REGIONAL CEREBRAL BLOOD FLOW AND EXTRAVERSION

GEORG STENBERG,* PETER E. WENDT and JARL RISBERG

Department of Psychology, University of Lund, Sweden

(Received 17 November 1992)

Summary—Regional cerebral blood flow (rCBF) was examined in a group of 17 subjects (8 men, 9 women, ages 22–35 years) at rest and during three mental activations, inducing perceptual and spatial processing. The subjects completed two personality questionnaires, the Eysenck Personality Inventory and the Karolinska Scales of Personality (KSP). The aim of the study was to examine the relation between rCBF and the extraversion–introversion dimension. Earlier studies of rCBF at rest have found higher blood flow in the temporal lobes for introverts than for extraverts, and a negative correlation between extraversion and global CBF among women. Both findings were confirmed in this group. The importance of related personality dimensions, such as impulsivity and anxiety, for rCBF differences between extraverts and introverts were examined, using scales from the KSP questionnaire. It was found that anxiety-proneness aspects of introversion were more important in determining high temporal blood flow than low-impulsivity aspects. Global CBF in women, as a measure of general arousal, was mainly related to the sensation-seeking aspects of extraversion. Results from the spatial processing tasks showed more right-hemispheric activation for introverts than extraverts in a mental rotation task.

INTRODUCTION

The relation between brain activity and personality is central to theories of the biological basis of personality. The large proportion of hereditary variance in fundamental traits (Zuckerman, 1991) leaves little doubt that biological mechanisms are at work in shaping personality. In delineating the causal avenues between genes and individual differences in behaviour, measures of brain activity and brain chemistry are indispensable tools.

Research in the area of brain correlates of personality traits has largely focused on the extraversion–introversion dimension. Reasons for this are the fact that extraversion in most personality systems assumes the role of a basic dimension (Costa & McCrae, 1992; Eysenck, 1992), and the impact of the influential theory of Eysenck (1967), which links extraversion to the concept of cortical arousal. Introverts are assumed to have a higher degree of habitual arousal than extraverts, and the characteristic behaviour patterns of extraverts and introverts are thought to be shaped by the need to counteract inherent proclivities toward under- and overarousal, respectively. Measures of brain activity have been applied to the task of testing this hypothesis.

A number of studies have used facets of EEG activity as operationalizations of cortical arousal. A majority of these studies, reviewed by Gale (1983) and O’Gorman (1984) have had outcomes favourable for Eysenck’s hypothesis, but remaining inconsistencies have prompted discussion about sources of error, such as variability in measurement conditions (Gale, 1983), and in personality measures (O’Gorman, 1984). Recent investigations have shown that the subtrait of impulsivity is more likely to be linked to biological underarousal than the broader trait of extraversion (O’Gorman & Lloyd, 1987; Stenberg, 1992).

An alternative measure of brain function, regional cerebral blood flow (rCBF) is known to reflect differences in cortical activity related to mental effort and task execution (Risberg, 1980, 1986). Blood flow reflects cortical activity, because the perfusion of the brain tissue is closely regulated by functional demands. Indices of rCBF are obtained by tracing the clearance of an inert radioisotope from an array of detectors positioned around the head. The method has been used to demonstrate intra-individual differences related to perception and problem solving as well as inter-individual differences caused by brain diseases or normal aging (Risberg, 1986).

*To whom correspondence should be addressed at: Department of Clinical Neurophysiology, University Hospital, 22185 Lund, Sweden.

In a study by Mathew, Weinman and Barr (1984), the rCBF method was applied to the question of arousal differences between introverts and extraverts. In a sample of 51 women, negative correlations between extraversion and rCBF were found, in agreement with Eysenck's theory. Correlations were approximately uniform over all brain regions examined (eight for each hemisphere), with an average of -0.36 .

An earlier study from our laboratory (Stenberg, Risberg, Warkentin & Rosén, 1990) examined the relation between extraversion and CBF, globally and in regional distribution, in a sample of 37 men and women. We did not find a relationship between global CBF level and extraversion in the sample as a whole, but there was a non-significant tendency toward the expected negative correlation in the subsample of women, in some compatibility with the study of Mathew *et al.* (1984). The most conspicuous finding was a difference in regional distribution. Blood flow in the temporal lobes was higher for introverts than for extraverts. It was hypothesized that this might be caused by differences in emotional activation, chronic or caused by the unfamiliar laboratory setting, since temporal lobe activity has been suggested to be associated with the experience of emotion, especially fear and anxiety, and fronto-temporal areas have been found to be engaged in both state and trait aspects of anxiety (Risberg, Hagstadius, Johanson & Stenberg, 1991).

Based on these earlier studies, it could be surmised that different facets of the extraversion trait relate to brain activity in different ways. High temporal lobe activity could be related to anxiety-prone introversion, i.e. a dimension rotated in the plane defined by extraversion and neuroticism, as suggested by Gray (1981). Indices of global arousal, on the other hand, may be related to impulsivity more strongly than to extraversion.

The aims of the present study are, first, to examine whether earlier rCBF findings can be replicated both concerning global level (Mathew *et al.*, 1984) and regional distribution (Stenberg *et al.*, 1990). Second, it aims to elucidate the relationship between traits such as impulsivity and anxiety, and measures of brain activity, in line with the above hypotheses.

METHOD

Subjects

A total of 20 Ss, men and women in equal proportions, participated in a study concerning brain activity during spatial problem solving, and were paid for their participation. All but one were students at the University of Lund. Ss underwent screening through a health questionnaire, to exclude psychiatric or neurological disease, as well as drug or alcohol dependency.

After the laboratory session, they were asked to provide additional data by completing two personality questionnaires at home. One S declined to participate in this part of the study. Another S was excluded because of technical malfunctions during the recording session. In the analysis of the personality questionnaires, it was found that 1 S had an unusually high Lie score (L-score: 8, N-score: 0). This S's responses were deemed unreliable, and he was excluded from further analysis. Of the remaining 17 Ss, 8 were men, and 9 were women. Mean age was 28.5 (range 22–35). No S in the study had a Lie score exceeding 4.

Personality measurement

The Eysenck Personality Inventory (EPI, form A) and the Karolinska Scales of Personality (KSP) were used (Eysenck & Eysenck, 1969; Schalling, Edman & Åsberg, 1983). The EPI was preferred to the more recent EPQ, because the aim was to replicate the results of Stenberg *et al.* (1990), and because the Extraversion scale has a higher content of impulsivity items (Rocklin & Revelle, 1981), believed to be of importance for the relation between extraversion and its biological correlates. The distribution of Extraversion scores were split by the median into a group of extraverts (E-score > 13 ; 8 Ss), and a group of introverts (E-score ≤ 13 ; 9 Ss).

The KSP has a number of scales, measuring traits of importance for the biological basis of personality. Of particular importance for the present purposes were scales related to the Anxiety axis (from neurotic introversion to stable extraversion) and the Impulsivity axis (from neurotic extraversion to stable introversion). For this reason, the Psychic Anxiety and the Psychasthenia

scales were selected as markers of the Anxiety dimension, and the Impulsivity and Monotony Avoidance scales as markers of the Impulsivity dimension.

Procedure

The laboratory session included four measurements of rCBF: at rest and during three mental activations. The resting measurement was always placed first. Since it is the one of greatest interest for the purposes of this study, analyses will be concentrated on it. The mental activations included: (a) a perceptual control condition, with visual presentation of two-dimensional geometric objects, the number of which was to be reported, (b) a spatial analysis task, in which a three-dimensional arrangement of cubes—some of them hidden—was presented, and the total number of cubes was to be inferred and reported by the *S*, and (c) a mental rotation task, in which pairs of three-dimensional objects were presented, and the task was to report whether the two objects were identical, except for a rotation, or different (Shepard & Metzler, 1971; Deutsch, Bourbon, Papanicolau & Eisenberg, 1988). Whereas the perceptual control condition always followed the initial resting measurement, the order of the remaining two tasks was counterbalanced across *Ss*.

After receiving an explanation of the measurement procedure and its purpose, *Ss* were instructed to lie down and breathe through a face mask. During the resting measurement, eyes were covered with eye pads and were to remain closed throughout the measurement. The instruction was to relax without falling asleep. The laboratory was silent except for some white noise from the recording equipment.

During the mental activations, task stimuli were presented on slides, projected on a screen above the *S's* head. Responses were given orally and recorded by the experimenter.

During the first minute of each measurement, inhalation air was mixed with the odourless and chemically inert, gamma radiating gas $^{133}\text{xenon}$. For the following 10 min, *Ss* continued to breathe through the face mask, but no more xenon was supplied to the inhalation air. During this period, the washout of the gas was monitored by the 254 scintillation detectors of the measurement system (*Cortexplorer*; Risberg, 1987), radially directed towards the center of the head. The recorded clearance curves were submitted to bi-compartmental analysis (Obrist, Thompson, Wang & Wilkinson, 1975), through which estimates of fast circulation (mainly grey matter flow) and slow circulation (mainly white matter flow) are obtained. All subsequent analyses are based on the *f1* estimate of the grey matter flow. The arterial partial pressure of carbon dioxide (pCO_2) was estimated from capnograph recordings of end-tidal CO_2 concentrations. Measurements after the first one were corrected for remaining radiation caused by earlier tracer doses.

Data analysis

The *f1* flow values were aggregated into 14 regions, 7 for each hemisphere, covering prefrontal, superior frontal, frontotemporal, temporal, central, parietal and occipital areas of the brain. Mean flow was calculated as the average across all regions, and the distribution (relative) value for each region was computed as that region's flow value, converted to a percentage of the mean flow.

In repeated-measures analyses of variance, probabilities of effects involving more than one degree of freedom in the numerator will be given after Greenhouse–Geisser correction.

RESULTS

Personality

The group means for Extraversion (13.1 ± 2.6 ; mean $\pm$ SD) and Neuroticism (7.1 ± 4.1) did not deviate significantly from those of the Swedish standardization group (12.3 and 7.6). Correlations between the personality measures are given in Table 1. The theoretically expected relationship between EPI and KSP scales emerged, with the Psychasthenia and Anxiety variables correlating positively with Neuroticism and negatively with Extraversion, and the Impulsivity and Monotony Avoidance scales correlating positively with Extraversion. However, essentially zero correlations were obtained between Neuroticism and the impulsivity markers, instead of the expected moderate positive ones.

The median-split Extraversion groups were not biased in sex distribution. In the group of

introverts there were 4 men and 5 women; among extraverts 4 men and 4 women [$\chi^2(1) = 0.05$; NS]. The groups differed, however, in mean age [30.4 years for introverts, 26.3 for extraverts, $t(15) = 2.17$; $P = 0.05$]. For this reason age will be introduced as a covariate in appropriate analyses to avoid confounding of age and extraversion effects, although it is highly unlikely that the small age difference will entail any age-related physiological changes.

Regional analysis

Group means of regional distribution values for extraverts and introverts are shown in Fig. 1.

Based on the results of our previous investigation, it was expected that the temporal regions would show differences between Extraversion groups. Therefore, a repeated measures ANOVA was conducted on the relative flow values from the two temporal regions in the rest measurement, using Gender, Extraversion and Hemisphere as factors, with repeated measures on the last one. The results showed significant effects of both Extraversion [$F(1,13) = 5.31$; $P = 0.038$] and Gender [$F(1,13) = 13.41$; $P = 0.003$]. Group means are illustrated in Fig. 2. As in our previous group of Ss, introverts had significantly higher temporal flows, bilaterally, than extraverts. The Gender $\times$ Extraversion interaction was not significant, nor were the effects involving Hemisphere. Age did not correlate with the temporal relative flows, and introducing it as a covariate did not alter any conclusions.

In our earlier study, there was a non-significant tendency towards higher frontal flows for extraverts (only one larger frontal region was used in that aggregate analysis). To examine this aspect, and to facilitate direct comparisons with our earlier data, a four-way ANOVA was computed, using Gender, Extraversion, Hemisphere and Frontal Region (3 levels: Prefrontal, Superior Frontal and Frontotemporal) as factors. The main effect of Extraversion exhibited a non-significant tendency [$F(1,13) = 2.97$; $P = 0.109$] toward higher frontal flows for extraverts. Other between-S effects were not significant.

In the central regions, introverts had higher flows, $F(1,13) = 6.50$; $P = 0.024$. The effects involving Gender or Hemisphere were not significant. Introducing age as a covariate eliminated the Extraversion effect for the central regions. There were no main effects of Extraversion for the parietal and occipital regions. However, there was a Gender $\times$ Extraversion $\times$ Hemisphere interaction for the parietal regions, due to the fact that introverted males had a left-over-right asymmetry, whereas the other groups had the reverse asymmetry [$F(1,13) = 5.90$; $P = 0.030$].

Anxiety or impulsivity

As stated in the Introduction, an object of this study was to investigate whether the observed relationship between temporal blood flow and extraversion can be attributed mainly to the impulsivity or anxiety components. Therefore the four marker variables from the KSP questionnaire: Psychasthenia, Psychic Anxiety, Impulsivity and Monotony Avoidance were entered as potential regressors, along with gender and age in a stepwise (forward) regression analysis. The dependent variable was the sum of temporal relative flow values. With the set *F*-to-enter criterion of 4, two variables were entered: Gender ($F = 13.49$) and Psychasthenia ($F = 7.16$), resulting in an $F = 11.87$, $P = 0.001$, for the regression equation. After this step no remaining variable had an *F*-to-enter exceeding 1. Thus, the hypothesis was confirmed that temporal blood flow is more strongly related to anxiety-proneness aspects of introversion than to (low degrees of) impulsive or sensation-seeking subtraits. Correlations with temporal flow were higher for Psychasthenia and Psychic Anxiety (0.52 and 0.41, respectively) than for Extraversion (-0.36), or for Impulsivity and

Table 1. Intercorrelations between personality variables from the EPI (first two variables) and KSP questionnaires

	E	N	PA	Ps	I	M
E	1.000	-0.193	-0.403	-0.295	0.407	0.743
N	-0.193	1.000	0.717	0.622	-0.051	-0.096
PA	-0.403	0.717	1.000	0.643	-0.562	-0.362
Ps	-0.295	0.622	0.643	1.000	-0.102	-0.373
I	0.407	-0.051	-0.562	-0.102	1.000	0.355
M	0.743	-0.096	-0.362	-0.373	0.355	1.000

E: Extraversion, N: Neuroticism, PA: Psychic Anxiety, Ps: Psychasthenia, I: Impulsivity, M: Monotony Avoidance.

Fig. 1. Relative regional flow values for extraverts and introverts in the rest measurement.

Fig. 2. Relative flow values in the temporal regions (averaged over hemispheres) for male and female extraverts and introverts.

Monotony Avoidance (-0.13 and -0.37). The correlation with Neuroticism was non-significant: $r = 0.24$.

Mean flow

For the whole group, the correlation between Extraversion and mean flow was -0.37 , NS. For men, the correlation was -0.07 , whereas in the group of women it was -0.71 ; $P = 0.03$. (See Fig. 3.) To further elucidate the relation between mean flow and extraversion, a multiple regression analysis was performed, in which mean flow was the dependent variable, and Extraversion, age, and $p\text{CO}_2$ were entered as predictors, the latter two being variables known to have a potential influence on blood flow. The analysis was conducted for men and women separately. For men, no predictor exerted a significant influence. For women, both $p\text{CO}_2$ and Extraversion had significant effects, but age did not. The t -values associated with the regression coefficients were -3.04 for

pCO₂ ($P = 0.029$), and -5.31 for Extraversion ($P = 0.003$), resulting in a multiple $r = 0.93$ for the model ($P = 0.015$).

As can be seen in the scatter plots of Fig. 3, one extreme data point heavily influences the correlation between Extraversion and mean flow in women. To examine whether the relationship would still hold in the remaining group, a regression analysis was performed in which this individual was excluded. The effects were reduced in size but the pattern remained the same: for pCO₂, $t = -2.75$, $P = 0.052$; and for Extraversion, $t = -2.96$; $P = 0.042$.

To examine the question whether impulsivity- or anxiety-related aspects of extraversion were more important for the correlation with mean blood flow in women, correlations were computed between mean flow and the marker variables from the KSP questionnaire. They were non-significant for the anxiety-related markers Psychasthenia and Psychic Anxiety (0.15 and 0.27), whereas the correlation with Monotony Avoidance was -0.65 ($P = 0.056$) and Impulsivity -0.15 (NS). Although the evidence is not conclusive, it seems that the relationship with mean flow can mainly be attributed to sensation-seeking aspects of extraversion.

Activation responses

Effects of the mental activations on rCBF—across personality groups—are not the main concern of this report, and results in this regard are reported separately (Wendt & Risberg, in press). However, to answer the question whether the Extraversion groups differed in their activation patterns while performing the spatial tasks, a 5-way ANOVA was performed, using Extraversion (2 levels), Gender (2 levels), Conditions (4 levels), Hemisphere (2 levels), and Region (7 levels) as factors, with repeated measures on the last three. The analysis showed a significant Extraversion $\times$ Condition $\times$ Hemisphere interaction, $F(3,39) = 3.90$; $P = 0.026$ (Greenhouse-Geisser corrected). The nature of this interaction is shown in Fig. 4. While there was a slight right-over-left asymmetry for both groups in the other tasks, the mental rotation task induced a very marked asymmetry in introverts and virtual symmetry in extraverts. An analysis of simple effects in the mental rotation task confirmed this by yielding a significant Extraversion $\times$ Hemisphere effect, $F(1,13) = 7.78$; $P = 0.015$. It thus seems that introverts mainly solved the task by activating their right hemisphere, extraverts by activating their left.

DISCUSSION

The aim of this study was to replicate and extend earlier findings concerning extraversion and rCBF. The earlier findings were confirmed. First, the regional distribution of blood flow differed between extraverts and introverts. As in our earlier study (Stenberg *et al.*, 1990), temporal lobe activity was found to be higher for introverts. If this is interpreted to be a consequence of the emotion-processing functions of the temporal lobes, it could be expected that temporal lobe activity

Task-induced asymmetries

Fig. 4. Mean hemispheric relative flow values in the four measurement conditions for extraverts and introverts.

would correlate more closely with anxiety-related aspects of introversion than other aspects, such as low impulsivity. This was found to be the case. Correlations with the Anxiety and Psychasthenia scales were higher than those with Extraversion proper, and higher than those with Impulsivity and Monotony Avoidance. In the personality system of Gray (1982), anxiety as a trait is associated with a high potential for activation of the septo-hippocampal system. Activity in this system could secondarily give higher activity in the neocortical parts of the temporal lobes. In an EEG study of emotional imagery, Stenberg (1992) found that High Anxiety Ss showed stronger temporal activation than Low Anxiety Ss when recollecting unpleasant personal memories, but not when recollecting pleasant ones, or in an emotionally neutral condition. However, it is to be noted that anxiety-proneness in the sense connected to high temporal lobe activity is not to be identified with neuroticism in Eysenck's personality system, since the Neuroticism scale did not correlate with temporal lobe activity, in this study or the previous ones.

As a potential measure of general arousal, global flow level should be expected to correlate negatively with extraversion, according to the Eysenckian hypothesis. This was found to apply to the group of women, but not the men. The result is compatible with a non-significant tendency in our earlier study, and the results of Mathew *et al.* (1984), whose study comprised an all-female

group. It is not entirely clear why the outcomes for the sexes should be different, but it is known that cerebral blood flow characteristics differ between men and women, both as to global level and regional distribution (Rodriguez, Warkentin, Risberg & Rosadini, 1988). The moderate support given to the arousal hypothesis seems to link low arousal more closely with impulsivity-related sensation-seeking traits than with other aspects of extraversion. In this respect, the results agree with findings from other fields, such as the EEG (O'Gorman & Lloyd, 1987; Stenberg, 1992), conditioning (Eysenck & Levey, 1972) and cognitive performance under stressors (Revelle, Humphreys, Simon & Gilliland, 1980).

Lastly, the pattern of activation-induced asymmetries differed between extraverts and introverts. The mental rotation task evidently evoked different strategies, associated with different asymmetry patterns in the Ss. Degree of asymmetry was found to covary with performance outcome in the Cube Analysis task (Wendt & Risberg, *in press*). The possibility that hemispheric preference under mental activation conditions is a personality-related characteristic merits further exploration.

Acknowledgements—This study was supported by a grant from the Swedish Research Council for the Humanities and Social Sciences.

REFERENCES

- Costa, P. T. & McCrae, R. R. (1992). Four ways five factors are basic. *Personality and Individual Differences*, 13, 653–665.
- Deutsch, G., Bourbon, W. T., Papanicolaou, A. C. & Eisenberg, H. M. (1988). Visuospatial tasks compared via activation of regional cerebral blood flow. *Neuropsychologia*, 26, 445–452.
- Eysenck, H. J. (1967). *The biological basis of personality*. Springfield, IL: Thomas.
- Eysenck, H. J. (1992). Four ways five factors are not basic. *Personality and Individual Differences*, 13, 667–673.
- Eysenck, H. J. & Eysenck, S. B. G. (1969). *Personality structure and measurement*. London: Routledge & Kegan Paul.
- Eysenck, H. J. & Levey, A. (1972). Conditioning, introversion-extraversion and the strength of the nervous system. In Nebelitsyn, V. D. & Gray, J. A. (Eds), *Biological bases of individual behavior*. New York: Academic Press.
- Gale, A. (1983). Electroencephalographic studies of extraversion-introversion: a case study in the psychophysiology of individual differences. *Personality and Individual Differences*, 4, 371–380.
- Gray, J. A. (1981). A critique of Eysenck's theory of personality. In Eysenck, H. J. (Ed.), *A model for personality* (pp. 246–276). Berlin: Springer.
- Gray, J. A. (1982). *The neuropsychology of anxiety. An enquiry into the functions of the septo-hippocampal system*. Oxford: Oxford University Press.
- Mathew, R. J., Weinman, M. L. & Barr, D. L. (1984). Personality and regional cerebral blood flow. *British Journal of Psychiatry*, 144, 529–532.
- O'Gorman, J. G. (1984). Extraversion and the EEG: I. An evaluation of Gale's hypothesis. *Biological Psychology*, 19, 95–112.
- O'Gorman, J. G. & Lloyd, J. E. (1987). Extraversion, impulsiveness, and EEG alpha activity. *Personality and Individual Differences*, 8, 169–174.
- Obriest, W. D., Thompson, H. K., Wang, H. S. & Wilkinson, W. E. (1975). Regional cerebral blood flow estimated by 133-xenon inhalation. *Stroke*, 6, 245–256.
- Revelle, W., Humphreys, M. S., Simon, L. & Gilliland, K. (1980). The interactive effect of personality, time of day, and caffeine: a test of the arousal model. *Journal of Experimental Psychology: General*, 109, 1–31.
- Risberg, J. (1980). Regional cerebral blood flow measurements by 133Xe-inhalation: Methodology and applications in neuropsychology and psychiatry. *Brain and Language*, 9, 9–34.
- Risberg, J. (1986). Regional cerebral blood flow. In Hannay, J. (Ed.), *Experimental techniques in human neuropsychology* (pp. 514–543). Oxford: Oxford University Press.
- Risberg, J. (1987). Development of high-resolution two-dimensional measurement of regional cerebral blood flow. In Wade, J., Knezevic, S., Maximilian, V. A., Mubrin, Z. & Prohovnik, I. (Eds), *Impact of functional imaging in neurology and psychiatry* (pp. 35–43). London: John Libbey & Co.
- Risberg, J., Hagstadius, S., Johanson, A. & Stenberg, G. (1991). Regional cerebral blood flow correlates of anxiety and personality traits. In Ingvar, D. H., Lassen, N. A., Raichle, M. E. & Friberg, L. (Eds), *Brain work II*. Copenhagen: Munksgaard.
- Rocklin, T. & Revelle, W. (1981). The measurement of extraversion: a comparison of the Eysenck Personality Inventory and the Eysenck Personality Questionnaire. *British Journal of Social Psychology*, 20, 279–284.
- Rodriguez, G., Warkentin, S., Risberg, J. & Rosadini, G. (1988). Sex differences in regional blood flow. *Journal of Cerebral Blood Flow and Metabolism*, 8, 783–789.
- Schalling, D., Edman, G. & Åsberg, M. (1983). Impulse cognitive style and inability to tolerate boredom: Psychobiological studies of temperamental vulnerability. In Zuckerman, M. (Ed.), *Biological bases of sensation seeking, impulsivity and anxiety*. Hillsdale, NJ: Erlbaum.
- Shepard, R. N. & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science*, 171, 701–703.
- Stenberg, G. (1992). Personality and the EEG: arousal and emotional arousability. *Personality and Individual Differences*, 13, 1097–1113.
- Stenberg, G., Risberg, J., Warkentin, S. & Rosén, I. (1990). Regional patterns of cortical blood flow distinguish extraverts from introverts. *Personality and Individual Differences*, 11, 663–673.
- Wendt, P. E. & Risberg, J. (*in press*). Cortical activation during visual spatial processing. Relation between hemispheric asymmetry of blood flow and performance. *Brain and Cognition*.
- Zuckerman, M. (1991). *Psychobiology of personality*. Cambridge: Cambridge University Press.