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Electrophysiology and intelligence: the electrophysiology of intellectual functions in intellectual disability

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Abstract

The electroencephalograms (EEGs) of 127 subjects with intellectual disability were analysed with regarding to their correlation to intellectual functions in order to further understand the relationships between EEG and intelligence. The EEG frequency spectrum was subdivided into 15, 2-Hz-wide bands and was recorded from electrodes F1, Fpz, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, Oz and O2. Patterns of acorrelation showed several similarities when compared to other analogous studies with normal subjects. However, the typical finding in the present study was a high number of correlations involving the frontal lobes, mainly the prefrontal portions, which is at variance with the patterns of normal subjects. Frontal lobes, especially the prefrontal regions, seem to be affected, regardless of its aetiology, in subjects with intellectual disability.

Keywords electrophysiology, intellectual functions, intelligence

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Introduction

A major feature of the definition of intellectual disability (ID) is the presence of an abnormally low IQ. Classically, the IQ threshold for the diagnosis of ID has been defined as 70 (APA 1994), although recent developments have argued for a higher figure, such as 75 (Luckasson *et al.* 1997). Subjects classified as intellectual disabled must also show adaptive deficits in several aspects of daily life; for example, communication, self-care, social skills and leisure (King *et al.* 1997). Although there is also some controversy about which of these factors, i.e. IQ or adaptive behaviour, should be emphasized, it nevertheless appears that the presence of a notably below-average IQ is imperative in the diagnosis of ID.

Therefore, ID could be considered to be a heterogeneous condition according to its possible aetiologies. Because the diagnosis is mainly based on IQ, many pathogenic processes could exhibit this sign. The American Association on Mental Retardation actually enumerates more than 350 causes of ID (Luckasson *et al.* 1997).

As a consequence of this heterogeneity, several electroencephalogram (EEG) handbooks have usually preferred not to define an EEG pattern for ID (Nogueira de Melo & Niedermeyer 1993). In fact, this has been the situation not only for EEGs, but also for neuro-imaging techniques in general (Peterson 1995). However, ID could be treated as a unitary pathology since there is a major and common feature in subjects with ID, regardless of the specific aetiology, i.e. low intellectual performance. Indeed, with the exception of neuro-imaging studies, there has been a large amount of research in which ID is considered as a unitary syndrome, regardless of its aetiology (e.g. Hughenin 1997; Polloway *et al.* 1997; Wyatt & Conners 1998). On the other hand, low intellectual performance is rather unspecific, i.e. it is not just one or two concrete intellectual areas which are affected; the low IQ scores found in subjects with ID are usually a consequence of low mean scores in the majority or even in all of the intellectual functions measured by intelligence tests. It also appears clear that a generalized impairment in intellectual performance cannot be a consequence of damage to any single part of the brain. Apart from specialized brain areas, there are also several brain regions or nuclei involved in many functions or types of cognitive function; for example, the prefrontal lobes (e.g. Fuster 1997). Accordingly, it appears plausible that certain brain areas could be more frequently affected than others in subjects with ID. However, brain-imaging studies of subjects with ID have been so scarce and usually so restricted to specific aetiologies that no firm conclusion could be drawn (King *et al.* 1997).

With regard to EEG, which is one of these brain-imaging techniques, the main studies of ID, regardless of aetiological variables, were made several years ago (Gasser *et al.* 1983a, b, c) and recent studies are rare (e.g. Psatta *et al.* 1991). This has not been the case for the EEG-derived event-related potentials technique (e.g. Zurrón & Díaz 1997; for a review, see Deary & Caryl 1997). However, event-related potentials are a good index for concrete dysfunctions since these require that the task used to elicit event-related potentials involves those dysfunctions. Therefore, event-related potentials are not so optimal in detecting general patterns of brain deterioration, the common factors in ID; EEG is preferable for these purposes.

In the few EEG studies in which ID has been studied as a unitary syndrome, an increase in low-frequency bands (i.e. the delta and theta bands) relative to normal population has been reported for subjects with ID (Gasser *et al.* 1983a; Psatta *et al.* 1991). On the other hand, the high-frequency bands (i.e. the alpha and beta bands) have been seen to display a somewhat different pattern. The alpha band has sometimes been seen to decrease in subjects with ID (Psatta *et al.* 1991), but on other occasions, this band has shown significantly higher values in subjects with ID compared to normal individuals, being this the case of absolute power over frontal leads (especially the lowest frequency range of the alpha band) (Gasser *et al.* 1983a). However, in the above study, the use of relative values inverted these differences, mainly at posterior sites, and affected the highest frequency range of this band (Gasser *et al.* 1983a). At variance with the usual finding of a beta band decrease with cognitive impairment (Barlow 1993), this band can be found to increase in children with ID (Gasser *et al.* 1983a). However, this finding is not restricted to subjects with ID since several other pathologies have also been seen to show this unusual pattern for the beta band (e.g. depression; see John *et al.* 1989).

Intellectual disability has also been considered as an entity, regardless of aetiology, in an EEG study by Gasser *et al.* (1983c), in order to further understand the relationships between intellectual and electrophysiological variables. This kind of study is of interest because it permits a better understanding of both the neurophysiological basis of intellectual functions (by relating involved brain areas to concrete intellectual tasks) and the EEG itself (by relating particular bands or frequencies to concrete intellectual functions over concrete brain areas). Different results were found depending on whether the study population was composed by normal individuals or people with ID.

The most complete and interesting study of normal subjects is by Giannitrapani (1985). The above author studied the performance of a large sample of young adolescents on each subtest and scale of the Wechsler Intelligence Scale for Children (WISC), and correlated their attainments to each of the 2-Hz-wide EEG bands ranging from 0 to 32 Hz. Hence, classical bands were subdivided, yielding a detailed analysis of the differential roles which discrete frequencies within the classical divisions could play. These analyses were made at several electrode sites. The results of the Giannitrapani (1985) study broadly confirmed the above-mentioned general pattern of correlations, but also found positive correlations between EEG amplitude and intellectual functions along bands within the delta and theta ranges, and around the 23-Hz frequency band (ranging from 22 to 24 Hz). Of course, the above study also provided an extensive amount of detailed data, mainly regarding the relationships between specific frequencies and specific intellectual functions at specific brain regions.

On the other hand, when subjects with ID have been studied, the relationships between intellectual functions and electrophysiological variables have shown a different but interesting pattern. The main correlations have been found to be the inverse of those previously described for normal subjects, i.e. a negative correlation was found between EEG amplitudes and intellectual functions, and this was mainly so for delta band over frontal leads (Gasser *et al.* 1983c). This inverse pattern has been interpreted as a result of differences in the maturational development of the subjects within the studied sample. Hence, these findings indicate that children with ID who are more developmentally advanced in their EEG parameters also show higher IQ scores.

A positive relationship between beta bands and IQ scores, mainly at posterior electrodes, was also observed in the Gasser *et al.* (1983c) study in children with ID, whereas a control group showed the inverse pattern in Beta-1 band (ranging from 12.5 to 17.5 Hz). Therefore, considering above-mentioned results relative to a beta band increase in subjects with ID found by the same group (Gasser *et al.* 1983a), it can be determined that the pattern for this band in relation to intellectual functions remains unclear.

Interestingly, the different scales of the WISC have not been considered nor has the EEG spectrum been subdivided into 2-Hz-wide bands in any study of subjects with ID. Therefore, a population with ID has not been studied in such a complete manner as Giannitrapani's (1985) study with normal subjects. In the present study, the authors aimed to address this situation by correlating 2-Hz-wide bands, and each subtest and scale of the WISC in a large sample of subjects with ID. By doing so, important conclusions can be drawn not only about which brain areas seem to be more commonly affected in ID, but also about the electrophysiology of intellectual functions. Paralleling the Giannitrapani (1985) study, these analyses correspond to a first stage in data processing, where valuable and independent conclusions can be obtained. A second data-analysis stage, in which principal components analyses would be performed, should also be undertaken, but this would be the subject of a subsequent and independent study.

Subjects and methods

A sample of 127 subjects (86 males and 41 females) was included in the present study. The mean age of these individuals was 16.4 years (range = 11.1–20.7 years). All subjects were students in a school for children with ID and learning disabilities. Several days before or after the EEG recordings, the Spanish version of the WISC-R intelligence test (TEA 1993) was administered to the subjects. Their mean psychometric measures on this test are summarized in Table 1. At variance with the usual summation in Digit Span of the digits repeated both forwards and backwards, these two possibilities were differentiated in the present study and are termed as Direct Digits and Inverted Digits, respectively. All subjects fitted the criteria for the diagnosis of ID according to the DSM-IV (APA 1994), and therefore, they all presented with an IQ score under 70 and over 30, forming a sample of subjects with severe ($IQ < 50$, $n = 50$) and mild ($50 > IQ < 70$, $n = 77$) ID. All but 12 (9.4%) subjects were right-handed. Only 27.5% of the subjects were medicated, with the following distributions from the total: 5.5% of the subjects used neuroleptics, and one case (0.7%) used both neuroleptics and antidepressants; 14.9% used antiepileptic drugs; 1.5%, anxiolytics (benzodiazepines); 1.5%, thyroid hormone; 0.7%, somatotropic hormone; 0.7%, antidepressants; and 1.5% used methylphenidate.

Aetiologies for ID were known for a high proportion of the subjects. The highest percentage were subjects who had suffered perinatal or prenatal anoxia, forming 45% of the total sample. Subjects suffering kernicterus made up 3.9% of the sample. Meningitis was the aetiology in 2.3% of the sample and the same was true for prematurity. Subjects suffering from fragile-X syndrome, Prader–Willi

Table 1 Results for the sample of psychometric measures on the Wechsler Intelligence Scale for Children – Revised

Measure	Mean	Minimum	Maximum
Full-Scale IQ	55.15	31	70
Verbal IQ	57.78	35	87
Performance IQ	63.42	38	87
Information	10.61	4	22
Comprehension	11.18	3	21
Arithmetic	6.36	3	12
Similarities	10.86	5	17
Vocabulary	29.99	11	54
Direct Digits	4.16	2	6
Inverted Digits	2.68	2	5
Picture Completion	10.73	6	17
Picture Arrangement	17.56	6	34
Block Design	13.93	1	48
Object Assembly	18.06	7	28
Coding	2.17	14	61
Mazes	12.98	2	21

syndrome, elastopathia and Down's syndrome were also present, each 1.5% of the total sample. One case (0.7%) was observed for each of the following aetiologies: Recklinghausen neurofibromatosis, rubella embryopathia, head trauma, astrocytoma in the IV ventricle, Sotos syndrome, hydrocephalia, Lawrence Moon Bield syndrome, partial agenesia of the corpus callosum and piruvicoquinase enzyme defect. The rest of the subjects (34.2%) had ID of unknown origin.

Following the 10–20 system, 21 derivations (i.e. F1, Fpz, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, Oz and O2) with linked mastoids as reference were chosen. Tin electrodes attached by means of a cap (Electro-Cap International, Eaton, OH, USA) were used. Impedance was always kept below 3 kOhms. The band-pass used was 0.5–37.5 Hz and the sampling rate was 128 Hz.

The recordings were made during a 3-min period at rest while the subjects' eyes open. The EEG was visually inspected and at least 10, 2-s EEG epochs free of artefacts were obtained for each subject. The fast Fourier transformation (FFT) was performed and 21 frequency spectra were obtained (one for each electrode) for each subject. All data were processed and analysed with a Brain Atlas III (Bio-Logic Systems Corporation, Illinois, USA).

The frequency spectrum was further subdivided into 15, 2-Hz wide frequency bands. These bands mainly corresponded to: 0.5–2.0, 2.5–4.0, 4.5–6.0, 6.5–8.0, 8.5–10.0, 10.5–12.0, 12.5–14.0, 14.5–16.0, 16.5–18.0, 18.5–20.0, 20.5–22.0, 22.5–24.0, 24.5–26.0, 26.5–28.0 and 28.5–30.0 Hz. This subdivision of the EEG frequency spectrum largely follows the studies of Giannitrapani (1985) and Martín-Loeches *et al.* (1993). As in the above work and for the sake of brevity, these frequency bands are named according to their centroids, i.e. 1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, 25, 27 and 29 Hz. The absolute spectral parameters at each of these bands were further logarithmically transformed to yield an approximate normal distribution (Oken & Chiappa 1986).

In order to quantify the relationships between parameters of EEG activity, and the scores in tests and subtests of intelligence, Pearson correlations were preferred rather than a non-parametric test such as the Spearman test (used in Giannitrapani 1985) given the large number of subjects and the normalization of absolute amplitude performed. For the sake of clarity, the matrices show only significances beyond the $P < 0.05$ level of confidence. Pure correlations are also analysed in the present study instead of using a data reduction such as canonical correlations or principal components analyses. The reason for this is an attempt to make the present results comparable to those in the first, most sizeable half of the study by Giannitrapani (1985), who performed the same procedure. In this way, and paralleling the above study, a rich amount of unique information relating to each particular WISC-R test and subtest, and the relationship of these to each particular 2-Hz EEG band at each electrode, can be gathered, allowing the present authors to focus on either variable. This freedom cannot be obtained with other procedures. A follow-up principal components analysis is the subject of an extension of the present study that is currently in preparation.

Also, given that independence of many of the variables employed (i.e. EEG bands, intellectual subtests and electrodes) cannot be totally warranted, a Bonferroni correction of the significance level did not appear appropriate. Additionally, the present authors could miss truly significant results (type II errors) by using the above method (Berns 1999). Therefore, the $P < 0.05$ level was maintained. Once again, this approach resembles the Giannitrapani (1985) study which the present authors wanted to make their results comparable with. However, this approach has a limitation: the large number of calculations can yield a certain amount of significant results just by chance (theoretically, 5% of the comparisons). This problem always has to be considered when interpreting the present data. However, so as to minimize or even remove this trade-off, only clusters of correlations are discussed. While it is true that randomization may make significant approximately 5% of the present comparisons, what appears implausible is that these 5% random results should appear polarized around EEG bands or around electrodes, or even around both simultaneously. This is basically the same argument used in current positron emission tomography (PET) or functional magnetic resonance imaging (fMRI) neuro-imaging techniques (Frackowiack *et al.* 1997). Also, given the age of the sample, maturational factors were not considered to be a relevant factor (Niedermeyer 1993). Nevertheless, age was controlled by the use of partial correlations.

Results

Figure 1 displays the plot of the mean power values at each of the 15, 2-Hz-wide bands at a representative electrode (Oz). Separate plots were performed for the subjects with mild ID and those with severe ID. As can be observed, there is a peak interrupting the trend for power decrement with increasing fre-

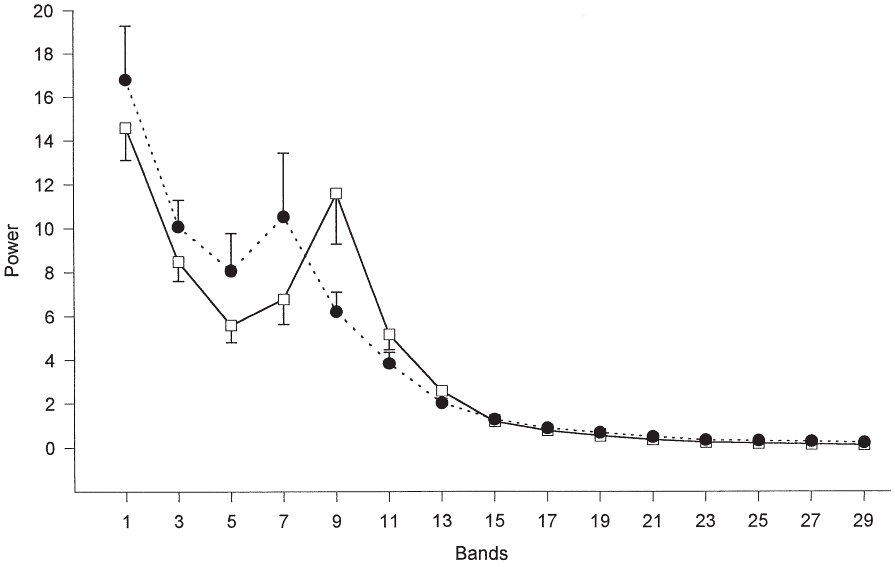

Figure 1 Plots of the mean power values at each of the 15, 2-Hz-wide bands in the Oz electrode. Separate plots were performed for both the subjects with mild (□) and severe (●) intellectual disability.

quency in both groups, occurring at 9 Hz and 7 Hz for the subjects with mild and severe subjects ID, respectively.

Figures 2–5 display the correlation matrices in a topographical layout containing the results in terms of significance obtained when relating the Full-Scale IQ, the Verbal IQ, the Performance IQ and each of the WISC-R subtests with each of the 15, 2-Hz wide-bands studied. The results are displayed using a topographical arrangement so that the correlational results are easily interpreted and comprehensive.

According to Fig. 2a, correlations involving the Full-Scale IQ clearly form two differentiated and independent groups or clusters. On the one hand, negative correlations corresponding to the lowest frequency bands (between 1 and 5 Hz, mainly the latter) were observed, but these were limited to the frontal regions. On the other, a small group of significant positive correlations can be identified in the 9 Hz frequency band at electrodes in the most posterior regions (central and right occipital). Figure 2b displays correlations involving Verbal IQ. Significant correlations, all of them negative, were only obtained at the 5 Hz band and over the frontal regions. On the other hand, the correlations between Performance IQ and EEG variables displayed in Fig. 2c were limited to fronto-polar leads and implicate the lowest frequency band (1 Hz).

Correlations involving the Information subtest (Fig. 3a) show negative relationships, mainly at the 5 and 11 Hz bands, and in both cases, mainly over

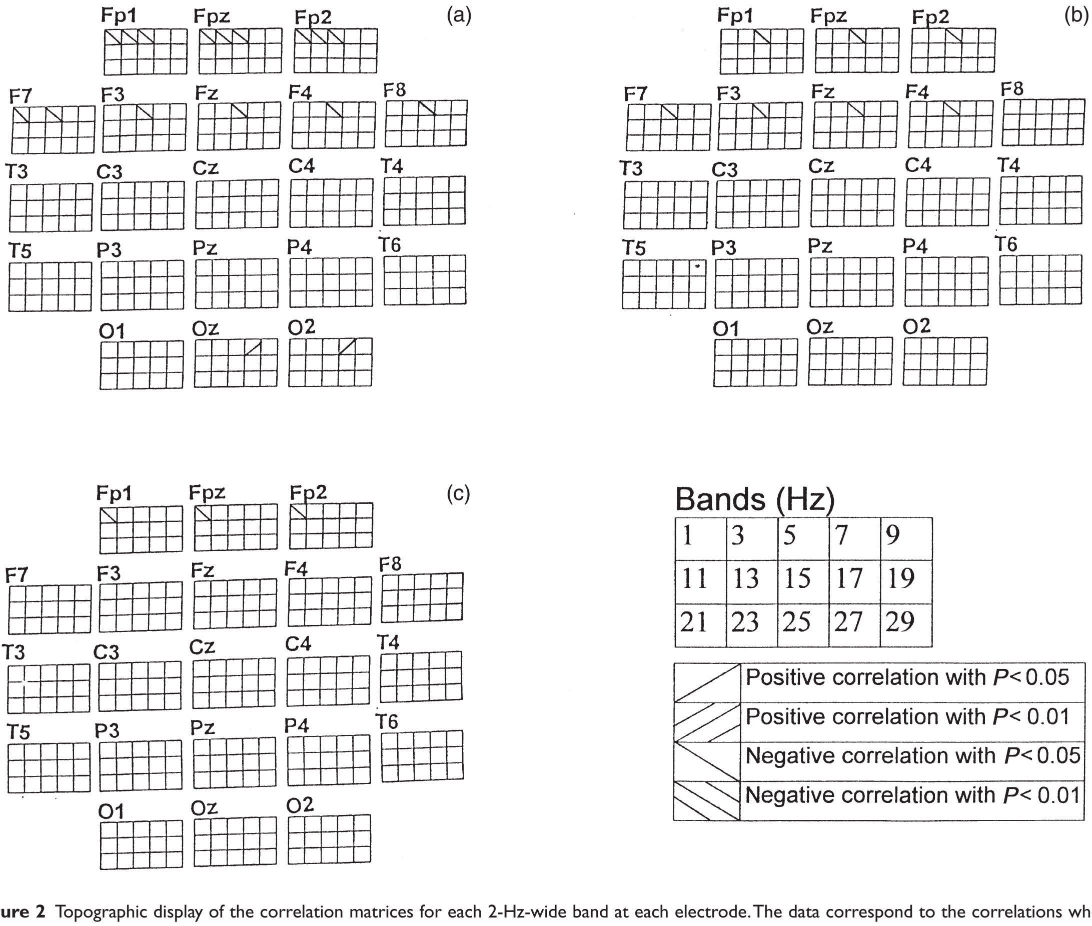

Figure 2 Topographic display of the correlation matrices for each 2-Hz-wide band at each electrode. The data correspond to the correlations where (a) Full-Scale IQ, (b) Verbal IQ and (c) Performance IQ were the intellectual variables. Correlations with $P < 0.05$ correspond to a Pearson's r of 0.20–0.30. Correlations with $P < 0.01$ correspond to a Pearson's r of 0.30–0.40.

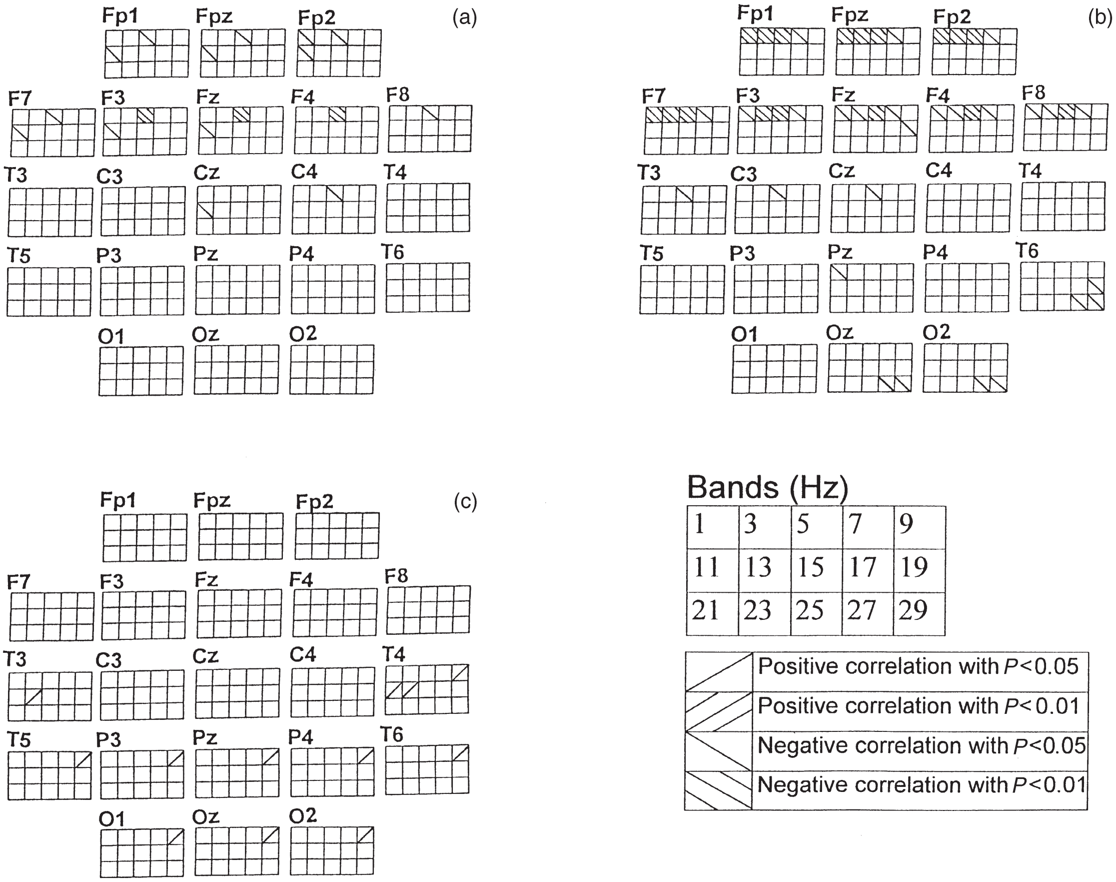

Figure 3 Topographic display of the correlation matrices for each 2-Hz-wide band at each electrode. The data correspond to the correlations where (a) Information, (b) Comprehension and (c) Arithmetic were the intellectual variables. Correlations with $P < 0.05$ correspond to a Pearson's r of 0.20–0.30. Correlations with $P < 0.01$ correspond to a Pearson's r of 0.30–0.40.

frontal regions. Comprehension (Fig. 3b) shows a high number of correlations, all of them of negative and mainly involving low frequency bands (from 1 to 7 Hz, mainly 5 Hz) over the frontal regions. Another group of correlations for Comprehension involved the right temporo-occipital regions and the highest (27 and 29 Hz) frequency bands. Correlations for Arithmetic (Fig. 3c) were positive, involved the posterior regions and collapsed at the 9 Hz band, although over correlations extended beyond the 13 Hz band in the T4 region.

Inverted Digits (Fig. 4a, top left) also presented positive correlations, but over the left temporal (T5) region in the 13–29 Hz bands. Figure 4b shows the results corresponding to Vocabulary. For this subtest, negative correlations were found at 1 and 5 Hz over the fronto-polar electrodes. Similarities (Fig. 4c) showed a pattern consisting of negative correlations in low-frequency bands (from 1 to 5 Hz, mainly the latter) limited to the frontal regions.

Picture Completion (Fig. 5a) showed positive correlations involving the 9 Hz band with a distribution mainly in the central areas, but also implying the posterior frontal, temporal and parietal regions. Picture Arrangement (Fig. 5b) showed a high number of negative correlations mainly involving the lowest frequency bands (1–7 Hz), especially 1 and 5 Hz. The regions showing correlations with this test were extensive, but the frontal areas were

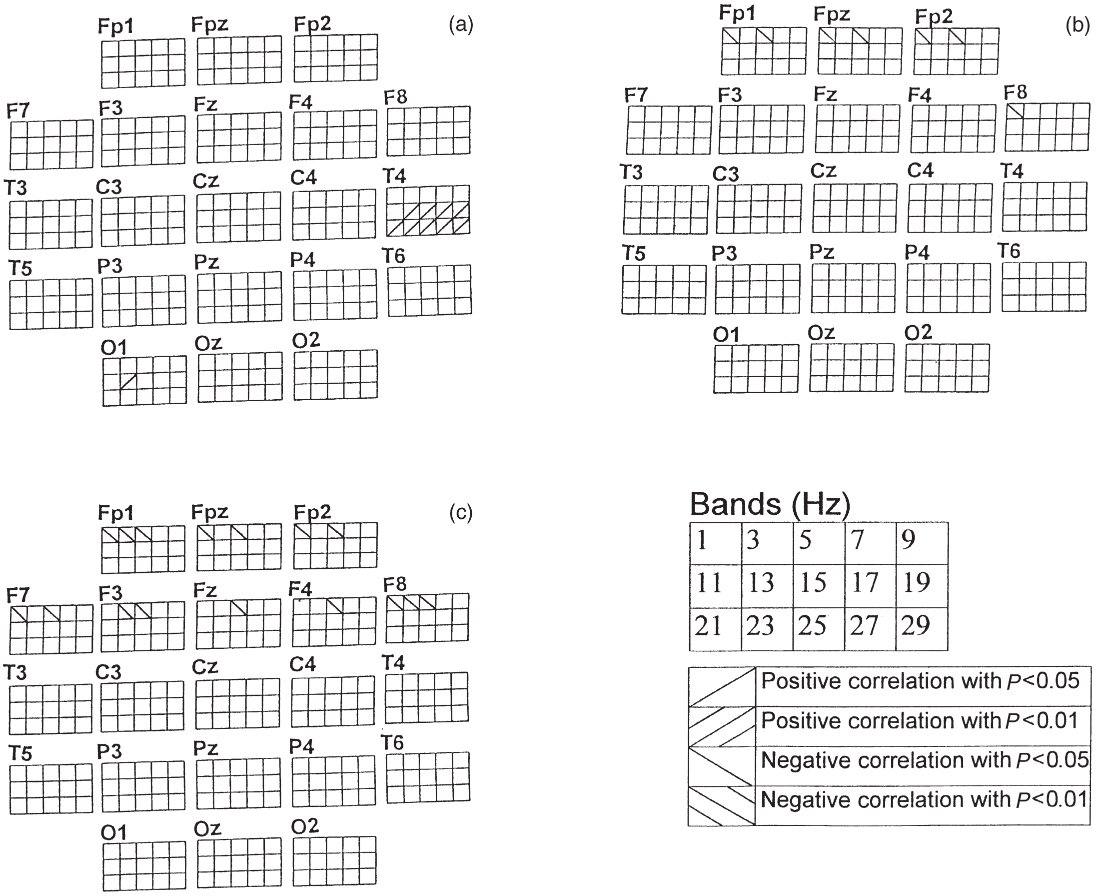

Figure 4 Topographic display of the correlation matrices for each 2-Hz-wide band at each electrode. The data correspond to the correlations where (a) Inverted Digits, (b) Vocabulary and (c) Similarities were the intellectual variables. Correlations with $P < 0.05$ correspond to a Pearson's r of 0.20–0.30. Correlations with $P < 0.01$ correspond to a Pearson's r of 0.30–0.40.

the most affected. Figure 5c shows correlations corresponding to Block Design, which were negative over the posterior regions (mainly occipital) and involved the highest frequency bands (23–29 Hz). Object Assembly and Mazes did not show any significant correlation, whereas Direct Digits yielded a few positive correlations at O1, Oz, O2 and T6 in the 1 Hz band, and Coding only implied two positive correlations at the 15 and 17 Hz bands over left temporal electrode (T3). For these reasons, no correlation matrix is displayed for these subtests.

Discussion

The results of present study have major implications for our knowledge about the differential role of cortical regions in intellectual functions, and especially, for their degree of affectation and involvement in ID. However, because this kind of study could yield an extensive amount of comments and discussion, only the most remarkable findings and implications are discussed here.

Firstly, it should be noted that the frontal poles, measured by the F1, Fp2 and Fpz electrodes, showed the highest number of correlations across the IQ scales and subscales. These correlations were always negative and involved the lowest frequency bands. This is striking since Giannitrapani (1985) showed that these regions are among those with the smallest number of significant correlations with intellectual functions in the normal population. The above author's subjects differed slightly from those

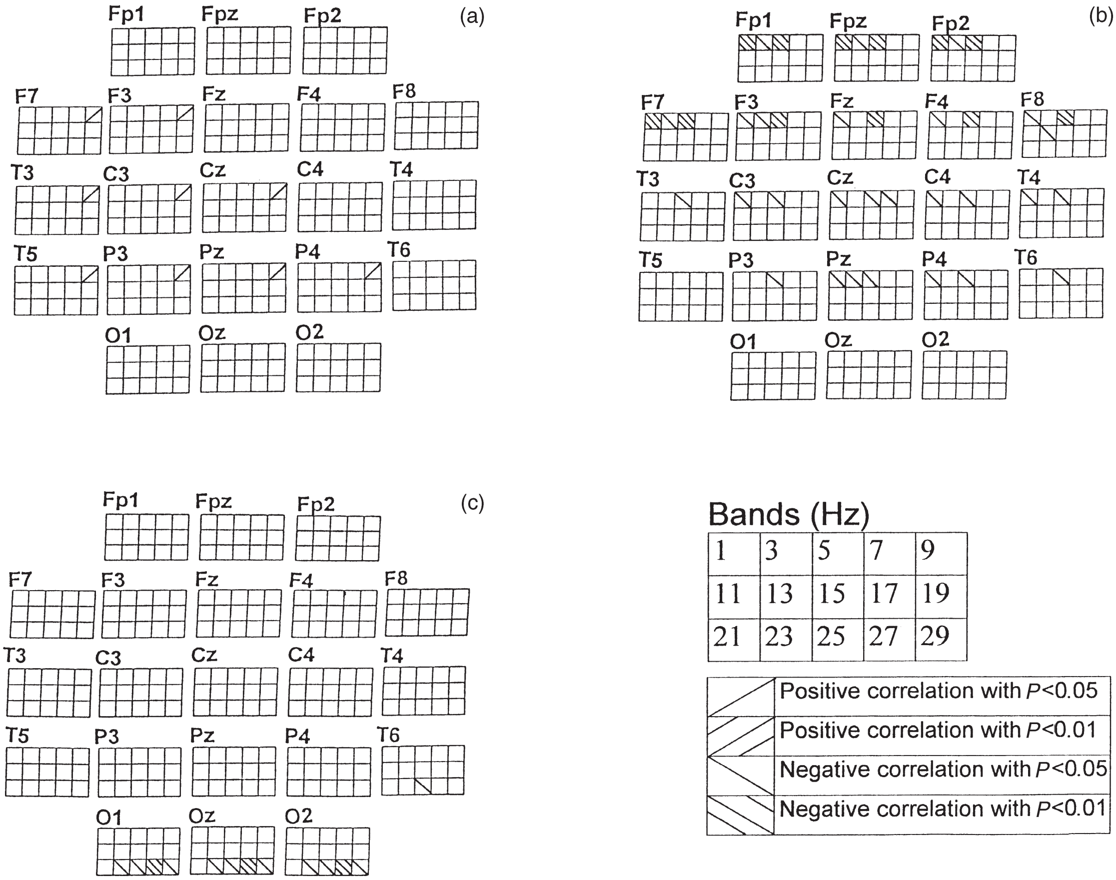

Figure 5 Topographic display of the correlation matrices for each 2-Hz-wide band at each electrode. The data correspond to the correlations where (a) Picture Completion, (b) Picture Arrangement and (c) Block Design were the intellectual variables. Correlations with $P < 0.05$ correspond to a Pearson's r of 0.20–0.30. Correlations with $P < 0.01$ correspond to a Pearson's r of 0.30–0.40.

in the present study in terms of chronological age, although the current sample included subjects of the same age as those in Giannitrapani's (1985) work. In any case, slight age differences are an implausible explanation for these remarkably qualitative differences in the patterns of correlations between the two studies. Actually, the frontal poles were the areas exclusively (or almost exclusively) involved in the correlations with Performance IQ, Vocabulary and Coding. This heterogeneity in the type of task involved would confirm that these areas, usually termed as prefrontal cortex, have a multipurpose role, i.e. they are involved in many types of tasks. This statement would be completely in line with their classical role as overall controlling areas, necessary for tasks requiring a delay, elaborate anticipations, or the programming of a sequence of movements or acts (Kolb & Wishaw 1995). Nevertheless, it remains difficult to explain their involvement in a task such as Vocabulary unless their proximity to areas related to verbal working memory processes is evoked (Paulesu *et al.* 1994).

On the other hand, the whole frontal region, including the frontal poles, was commonly involved in correlations in many instances. In fact, the frontal regions as a whole were the brain areas which showed the majority of the correlations in the present study. As with the frontal poles, the correlations over the frontal regions as a whole were always negative and mainly involved the lowest frequency bands. This group of correlations between the low-frequency bands and the frontal regions could be found to a greater or lesser extent for Full-Scale IQ, Verbal IQ, Information, Comprehension, Similarities and Picture Assembly. Accordingly, the frontal regions as a whole are again involved in tasks involving heterogeneous demands, with a particular incidence of those requiring verbal abilities or planning behaviour. With the exception of the involvement of the frontal poles, the present results are very much in accordance with Giannitrapani's (1985) findings regarding intellectual functioning in normal subjects .

Taken together, these results relating to the frontal regions (frontal poles included) confirm the classical view of the implication of these areas in many types of higher cognitive functions (Feuerstein *et al.* 1997; Fuster 1997), and according to the present data, these areas probably play a major and critical role in ID. This is especially true given that the highest number of correlations involved the frontal poles which have been considered to be the most unspecific overall controlling areas within the frontal lobes (Niedermeyer 1998). As mentioned above, these regions scarcely correlate with intelligence in normal subjects (Giannitrapani 1985). Therefore, according to the present results, something specific for subjects with ID should be ascribed to these areas. Thus, it does not seem implausible to assert that a direct or indirect impairment of the frontal (mainly prefrontal) regions might be the basis for ID, regardless of aetiology. The impairment of a multipurpose area such as the prefrontal lobes would be likely to accompany the intellectual impairment underlying ID.

The lowest frequency bands have been supposed to reflect structural and/or metabolic damage to the brain (Martín-Loeches *et al.* 1993; Sharbrough 1993; Saletu 1997). Nevertheless, the present results do not rule out the possibility that the actual damage has taken place, not at the frontal cortex itself, but in the underlying white matter or thalamo-cortical connections (Barlow 1993; Gloor *et al.* 1977). Therefore, the data would be better interpreted as showing that commonly or very frequently affected sites in the brains of subjects with ID are either the frontal lobes, mainly the prefrontal portions, or the thalamo-cortical pathways to these regions. Interestingly, this latter possibility would be, to some extent, in accordance with Yokochi & Fujimoto's (1996) report of lesions on the periventricular white matter and the thalamus in children with ID caused by neonatal asphyxia. The highest proportion of the present subjects suffered perinatal anoxia, but although they represented the largest group, these individuals were not in the majority; therefore, the present population was far from potentially being labelled as anoxic subjects. Therefore, it seems that the data reported by Yokochi & Fujimoto (1996) can be extrapolated to other populations of subjects with ID.

An alternative or even complementary possibility might be that the areas mainly affected in ID are not the frontal or prefrontal areas, but that the latter are subsequently affected by diaschisis to some degree. In fact, lesions in many cortical or subcortical areas have been found to affect frontal regions by diaschisis, as in the case of the lenticular nucleus (Giroud *et al.* 1997), the cerebellum (Botez-Marquard & Botez 1997), the pons (Blazquez *et al.* 1995) and the thalamus (Casado *et al.* 1995), for example. All in all, the present results indicate that further research is needed on functional neuro-imaging of the prefrontal lobes in subjects with ID.

As mentioned above, most of the correlations involved the lowest frequency bands (1–7 Hz). Classically, the division within this range has been between the delta (0.5–3 Hz) and the theta (3–7 Hz) bands, and different types of lesions have even been ascribed to each of these bands (e.g. delta activity seems to be specifically sensitive to brain tumours). Nevertheless, the low-frequency waves in the present study neither correlated as a block nor corresponded with the classical divisions. Indeed, the most important bands seemed to be 1 and 5 Hz, which are only elements of the delta and theta bands, respectively. These data indicate that future research should be undertaken to elucidate which concrete lesions or dysfunctions reflect each of these 2-Hz-wide bands.

It should be mentioned that, although the main results appeared to be confined to the frontal or prefrontal regions for the majority of the tasks, there were also a few subtests which showed specific or exclusively affected regions. This was the case for Arithmetic, where positive correlations were found in the posterior, mainly central and temporal regions of the scalp, partially resembling the data reported by Giannitrapani (1985) for normal subjects, but involving a lower-frequency band (over 13 Hz in the above author's study and 9 Hz in the present work).

Block Design was another subtest that encompassed specific areas, mainly the occipital and right temporo-parietal regions, where negative correlations involving the highest frequencies were found. This is striking because it would imply that, the higher the voltage at these bands over these regions, the worse the performance in Block Design, which would be at variance with most expected amplitude increases for these frequencies during cognitive tasks (e.g. Petsche *et al.* 1986). However, it must be mentioned that an abnormal increase of the highest frequencies has been observed in several other psychiatric pathologies, such as depression, alcoholism or schizophrenia, and has been interpreted as reflecting a cognitive deficit particularly related to attentional aspects if the distribution is mainly over posterior regions (Ray & Cole 1985; Gruzelier & Liddiard 1989; John *et al.* 1989), which could be advanced to explain the present findings.

Digit tasks also implied specific brain areas. Direct Digits involved the occipital and right temporal areas, whereas Inverted Digits encompassed the left temporal regions. The strong difference between Direct Digits and Inverse Digits with regard to involved areas is a clear indication that both tasks imply notably different operations, i.e. that both are not merely differing in the degree of difficulty. However, both are computed together for the total punctuation of Digit Span in the WISC test. Perhaps they should be considered separately, as was done in the present study. However, this division was not performed for normal children by Giannitrapani (1985).

Finally, another set of interesting findings are related to what could be named as the dominant frequency. Giannitrapani (1985) found that the most of the correlations were around the 11 or 13 Hz bands, mainly the later. This was considered to be related to the dominant alpha frequency and served to reinforce the importance of these frequencies in normal subjects. This was not the case in the present study, where the pattern of correlations was different, mainly involving bands which could not be considered as pertaining to dominant frequencies. However, on a few occasions, correlations occurred around the alpha range, the most systematic examples being in the 9 Hz band. This might indicate that, whereas the dominant frequency surrounds the 13 Hz band in normal subjects, a decrease to about 9 Hz seems to take place in subjects with ID. These assumptions are confirmed in Fig. 1, where subjects with mild ID showed their dominant activity (considered as the slight increase of power breaking the asymptotic curve of power decrease with increasing frequency) at 9 Hz, whereas the subjects with severe ID showed it at 7 Hz. These findings would also be in line with the well-known slowing of the alpha rhythm in the presence of a disease or altered brain function (Barlow 1993), and would be in agreement with the data by Osaka & Osaka (1980) in the sense of a disappearance of the dominant 13 Hz peak activity in subjects with ID.

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