition in human extrastriate cortex. J Neurophysiol 1994; 71:821–5.
2. Droste DW, Harders AG, Rastogi E. A transcranial Doppler study of blood flow velocity in the middle cerebral arteries performed at rest and during mental activities. Stroke 1989; 20: 1005–11.
3. Everhart DE, Shucard JL, Quatrin T, Shucard DW. Sex-related differences in event-related potentials, face recognition, and facial affect processing in prepubertal children. J Neuropsychol 2001; 15:329–431.
4. Fowler B, Comfort D, Bock O. A review of cognitive and perceptual-motor performance in space. Aviat Space Environ Med 2000; 71(9, Suppl.):A66–8.
5. Kim JJ, Andreasen NC, O'Leary DS, et al. Direct comparison of the neural substrates of recognition memory for words and faces. Brain 1999; 122:1069–83.
6. Manzey D. Monitoring of mental performance during spaceflight. Aviat Space Environ Med 2000; 71(9, Suppl.):A69–75.

7. Njemanze PC. Cerebral lateralization in linguistic and non-linguistic perception: analysis of cognitive styles in the auditory modality. Brain Lang 1991; 41:367–80.
8. Njemanze PC. Cerebral lateralization for motor tasks in simulated microgravity. A transcranial Doppler technique for astronauts. J Gravit Physiol 2002; 9:33–4.
9. Njemanze PC. Cerebral lateralization and general intelligence: gender differences in a transcranial Doppler study. Brain Lang (in press).
10. Oldfield RC. The assessment and analysis of handedness: the Edinburgh inventory. Neuropsychologia 1971; 9:97–114.
11. Saxe R, Kanwisher N. People thinking about thinking people. The role of the temporo-parietal junction in "theory of mind". Neuroimage 2003; 19:1835–42.
12. Sinha P, Poggio TI. I think I know that face. Nature 1996; 348:404.
13. Sonnby-Borgstrom M, Jonsson P. Models-of-self and models-of-others as related to facial muscle reactions at different levels of cognitive control. Scand J Psychol 2003; 44:141–51.