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Baseline EEG asymmetries and performance on neuropsychological tasks

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Abstract—Thirty-two participants were tested for both resting electroencephalography (EEG) and neuropsychological function. Eight one-minute trials of resting EEG were recorded from 14 channels referenced to linked ears, which was rederived to an average reference. Neuropsychological tasks included Verbal Fluency, the Tower of London, and Corsi's Recurring Blocks. Asymmetries in EEG alpha activity were correlated with performance on these tasks. Similar patterns were obtained for delta and theta bands. Factor analyses of resting EEG asymmetries over particular regions suggested that asymmetries over anterior scalp regions may be partly independent from those over posterior scalp regions. These results support the notions that resting EEG asymmetries are specified by multiple mechanisms along the rostral/caudal plane, and that these asymmetries predict task performance in a manner consistent with lesion and neuroimaging studies. © 1998 Elsevier Science Ltd. All rights reserved.

Key Words: Tower of London; Corsi's Recurring Blocks; Verbal Fluency; EEG asymmetry; laterality.

Introduction

Resting asymmetries in anterior electroencephalogram (EEG) alpha power density predict dispositional affect in both healthy [44, 47] and clinical populations ([18]; see [7] for a review). In contrast, resting asymmetries in posterior EEG alpha power density may predict cognitive styles (see [6] for a discussion). These asymmetries have good psychometric properties, including high internal consistency reliability and good test–retest reliability [45]. Resting EEG asymmetries might be viewed as reflecting tonic, trait aspects of brain activation that have implications for cognitive and emotional behaviors.

The stability of resting EEG alpha asymmetries is consistent with the notion of Levy *et al.* of characteristic arousal differences between the hemispheres. Levy *et al.* [29] showed that individuals with large right visual hemifield (RVH) advantages on a verbal tachistoscopic task, specialized to the left hemisphere, out performed those with weak or no asymmetry. This finding suggested to these authors that greater arousal in the presumed neural substrate of a task predicts cognitive performance. Moreover, individual differences in asymmetry on a verbal tachistoscopic task were correlated with asymmetries on a free vision chimeric faces task for which the sample as a whole showed a leftward bias. These findings have been extended and replicated [23, 24, 28]. For instance, Levine *et al.* [28] had participants perform three different tachistoscopic tasks: a chair identification task (for which the sample showed no asymmetry), a face identification task (for which the sample showed an LVH asymmetry), and a nonsense syllable identification task (for which the sample showed a RVH advantage). They found that asymmetries on the chair task predicted those for the other two tasks. These findings, in sum, suggest that individuals retain the same relative position in the distribution of asymmetries across tasks.

Levy and colleagues [23, 24, 28, 29] suggested a model in which asymmetries in task performance can be described by individual differences in tonic hemispheric activation or perceptual asymmetry that are superimposed on population-based differences in hemispheric competence (specialization) for a given task. Kim and Levine [23] conducted a principal component analysis (PCA) on asymmetry scores on several lateralized verbal and nonverbal tasks in both visual and auditory modalit-

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ies. They found that approximately 50% of the variance in asymmetry scores among tests in each modality could be accounted for by a component on which all tasks loaded positively. When the tests in both modalities were entered into the PCA, they found modality specificity for the asymmetry scores. These modality specific effects were interpreted by Kim and Levine as being partially due to peripheral pathways (see also [17]) and partly due to central factors.* Thus, characteristic perceptual asymmetries may be specified by more than one cortical mechanism.

Unfortunately, these studies did not use physiological measures so that the neural basis for these patterns remains unclear. Moreover, relations might differ for different brain regions. Thus, tonic hemispheric asymmetries over anterior regions may be independent from those over posterior regions. Such a fractionation was suggested by Davidson and Hugdahl [9] and Heller [15, 16]. The tests used in the Levy *et al.* [29] and Kim and Levine [23, 24] studies may have all critically depended on functioning in posterior brain regions. A different set of tests might have revealed a different pattern, with asymmetries for particular groups of tasks loading together depending on whether they reflected asymmetries in anterior or posterior cortical regions. It is, therefore, not known whether one or multiple mechanisms underly these characteristic perceptual asymmetries.

Studies showing that task performance is associated with asymmetries in ongoing EEG alpha in the expected direction have a long history. For example, Galin and Ornstein [12] showed that tasks putatively dependent upon left hemispheric function were associated with relative left hemisphere activation in the EEG. The opposite was found for tasks putatively related to right hemisphere function. Similar results were found by Davidson *et al.* [8] using tasks matched on their psychometric properties. These phasic task-related EEG alpha asymmetries show high test–retest reliability [1, 11]. Asymmetries in other EEG bands (delta and theta power) also have been shown to predict cognitive performance in much the same way [8, 31, 46]. Although performance on cognitive tasks has been associated with asymmetries in ongoing EEG activity, few studies have examined the relation between individual differences in resting EEG asymmetries and performance on cognitive tasks (e.g. [9]).

The relation between anterior and posterior EEG alpha asymmetries may be dependent upon the context in which brain activity is recorded. Several studies of task-related changes in physiological asymmetries have shown inverse relations between anterior and posterior regions. For example, Davidson *et al.* [10] found inverse relations between anterior and posterior EEG alpha asymmetries in responses to lateralized presentations of facial stimuli in depressed and nondepressed patients. Similarly, Wood *et al.* [48] discuss the findings of a series of studies in which negative correlations were observed between anterior and posterior regional cerebral blood flow asymmetries during verbal tasks.

This pattern may not persist for resting EEG alpha asymmetries. Recently, Davidson and Hugdahl [9] found relations between performance asymmetries on a dichotic listening task and resting EEG alpha asymmetries. These authors found that the magnitude of the right ear advantage on a consonant vowel (CV) dichotic listening task was correlated with relative left posterior and relative right anterior EEG activation. A possible explanation for this latter finding is that different mechanisms, each of which contribute to the prediction of dichotic listening performance, are associated with anterior and posterior resting asymmetries. Importantly, anterior and posterior asymmetries were themselves uncorrelated in this study.

The fact that anterior and posterior asymmetries were reciprocally related in the Davidson *et al.* [10] study, which examined EEG in responses to tasks, and were unrelated in the Davidson and Hugdahl [9] study, in which EEG was recorded during a resting baseline, may be because of different mechanisms invoked during each of these contexts. The cognitive tasks clearly engage cortical mechanisms that are likely to activate cortico–cortical inhibitory pathways [26] that facilitate specific features of cognitive operations. Asymmetries observed during a resting baseline may reflect a greater influence of relatively independent local cortical processes.

The studies reviewed above suggest that individual differences in both behavioral and psychophysiological asymmetries predict cognitive performance. However, two issues unresolved in the current literature are: (a) whether resting EEG asymmetries are determined by one or more than one mechanism along the rostral-caudal plane, and (b) what the implication of these different mechanisms may be for cognitive function. If psychophysiological asymmetries are determined by one mechanism, only one factor should explain their variance. More than one factor would suggest multiple mechanisms. The validity of the multiple mechanisms hypothesis can be established by showing differential relations with performance on different neuropsychological tasks.

The current study attempts to address these questions by examining patterns of resting EEG asymmetries in anterior and posterior regions, and also by investigating relations between resting EEG asymmetries and performance on neuropsychological tasks. These tasks included Verbal Fluency, the Tower of London (TOL), and Corsi's Recurring Blocks. The first two of these were chosen because they are frequently used in neuropsychological investigations. The latter task was selected because it putatively reflects right temporal function ([5] cited in [27, 34]. The tests were part of a larger study assessing neuropsychological function in normal aging.

*Kim [22] conducted a meta-analysis and found that asymmetries for auditory and visual verbal tasks were modestly correlated in left-, but not right-handers. He suggested that this difference between handedness groups may partly reflect a restricted range in variability of language laterality among right-handers compared with left-handers.

Milner [33] and Benton [3] showed that performance on Verbal Fluency was disproportionately affected by left frontal lobe lesions. In addition, recent functional magnetic resonance imaging [32, 40] studies suggest a critical role for the left prefrontal cortex in Verbal Fluency performance. Our prediction is, therefore, that Verbal Fluency performance will be correlated with relative left-sided activation over anterior scalp sites.

The TOL test generally requires participants to move a set of disks or blocks to match a target display as quickly, and in as few moves, as possible. This task was initially shown to be disproportionately affected by left frontal lobe lesions [41]. A later lesion study [37] suggested that damage to either the left or right frontal lobe impaired TOL performance. Neuroimaging studies (regional cerebral blood flow; rCBF) using Single Photon Emission Computerized Tomography (SPECT) on healthy participants showed that performance on the TOL is associated with increased activation especially in dorsolateral prefrontal regions, either predominantly on the left [35], or bilaterally [38]. This latter study also showed that performance was associated with right parietal activation and reduced left occipital activation. The previous two studies acquired rCBF data only from one [38] or two slices [35].

A more recent PET study of rCBF [2] acquired data from 31 slices using a computerized touch-screen version of the Tower of London. Participants responded by indicating the minimum number of moves in which a given problem could be solved. The control task used the same stimulus set and required participants to touch a fixed location on the screen in response to a brightening of one of the stimuli in the set. This study found more widespread activation than the studies discussed above, possibly as a consequence of the control task that was used, which differed from the experimental task on many dimensions. Better performance was associated with activation in the premotor cortex bilaterally, the anterior cingulate, dorsolateral prefrontal cortex (especially on the right) and right rostrolateral prefrontal cortex (Brodmann Area [BA] 10). Activations also were shown in the medial parietal cortex (BA 7), the left inferior parietal cortex (BA40), bilateral superior parietal cortex, and lateral occipital cortex (BA 18/19). Additional patterns of increased and decreased activation were seen in other cortical and subcortical regions. Thus there is still some controversy regarding the laterality of the regions most critical for TOL performance. Moreover, in virtually all PET studies, the assessment of task-related asymmetry is problematic because these studies typically use Statistical Probability Mapping (SPM). This technique examines only main effects for task, rather than the task × hemisphere interaction that should be examined to establish task-related asymmetry. Given the conflicting findings for anterior asymmetries with this task, we wished to investigate the direction of asymmetries in this region in the current study. We predicted, in addition, that TOL performance would be correlated with relative activation over right posterior scalp sites.

Corsi's Recurring Blocks performance is disproportionately impaired by right temporal lesions ([5] cited in [27, 34]), the severity of the deficit being related to the degree of hippocampal excision. For this reason, we predicted that Corsi's Recurring Blocks performance would be associated with relative right-sided activation over temporal scalp sites.

Method

Participants

Thirty-two right-handed participants were recruited for a study in which resting EEG asymmetries, neuropsychological function, and evoked potential (EP) measures of interhemispheric transfer were assessed. The EP data are reported elsewhere [20]. Handedness was assessed with the Chapman and Chapman [4] 13-item inventory. Subjects had an average age of 20.7±4.2 years, and a socioeconomic status [19] of 1.8±0.8.

Procedure

Testing was conducted in two sessions. Neuropsychological data were acquired in a first session, and the EEG was collected in a second session about one week after neuropsychological testing.

EEG

Participants were fitted with a stretchable Lycra cap containing tin electrodes (Electro-Cap, Eaton, OH). EEG was recorded from 14 active sites referenced to physically linked ears. Sites included F3, F4, F7, F8, T3, T4, C3, C4, P3, P4, T5, T6, Cz and Oz. Impedance at each site was below 5000 ohms, as was ear impedance. Ear impedances were matched to within 500 ohms.* To avoid some of the methodological issues surrounding the use of a linked-ears reference [13, 36, 39], an average reference was derived from these data. This reference was used in the analyses reported below.

Two electrooculography (EOG) channels also were recorded. Vertical EOG (VEOG) was recorded from electrodes at the supra and suborbit of one eye, whereas horizontal EOG (HEOG) was recorded from electrodes placed at the outer canthus of each eye. The eye at which VEOG leads were placed was determined at random. EOG impedances were below 20,000 ohms.

EEG was amplified by a Neurodata 12A5 system (Grass Instruments, Quincy, MA). Amplification was set at 30,000×, with a 1–300 Hz bandpass. MF6 chip low pass filters (48 dB/octave) were set at 100 Hz to avoid aliasing, and the 60 Hz notch filter was in. Data were digitized at 250 Hz on a 386–25 Mhz personal computer with a 12 bit A/D board (Analog Devices, Norwood, MA). Data acquisition was started and stopped by digital signals from the parallel port of a control computer to the parallel port of the acquisition computer. Eight one-minute trials were collected, four with eyes open (O) and four with eyes closed (C). Participants were randomly assigned to one of two

*For two women (differences = 0.9 and 2.1 kOhm) and one man (difference = 1.9 kOhm), this criterion could not be met.

orders: O–C–C–O–C–O–O–C or C–O–O–C–O–C–C–O. Before and after each session, calibration sequences were recorded using 25 and 50 uV signals at frequencies of 4, 10, 20 and 40 Hz.

Artifact editing. Data were carefully scored for eye movement artifact. Data from all channels were removed if artifact was present on any channel. Two participants showed electrode artifact at the Cz site, and one participant showed electrode artifact at the F7 site. Data for these individuals for these channels were eliminated from data analyses and were not included in the derivation of the average reference.

EEG data reduction. EEG data were analyzed using a Fast Fourier Transform. Continuous chunks of EEG data (1.024 s) were passed through a Hamming (cosine) filter. Chunks were overlapped by 50% to retain as much data as possible. The following bands were defined: delta (1–4 Hz), theta (4–7 Hz), and alpha (8–13 Hz). Beta power density was not examined because it is notoriously subject to myogenic contamination [6]. Power density was weighted by the number of 1.024 s chunks in each trial, separately for the eyes open and eyes closed conditions. After these weighted means were computed, data were averaged across the two conditions. Power density was then log-transformed to normalize distributions (after [6]).

Asymmetries in each band were computed by subtracting activity for the left site from its homologous right-sided site. Thus midfrontal EEG asymmetry was computed as the difference between log power density at F4 and that at F3. For alpha power density, this calculation has the result that positive values indicate relative left frontal activation, whereas negative values indicate relative right frontal activation (alpha power is thought to be inversely related to activation, [30]). Davidson *et al.* [8] have reported positive association among asymmetries in different bands. Log power density was used in the computation of asymmetries. It could be argued that an asymmetry ratio ($[R-L]/[R+L]$) should be used rather than absolute asymmetry. However, the two asymmetry metrics tend to be highly correlated, and the asymmetry ratio measure tends to be highly skewed [8]. Thus we used the absolute power density asymmetry measure in the current report.

Although the use of an asymmetry metric is informative in analyses assessing relations between individual differences in relative activation asymmetry and task performance, it is not useful in specifying which hemisphere is contributing most to the effects in question. To address this question, it is not appropriate to simply use alpha power at a given electrode site, because alpha power is strongly influenced by variations in skull thickness [47]. Our laboratory has developed a procedure for regressing each individual site on a sum of whole head power to remove the confounding effects of skull thickness on measures of individual power. We have referred to this measure as site-residualized power. The individual site-residualized power values for each electrode site that comprise an asymmetry score can then be used to determine which hemisphere is accounting for the majority of the variance in task performance.*

Neuropsychological testing

The three neuropsychological tests were given in one session. Participants were randomly assigned to one of two test orders.

Verbal Fluency was assessed with the Thurstone Word Fluency Test [43]. On the Thurstone test, participants were asked to write as many words beginning with S as they could in 5 min. they were then to write as many four-letter words beginning with C as they could in 4 min. The second part of the task was included as a more difficult condition of the first part. Scores on the two parts were highly correlated in our data, $r(32) = 0.56$, $P < 0.0001$.† Because performance on the two parts was highly correlated, we pooled scores across trials so that the dependent measure was the total number of words written in the 9 min writing time.

On our version of the TOL [41], participants were presented with a target pattern of three colored wooden disks that were placed on three wooden pegs of uneven height. They were to move their set of three disks (initially arranged in a standard pattern) so that they matched a target pattern as quickly and in as few moves as possible. There were 16 trials, 4 each requiring a minimum of 2, 3, 4, and 5 moves. Reciprocals of the time to completion were used both to normalize the distribution of scores [25] and to create a measure in which higher scores were associated with better performance.

Corsi's Recurring Blocks Task (CRB) [5, 34] is a spatial analog to Hebb's Recurring Digits test [14]. First, spatial span (the maximum number of taps on irregularly-positioned blocks that could be reproduced from immediate memory) was assessed using the WAIS-R as a Neuropsychological Instrument (WAIS-R, NI; [21]). After this was done, sequences of seven taps were made on the same blocks, and the participant was asked to reproduce them. Every third trial was repeated, and there were a total of 24 trials. The dependent measure was the percentage of correct taps from the beginning of the repeated sequences. Spatial span was used as a covariate to remove the influence of individual differences in immediate memory.

Because we had specific *a priori* hypotheses about the pattern of asymmetry that would predict performance for each task, 0.05 alpha level was used to test these effects. For exploratory analyses that were not predicted, a 0.01 alpha level was used.

Results

Task performance

Participants produced 59.2 ± 12.4 (mean ± SD) words on the 9-min Verbal Fluency task. On the TOL, mean performance was $0.16 \pm 0.03\ s^{-1}$. Cronbach's coefficient alpha for this task was 0.80. The mean Corsi's Recurring Blocks proportion correct (on repeated trials) was 0.66 ± 0.19. Coefficient alpha for this task was 0.67. The last measure was residualized for spatial span in the remaining analyses.

Relations between EEG asymmetries and neuropsychological performance

Alpha band. Mean EEG alpha power density asymmetries were: midfrontal (0.00 ± 0.15 uV^2/Hz), lateral frontal (0.01 ± 0.26 uV^2/Hz), anterior temporal

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*We did not base asymmetry computations on residualized site power because metrics based on residual power density were extremely highly correlated with asymmetries based on nonresidualized power density (median $r = 0.99$). This is because the subtraction used in the nonresidualized metric essentially removes variance common to either site.

†Unless otherwise noted, correlations are based on 32 subjects.

‡Because this metric was an asymmetry measure, it varied about a value of zero.

(-0.01 ± 0.27 uV^2/Hz), posterior temporal (0.34 ± 0.52 uV^2/Hz), central (-0.09 ± 0.33 uV^2/Hz), and parietal (0.14 ± 0.33 uV^2/Hz).‡ Analysis of individual site alpha power density (residualized for whole head raw power density) showed that Verbal Fluency was related to activation in the left central scalp region (C3), $r = -0.35$, $P < 0.049$ (see Fig. 1A). This correlation was significantly higher than the nonsignificant correlation for the homologous right central scalp lead (C4), $r = 0.18$, $t(29) = -4.12$, $P < 0.001$.* Moreover, performance on the Verbal Fluency task was correlated with relative left central activation (logC4−logC3 power density), $r = 0.47$, $P < 0.006$ (see Fig. 1B).

Performance on the TOL was not significantly related to alpha power density or to EEG asymmetries over any of the sites. Individual site analysis showed that subjects with better performance on the CRB had greater activation in the right posterior temporal scalp region (T6), $r = -0.44$, $P < 0.01$ (see Fig. 2A), which was significantly different from the nonsignificant correlation at the homologous right posterior temporal lead (T5), $r = 0.18$, $t(29) = -2.05$, $P < 0.05$. CRB performance was correlated with relative right posterior temporal activation, $r = -0.46$, $P < 0.007$ (see Fig. 2B).

Delta band. Verbal Fluency was unrelated to residualized delta band power density at any of the lateral sites, nor was it related to delta power density asymmetry. Although the correlation between Tower of London performance and delta power density over P4 did not reach significance, $r = -0.42$, $P < 0.02$, this correlation differed significantly from that over P3, $r = -0.07$, $t(29) = -5.27$, $P < 0.001$. CRB performance did not correlate with delta power density at any of the lateral sites, nor was it correlated with delta power density asymmetry.

Theta band. Verbal Fluency was unrelated to residualized theta band power density at any of the lateral sites, nor was it related to theta power density asymmetry. Although TOL performance did not correlate significantly with decreased theta power density over the right parietal scalp region (P4), $r = -0.37$, $P < 0.04$, this correlation differed from that over the left parietal scalp region (P3), $r = -0.15$, $t(29) = -6.11$, $P < 0.001$. Corsi's Recurring Blocks performance did not correlate with theta power density over any of the lateral sites, but was related to reduced relative right-sided theta power density over posterior temporal, $r = -0.51$, $P < 0.003$, and parietal, $r = -0.49$, $P < 0.005$, scalp sites.

*For this and other comparisons between homologous sites, significance was tested using Steiger's [42] formula for differences between dependent correlations.

†Factor analysis could only be performed on the 31 subjects who had data for all sets of lateral pairs. This resulted in the exclusion of one subject. Means for the neuropsychological tasks remained virtually identical to those obtained on all 32 subjects: $M_{\text{Verbal Fluency}} = 58.7 \pm 12.3$ words, $M_{\text{TOL}} = 0.16 \pm 0.03$ s^{-1}, $M_{\text{CRB}} = 0.65 \pm 0.18$.

Factor analysis of EEG alpha asymmetries

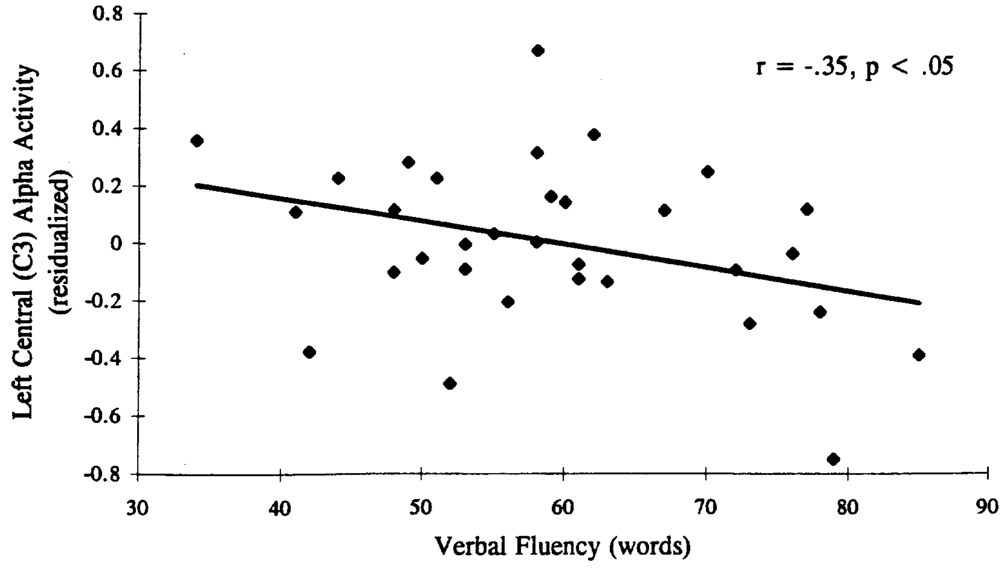
Factor analysis was carried out on alpha asymmetries using a PCA approach and Varimax rotation (see Table 1 for loading patterns).† Communalities were set at 1.0 in this analysis. Three factors emerged. Varimax rotation simplified this pattern. Lateral frontal, midfrontal, and anterior temporal alpha asymmetries loaded positively on Factor 1, which had an Eigenvalue of 2.51 (42% of the variance). Posterior temporal and parietal asymmetries loaded positively on Factor 2, which had an Eigenvalue of 1.33 (22% of the variance). Finally, central asymmetries loaded positively on Factor 3, which had an Eigenvalue of 1.15 (19% of the variance).

Correlational analyses were conducted examining relations between the alpha asymmetry factors and neuropsychological performance. These analyses showed that Verbal Fluency was related to Factor 3 scores, $r(31) = 0.50$, $P < 0.004$ (see Fig. 3), suggesting that performance on this task was related to relative left central activation. This correlation was significantly greater than that with Factor 2, $r = 0.20$, $t(28) = 2.42$, $P < 0.05$, and Factor 1, $r = -0.04$, $t(28) = 2.09$, $P < 0.05$.

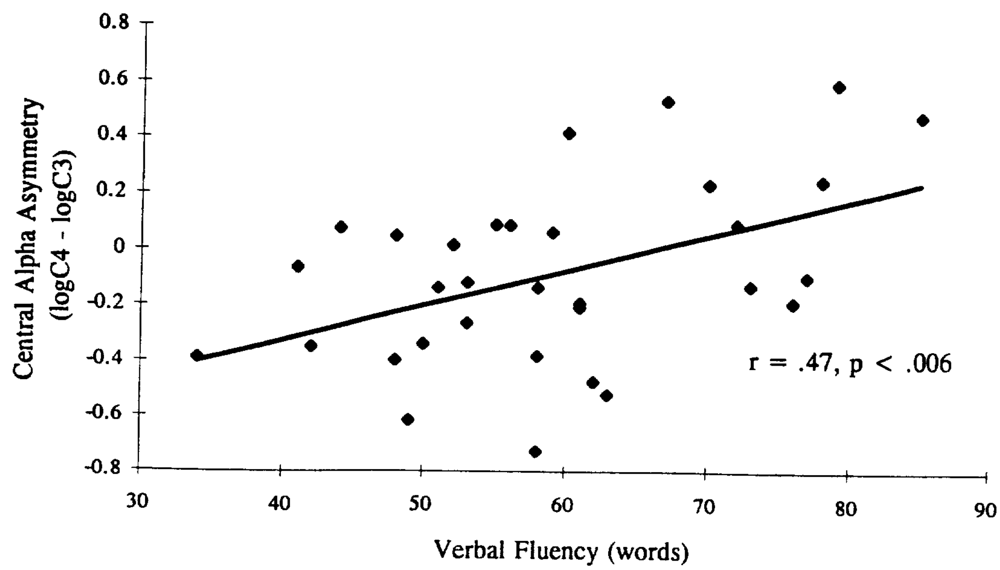
Performance on the TOL was related to Factor 2 scores, $r(31) = -0.36$, $P < 0.05$ (see Fig. 4). This correlation did not differ significantly from that for Factor 1, $r = -0.26$, $t(28) = -1.28$, *ns*, or Factor 3, $r = -0.05$, $t(28) = -1.41$, *ns*. Similarly, CRB performance was related to Factor 2 scores, $r(31) = -0.45$, $P < 0.012$ (see Fig. 5). This correlation was significantly greater than that for Factor 3, $r = 0.20$, $t(28) = -2.08$, $P < 0.05$, but not that for Factor 1, $r = -0.04$, $t(28) = -1.80$, *ns*. These correlations indicate that performance on these tasks was related to relative right posterior activation.

Discussion

The main findings were that performance on several neuropsychological tasks was predicted by resting EEG alpha asymmetries and that EEG alpha asymmetries over anterior, central, and posterior scalp regions were relatively independent. It should be emphasized that measures of brain electrical activity and of neuropsychological tests were obtained about one week apart, further underscoring the trait-like nature of the effects we describe. The correlations between resting EEG asymmetries and neuropsychological performance highlight the relevance of tonic hemisphere differences in activation for cognitive performance. Although the current sample was relatively small, the finding of three resting EEG alpha asymmetry factors suggest considerable differentiation and independence in the mechanisms of hemispheric activation across the rostral-caudal extent of the head. The finding of independence among resting asymmetries in anterior vs posterior regions stands in contrast to the inverse correlations between anterior and posterior regions during task performance, though it is



A



B

Fig. 1. Scatter plot of (A) left central (C3) alpha activity—residualized for whole head alpha power, and (B) central alpha asymmetries (log C4 − log C3) as a function of Verbal Fluency. For scatter plot (A) lower numbers on the ordinate are indicative of greater activation (less alpha). For scatter plot (B) higher numbers on the ordinate are associated with greater relative left-sided activation.

consistent with our previous data on resting asymmetries [9]. As noted in the Introduction, it may be that asymmetric systems that are independent under resting conditions become coupled during task performance.

In general, relations between resting EEG asymmetries and task performance were similar across alpha, delta, and theta bands. Most notably, correlations were invariably in the same direction across the various bands.

Fig. 2. Scatt
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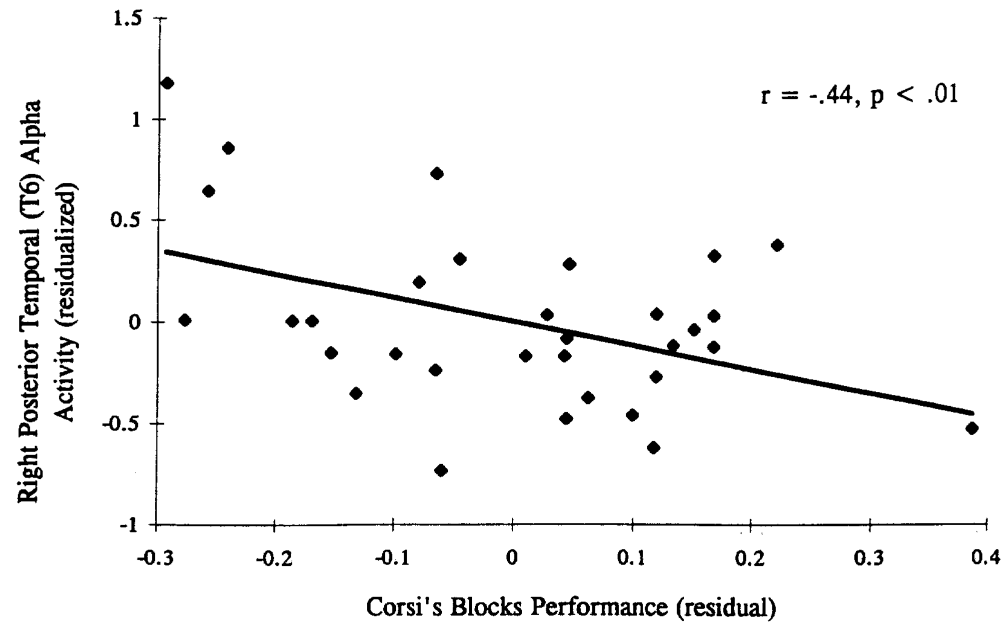

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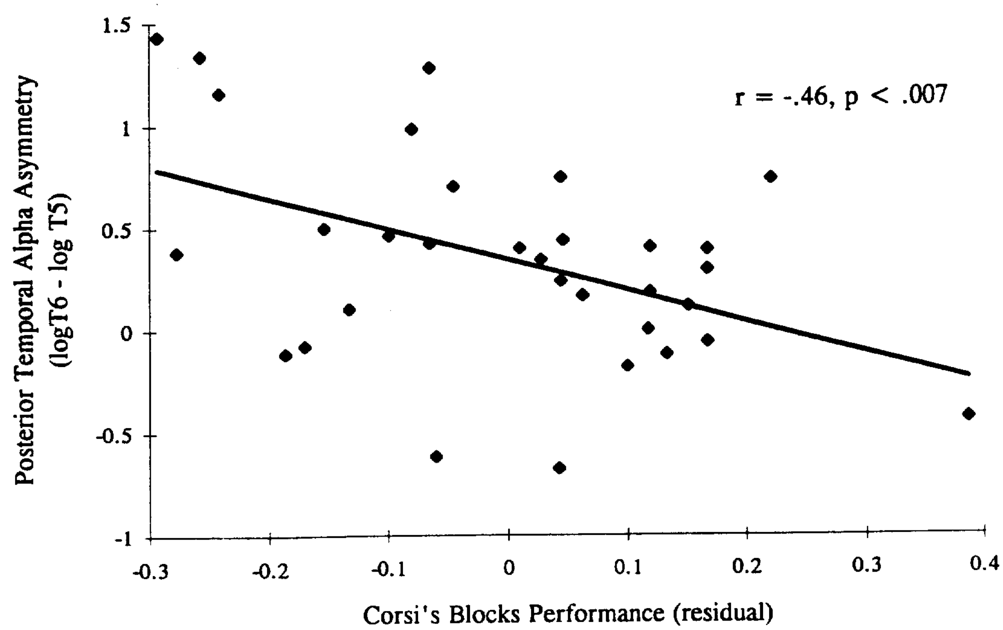

B

Fig. 2. Scatter plot of (A) right posterial temporal (T6) alpha activity—residualized for whole head alpha power, and (B) posterior temporal asymmetries (log T6 − log T5) as a function of Corsi's Recurrent Blocks performance—residualized for spatial span. For scatter plot (A) lower numbers on the ordinate are indicative of greater activation (less alpha). For scatter plot (B) higher numbers on the ordinate are associated with greater relative left-sided activation.

Table 1. Factor loadings of regional EEG asymmetries—varimax rotation

	Factor 1	Factor 2	Factor 3
Lateral frontal	0.88§§	−0.20	0.10
Midfrontal	0.83§§	0.09	0.30
Anterior temporal	0.76§§	−0.28	−0.31
Parietal	−0.14	0.93§§	0.15
Posterior temporal	−0.11	0.86§§	−0.36
Central	0.08	−0.09	0.92§§

Factor 1 Eigenvalue = 2.51, Factor 2 Eigenvalue = 1.33, Factor 3 Eigenvalue = 1.15.
§§ indicates high loadings.

Moreover, individual site powers were related in similar directions across the various EEG bands. These results are consistent with those of Davidson *et al.* [8], who examined relations between task performance and EEG activation during those tasks. Because of the similarities in findings across bands, and because alpha asymmetries have been shown to have higher internal consistency reliability than those for delta and theta bands [45], we will focus on the results for alpha asymmetries in the remainder of this article.

Performance on the CRB was associated with relative right activation over posterior temporal scalp sites. This correlation is consistent with a special role for the right temporal lobe in CRB performance (e.g. [5]) and suggests that persons with relative right activation over posterior temporal scalp sites under resting conditions tend to perform better on this task than do persons with other patterns of resting activation. Indeed, CRB performance was more strongly related to activity over the right than the left posterior temporal scalp regions, and it was more strongly related to relative right activation on the factor representing posterior scalp asymmetries than the factor representing central scalp asymmetries.

Although the spatial resolution of EEG is limited, the relation between relative left-sided activation over central scalp sites and Verbal Fluency suggests that left sided premotor/motor activation may be more predictive of Verbal Fluency than is activation over frontal scalp sites, at least under resting conditions. Individual site data revealed that increased activation over left central scalp sites was predictive of Verbal Fluency performance. In particular, Verbal Fluency was more highly associated with activity over the left central than the right central scalp region. Furthermore, Verbal Fluency was related to relative left activation on the factor representing asym-

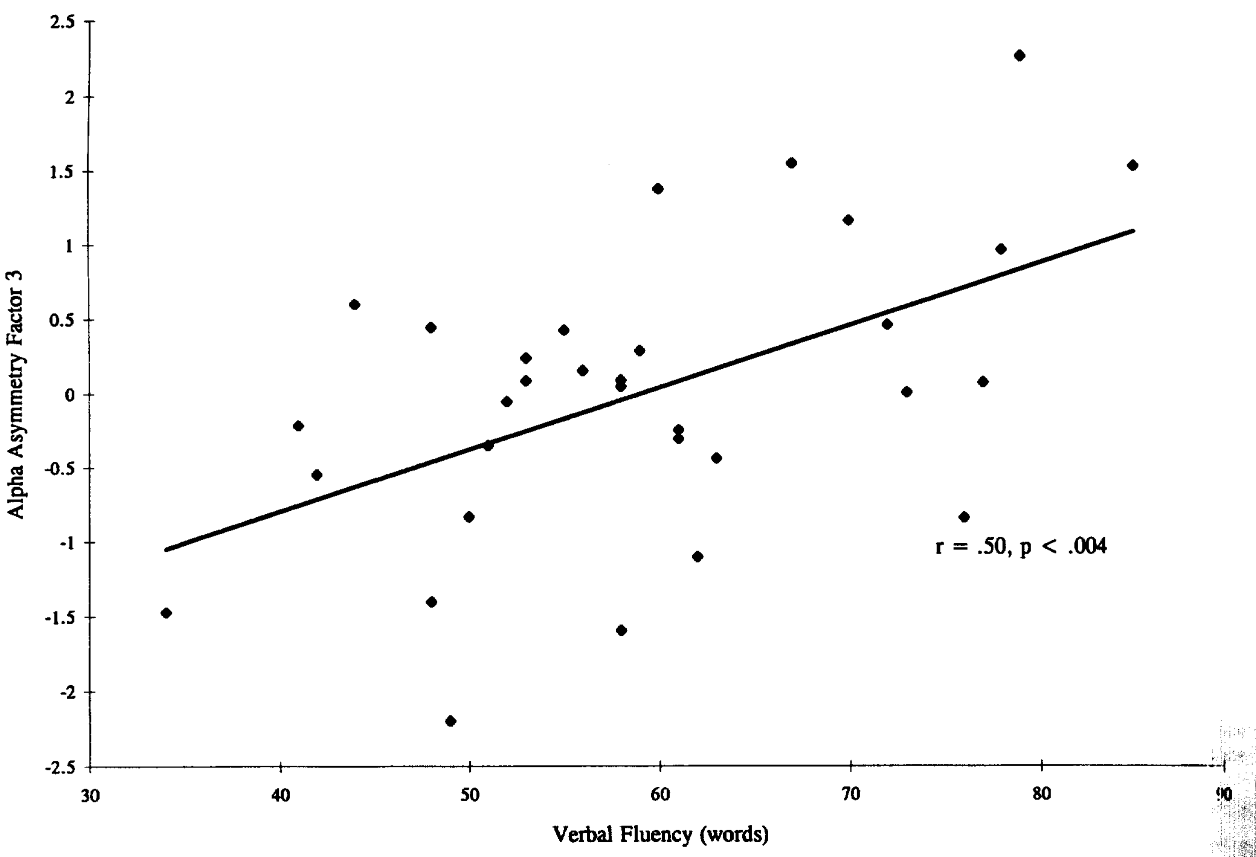

Fig. 3. Scatter plot of alpha asymmetry Factor 3 as a function of Verbal Fluency. Higher numbers on the ordinate are indicative of greater relative left-sided activation.

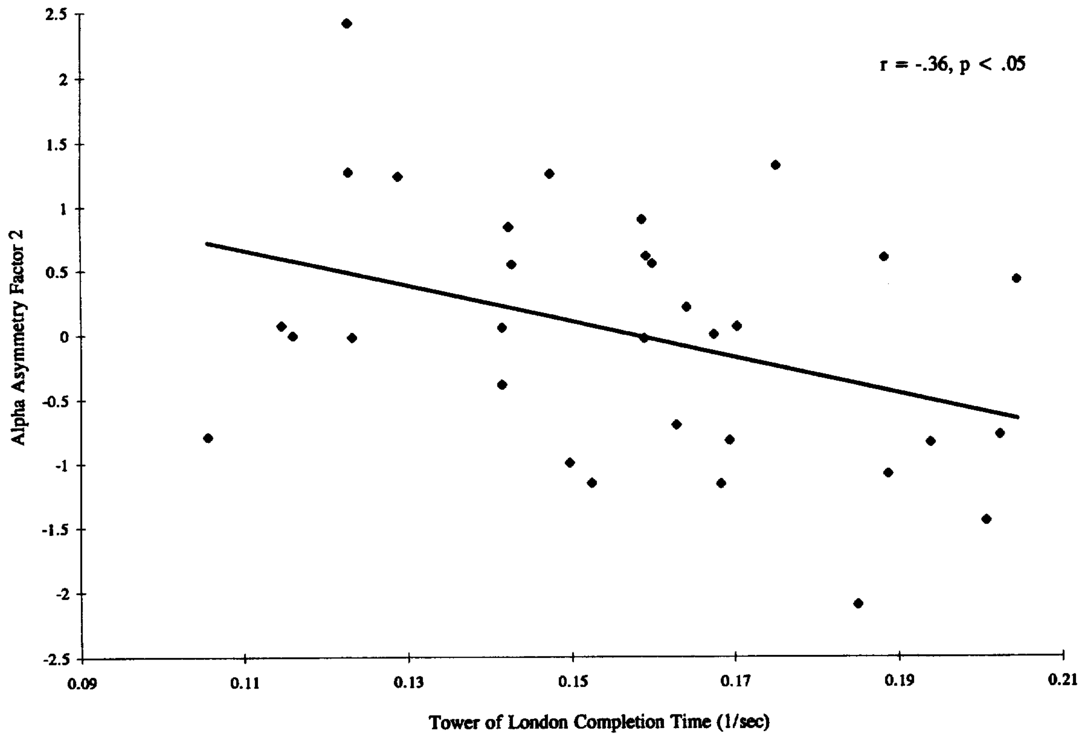

Fig. 4. Scatter plot of alpha asymmetry Factor 2 as a function of Tower of London (s^{-1}) performance. Lower numbers on the ordinate are indicative of greater relative right-sided activation.

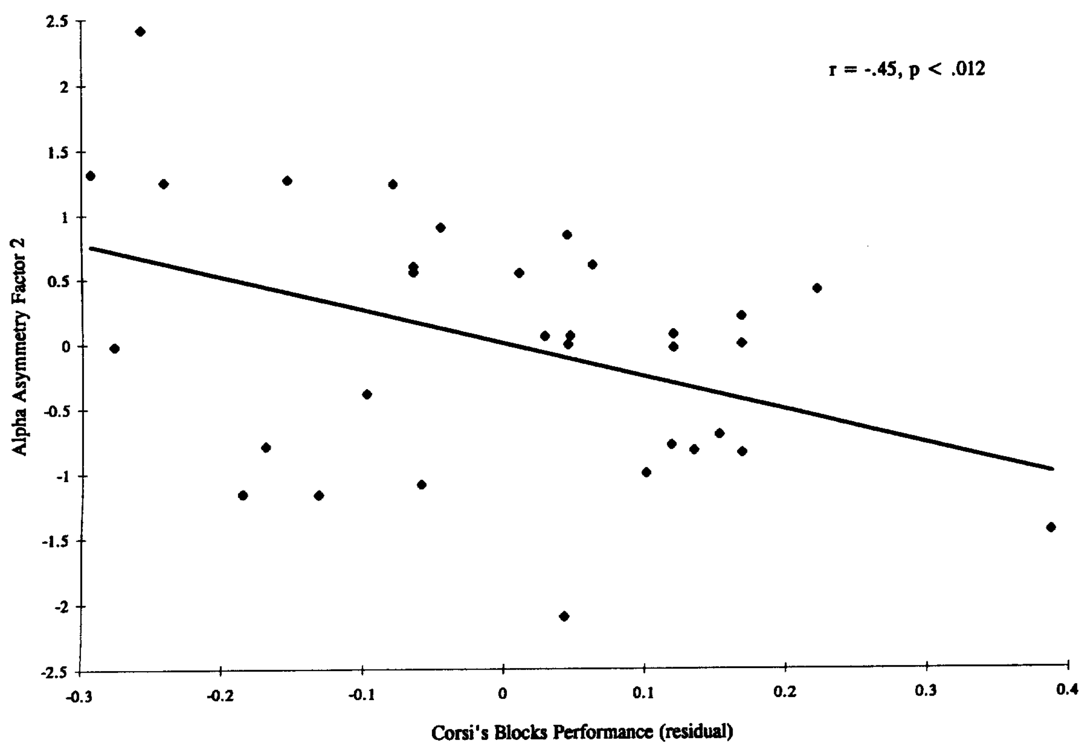

Fig. 5. Scatter plot of alpha asymmetry Factor 2 as a function of Corsi's Recurrent Blocks Performance—residualized for spatial span. Lower numbers on the ordinate are indicative of greater relative right-sided activation.

metry at central scalp sites, and this correlation was significantly stronger than with the asymmetry factors representing either anterior or posterior scalp regions.

The results for the Tower of London task also were not entirely as expected. Performance on this task was associated with the factor representing asymmetries over posterior temporal and parietal scalp regions. This finding is consistent with PET findings [2, 38] of parietal activation, especially on the right [38], during Tower of London performance, but not with findings of anterior activation [2, 35, 38]. Individuals with relative right activation over posterior scalp sites under resting conditions appear to have an advantage on this task, possibly due to the special role of this region in spatial organization of mental representations [2].

The present data are consistent with the idea that asymmetries of brain activation under resting conditions can predict performance on neuropsychological tasks. These data should not, however, be taken as evidence that the particular regions discussed are necessarily used during task performance. It would be of interest to compare the relation between anterior and posterior scalp asymmetries both during task performance and at rest. The present findings indicate that individual differences in baseline measures of brain electrical asymmetries provide important information about trait differences in patterns of cognitive performance.

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