THE ROLE OF FRONTAL LOBES IN SUSTAINED ATTENTION

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KLJUČNE BESEDE: dolgotrajna koncentracija, čelni reženj, nevropsihologija

POVZETEK

Tema, ki jo tukaj obravnavam, se uvršča med študije s področja nevropsihologije. V prvem delu sem osvetlil - ob nekaterih nevropsiholoških raziskavah, ki ponazarjajo vlogo čelnih reinjev pri dolgotrajni koncentraciji -, tudi psihofiziološke študije, ki opisujejo višanje krvnega obtoka predvsem v čelnem režnju desne možganske poloble, medtem ko bolnik rešuje več posebnih testov za koncentracijo.

V drugem delu raziskave pa sem poudaril dejstvo, da če ne vemo, ali je dolgotrajna koncentracija vedno sad delovanja desnega čelnega režnja. Vprašal sem se, ali ima desni čelni reženj isto vlogo pri posebnih testih za dolgotrajno koncentracijo, in sicer pri tistih testih, kjer mora biti vsakdo izmed nas dalj časa pozoren na določene znake in ne upošteva drugih. Raziskave s psihofiziološkega področja so že poudarile pomen desnega čelnega režnja tudi pri reševanju teh posebnih testov za dolgotrajno koncentracijo, vendar ne poznamo nobenega nevropsihološkega dela, ki bi prišlo do istih zaključkov.

Na računalniku sem sestavil nov nevropsihološki test, da bi ugotovil, če se dognanja s tega področja popolnoma skladajo z rezultati psihofizioloških raziskav. Test je sestavljen iz dveh delov: prvi del obravnava dolgotrajno koncentracijo pri vidnem sistemu, drugi del pa pri slušnem sistemu. Poleg nevropsihološkega testa, ki sem ga sestavil, sem nevrološkim bolnikom predstavil tudi standardizirane teste za druge frontalne možganske funkcije. Testiral sem bolnike, ki imajo poškodbo v enem samem možganskem režnju. Vse paciente sem na podlagi možganske poškodbe razdelil v štiri skupine. Nazadnje sem vse skupine primerjal na podlagi odgovorov na vse nevropsihološke teste.

Velika novost moje nevropsihološke raziskave je v tem, da je v njej prvič napisano, da je desni čelni reienj odgovoren za dolgotrajno koncentracijo tudi pri tistih nalogah, pri katerih moramo biti pozorni na določene signale in ignorirati druge. V študiji se je izkazalo, da se je število točnih odgovorov na nov test nižalo le pri bolnikih s poškodbo v desnem čelnem režnju, medtem ko so preostali nevrološki bolniki pri istem testu dokazali primerno stopnjo koncentracije. Bolniki z desno čelno poškodbo nekaterih znakov niso mogli ne upoštevati, in so zato dalj časa opazovali vse signale.

Druga novost je v tem, da so bili odgovori vseh bolnikov točnejši, ko sem na ekranu prikazoval signale s hitrostjo 1 Hz (Wilkins, Shallice in McCarthy so leta 1987 prišli do različnih zaključkov).

Rezultati, do katerih sem prišel na nevropsihološki osnovi, se popolnoma skladajo z zaključki, ki so jih drugi raziskovalci opisali s pomočjo psihofizioloških metod: študije s psihofiziološkega področja poudarjajo, da gre pri dolgotrajni koncentraciji kri v ista območja čelnih režnjev bodisi pri vidnem ali pri slušnem sistemu; v svojem delu pa sem dokazal, da poškodbe v prednjem možganskem predelu negativno vplivajo na dolgotrajno koncentracijo pri obeh omenjenih čutnih sistemih.

INTRODUCTION

A peculiar kind of attention is sustained attention often also called vigilance. Dimond and Beaumont (Dimond and Beaumont, 1971; Dimond and Beaumont, 1973) after a series of experiments, explained the different role of cerebral hemispheres in vigilance tasks. According to these authors, the left hemisphere, which plays a major role at the beginning of a vigilance task, has a decreasing performance, whereas the right hemisphere, which plays a minor role at the beginning of such a task, has a stable performance. Such findings were confirmed by Salmaso (1980). Indeed, lesions to the right hemisphere are overall a major cause of attentional disorders and can entail an increasing reaction latency before a verbal or motor response in vigilance tasks (Yokoyama, Jennings, Ackles, Hood and Boller, 1987) and even a reaction of indifference toward the disorder.

Among focal brain lesions, frontal lesions seem to produce more clearly a decreasing performance in vigilance tasks. Salmaso and Denes (1982) found that patients with such lesions are very vulnerable when they are asked to make a distinction between a signal and a noise: in fact, frontal patients have low capacity to discriminate the two categories of stimuli and can't find any signal (target). This would show that frontal regions are directly involved in target detection tasks. Such findings were confirmed in the first investigation on sustained attention involving patients with frontal lobe lesions (Wilkins, Shallice and McCarthy, 1987). Mennemeier, Chatterjee, Watson, Carter and Heilman (1994) also pointed out that the frontal and parietal cortices seem to have a major, even though different, role in adjusting sustained attention to the stimuli coming from the surrounding environment (such an adjustment is probably mediated by nerve fibers connecting frontal and parietal regions). Godefroy, Cabaret and Rousseaux (1994), on the other hand, demonstrated that frontal patients do not show a sustained attention deficit, in fact patients' errors on the vigilance test do not increase with the test duration.

PET (Positron Emission Tomography) has recently given a major contribution to the analysis of anatomic-physiological correlation in sustained attention (Cohen, Semple, Gross, Holcomb, Dowling and Nordahl, 1988; Pardo, Fox and Raichle, 1991). Posner, Petersen, Fox and Raichle (1988) in particular showed how sustained attention is mediated by an increased blood flow in the right hemisphere frontal regions, i. e. the right frontal lobe is activated when subjects are invited to carry out the go/no go paradigm and they have to draw their attention to target stimuli to which distraction elements are added.

In this article, we aim at:

- providing further evidence for or against the superiority of the right frontal lobe for tasks requiring both visual and auditory sustained attention;
- identifying hemispheric specialization in tasks involving the go/no go paradigm for visual and auditory stimuli; in particular a replication is seeked of data coming from recent PET studies.

In order to pursue these aims, a technique similar to that used by Wilkins et al. (1987) will be used. This technique requires that the patients count stimuli that are presented at a given rate. This task was meant to assess the integrity of sustained attention function, mediated by the working of the anterior attention system: Wilkins et al. argued in fact that if stimuli are presented at a low rate (i. e. at 1 Hz), the task would be very monotonous, and the patient's performance would be good only if he/she decides voluntarily to draw his/her attention to the task. When the patient would be unable to draw his/her attention to the stimuli, he/she may behave in one of the following ways:

- stop counting;
- keep counting after the end of stimuli;
- have difficulties in synchronizing counting with stimuli.

On the contrary, at a high rate, the patient would be automatically forced to draw his/her attention to stimuli, therefore he/she would avoid to draw voluntarily his/her attention to the task and perform better. Wilkins et al. indeed found that the performance of frontal lobe patients is worse when the stimuli are presented at the rate of 1 Hz, while their performance is better at higher presentation rates.

SUBJECTS

For this experiment, we have tested 36 patients with unilateral and unifocal frontal or parietal lesions coming from the Motor and Functional Reconditioning Unit of the "Santorio Santorio" and "Maggiore" Hospitals of Trieste, from the Neurological Unit of the "Maggiore" Hospital and from the

Neurosurgical Unit of the "Cattinara" Hospital. The aetiology of the lesion was: head trauma (in 8 cases), brain tumors (9 including meningiomas, 12 astrocitomas and 2 oligodendrogliomas) and vascular damages (1 including anterior communicating artery aneurysm rupture, 2 ischemic lesion and 2 cerebral hemorrhage). CAT scans showed cortical damage in all cases, sub-cortical structures not being significantly involved. Four groups were formed according to the brain lesion site:

- left frontal (6 males and 3 females);
- right frontal (5 males and 5 females);
- left parietal (5 males and 4 females);
- right parietal (5 males and 3 females).

Table 1. Details of the sex, age, educational level (in years) and aetiology of the patients participating in this study. The standard deviations are shown in parentheses after the means.

Patient group	M/F N=36	Age	Educational level	Aetiology
Left frontal	6/3	43.9 (11.5)	11.4 (2.5)	brain tumors (4 cases) head trauma (2 cases) vascular damages (3 cases)
Right frontal	5/5	42.4 (12.1)	11.8 (3.3)	head trauma (4 cases) brain tumors (6 cases)
Left parietal	5/4	45.4 (15.3)	9.7 (1.6)	brain tumors (6 cases) head trauma (1 case) vascular damages (2 cases)
Right parietal	5/3	38.4 (13.8)	9.9(1.8)	brain tumors (7 cases) head trauma (1 case)

With reference to the control group, including patients with posterior cortical lesions, we haven't chosen patients with temporal and occipital cortex lesions because in our investigation we have presented to patients visual and auditory stimuli that, as we know, respectively reach the occipital and temporal lobes.

All the subjects we have tested during this experiment were right-handed individuals, and some of them, during the whole test, were wearing glasses to avoid any difficulty in visual stimuli detection. Both hospitalized patients and patients coming daily to the hospital for functional reconditioning have always been tested in the morning (from about 09.00 a. m. to about 12.30 a. m.).

The results from the brain damaged groups were compared to those from age - and education - matched normal subjects.

MATERIALS AND METHODS

We have used a vigilance task designed by the True Basic program. Such a task lasts about 20-30 minutes and it presents both visual and auditory stimuli.

With reference to visual stimuli, a small square with a black border 7 mm long, and a double square (one inside the other), the outer square having a black border 7 mm long, were displayed. All these stimuli were displayed in a succession at the centre of an Apple Powerbook 170 portable computer screen, on a white background.

With reference to auditory stimuli, a 500 Hz sound and a 700 Hz sound were produced by the same computer using Sony stereo headphones. Sounds were produced in a succession. Headphones were used to try to minimize the influence of any sound or noise in the surrounding environment, which could affect the subjects' performance. Such a computer can produce mid-intensity sounds (on Powerbook 170 a sound intensity scale is available and we have chosen the 4th step: on this computer, 0 stands for the absence of sound and 7 stands for the maximum intensity). Visual and auditory stimuli (which are never mixed together) were presented in a succession according to different patterns: the shortest pattern is composed by 3 stimuli, whereas the longest one by 11 stimuli (obviously, patients were not told that the minimum number is 3 and the maximum number is 11). Globally, 9 series of stimuli were presented. The patient had to count the stimuli he/she was presented in each train and report, at the end of each train (when the word "Answer" is displayed by the computer) the number of stimuli he/she had counted from the beginning of the train until the end.

Visual and auditory stimuli were presented at two different rates, i. e. at 1 Hz and at 3 Hz: the 1 Hz rate is also used in the investigation of Wilkins et al. (1987), whereas the 3 Hz rate has been chosen because, in our opinion, it is more suitable to carry out a check on the 1 Hz rate (rates exceeding 3 Hz, in our opinion, are too fast to obtain a successful counting of all the stimuli which are presented to the patient). At the 1 Hz rate, the task is slow and very monotonous, hence the subject is bound to draw voluntarily his/her attention to the task to be able to report the number of squares or sounds he/she has counted at the end of the train, whereas at the 3 Hz rate the task is more lively and the subject is not bound to draw voluntarily his/her attention to the stimuli (Wilkins, Shallice and McCarthy, 1987).

Both visual and auditory stimuli were presented with different patterns under three different conditions:

- regular condition;
- irregular condition;
- condition with alternate stimuli.

The regular condition is chosen to confirm the findings obtained by Wilkins, Shallice and McCarthy (1987).

The irregular condition is taken into account to investigate how the subject's expectation about the moment when a stimulation should appear can affect the vigilance test.

The condition with alternate stimuli has been included in our experiment to identify any inter-hemisphere specialization for the go/no go paradigm applied to the vigilance test. Salmaso and Denes (1982) pointed out a special involvement of frontal regions in the go/no go paradigm, whereas we, throughout our experiment, have tried to find any brain lateralization under the condition with alternate stimuli.

All the patients (but only the patients) were submitted both the vigilance test and some neuropsychological frontal damage-sensitive tests, in order to identify any interhemisphere specialization for those tests. Such tests, which were all carried out in 20-30 minutes, could precede the vigilance test we have designed or follow it (the moment on which tests were carried out was randomized to avoid any sequence effects, hence some patients could be submitted to the vigilance test and then to the neuropsychological tests, some others could be submitted to the neuropsychological tests and then to the vigilance test).

The neuropsychological tests the patients have been submitted to are:

- Luria's test (Semenza and Cipolotti, 1993);
- Analogies (WAIS's verbal sub-test);
- Proverbs (sub-test of verbal judgement test, drawn from the collection of Neuropsychological Tests by Spinnler and Tognoni, 1987);
- Repetition of written sequences of signs (Semenza and Cipolotti, 1993);
- Cognitive estimates (Shallice and Evans, 1978).

All the patients were submitted to the aforementioned tests in a randomized order, which has always changed for all the subjects. Neverthless, three different randomized tasks were presented to the patients before the vigilance test:

- Counting of numbers from 1 to 20 (to assess if the patient could count the stimuli which were to be presented during the vigilance test);
- Memorization of numbers (WAIS's sub-test) because we did not want the patient to forget the number of stimuli he/she had already counted during the vigilance test;
- Visual and auditory distinction (because under the condition with alternate stimuli, the patient should be able to make a distinction between two kinds of stimuli).

HYPOTHESIS

1. In all the groups we have examined there should be no significant difference of performance with reference to visual and auditory stimuli (i. e. the performance under a regular condition with visual stimuli should not be different from the performance under a regular condition with auditory stimuli): PET has shown that an increasing blood flow is present in the same regions during visual and auditory stimuli;

2. In all the groups we have examined, at the 1 Hz and 3 Hz rates, the condition with alternate stimuli should give the best performance, followed by the regular condition and by the irregular condition.

Under the condition with alternate stimuli, the small number of stimuli to be counted, the task liveliness and the subjects' expectation about the moment on which the stimuli should appear (intervals between the stimuli are constant) should simplify the task.

Under the regular condition, there is a subjects' expectation about the moment on which the stimuli should appear, but the number of stimuli to which attention should be drawn is higher (than under the previous condition) and the task is monotonous.

Therefore, under the regular condition, the subjects' performance should be worse.

Under the irregular condition, the lack of expectations about the moment on which the stimuli should appear and the high number of stimuli to which attention must be drawn should be the cause of an increasing number of mistakes.

3. When visual and auditory stimuli are presented at a 1 Hz rate, the performance of right frontal patients under a regular condition should be significantly worse than the performance of all the other groups (according to the findings of the experiment of Wilkins, Shallice and McCarthy, 1987);

4. Under the regular condition, when visual and auditory stimuli are presented at a 3 Hz rate, the right frontal patients should perform better than under a 1 Hz rate condition: at a 3 Hz rate the task should make them automatically draw their attention, because it is lively (Wilkins et al., 1987);

5. With reference to neuropsychological tests (Luria's test, Analogies, Proverbs, Repetition of written sequences of signs, Cognitive estimations), the performance of frontal patients should be worse.

EXPERIMENT 1

Before submitting all the groups to the vigilance test, we have carried out a pilot-experiment on normal subjects belonging to different age groups, for three reasons:

- to observe if age can affect the results of our vigilance test to which different patients are submitted;
- to include, if necessary, in our vigilance test only the patients belonging to a specific age group;
- to identify the most suitable age of the control group patients to compare them with all the groups of patients.

Subjects

Our pilot-experiment has taken into account five different age groups and, within each age group, the subjects are compared on the basis of their school-years and sex (we wished to obtain balanced groups, including the same number of males and females). The five groups were the following:

- twenty-year old subjects (12 subjects: 6 males and 6 females);
- thirty-year old subjects (12 subjects: 6 males and 6 females);
- forty-year old subjects (12 subjects: 6 males and 6 females);
- fifty-year old subjects (12 subjects: 6 males and 6 females);
- sixty-year old subjects (12 subjects: 6 males and 6 females).

Statistical analysis

For each group of subjects, we have carried out (by means of a variance analysis by groups of Ray Meddis) a factorial design. We have manipulated the following two independent variables:

- rate of stimuli during the test;
- type of condition.

The first independent variable has two levels (1 Hz and 3 Hz), whereas the second one has three levels (regular condition, irregular condition and condition with alternate stimuli). The dependent variable is represented by the number of right answers given by the subjects under the various conditions and at different rates of stimuli during the vigilance test.

Results

Within the 5 groups, our findings were the following:

- the whole vigilance test gives a better performance at a slow rate (1 Hz) than at a high rate (3 Hz);
- the condition with alternate stimuli gives significantly better results than the regular and the irregular condition;
- the interaction between the 2 independent variables is not significant.

Discussion

The factorial designs of each group of subjects show that, usually, the performance is simpler during the vigilance test when the subjects are presented stimuli at a low rate (1 Hz) and when they are under a condition with alternate stimuli (the interaction between independent variables is not significant).

Each group of subjects does not show a significant difference between visual stimuli and auditory stimuli. Such findings confirm the results obtained from PET for vigilance tasks. PET points out that the same brain regions are activated during the subjects' sustained attention for both sensory stimuli.

Since (under the various conditions, for the various sensory stimuli, at different rates of stimuli) no significant difference of performance is recorded for subjects having a different age, we can include in our control group (to be compared with four groups of patients) subjects having different ages. We have included in our control group subjects others than those included in our pilot-experiment. They are compared on the basis of their school-years. Of course, we have tried to obtain, as far as possible, a similar age distribution in all groups.

EXPERIMENT 2

In this experiment we have tested four groups of patients and a control group.

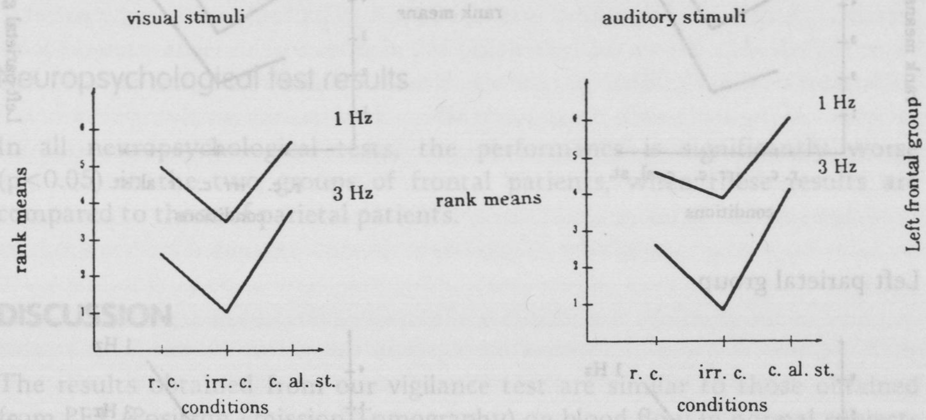
VIGILANCE TEST RESULTS

In all the groups taken into account, the performance is significantly better at a 1 Hz rate (for visual stimuli: $Z = 4.346$, $p < 0.001$; $Z = 3.505$, $p<0.001$; $Z = 4.217$, $p<0.001$; $Z = 4.097$, $p<0.001$; $Z = 5.327$, $p<0.001$; for auditory stimuli: $Z = 5.451$, $p<0.001$; $Z = 3.547$, $p<0.001$; $Z = 5.051$, $p<0.001$; $Z = 4.837$, $p<0.001$; $Z = 5.126$, $p<0.001$);

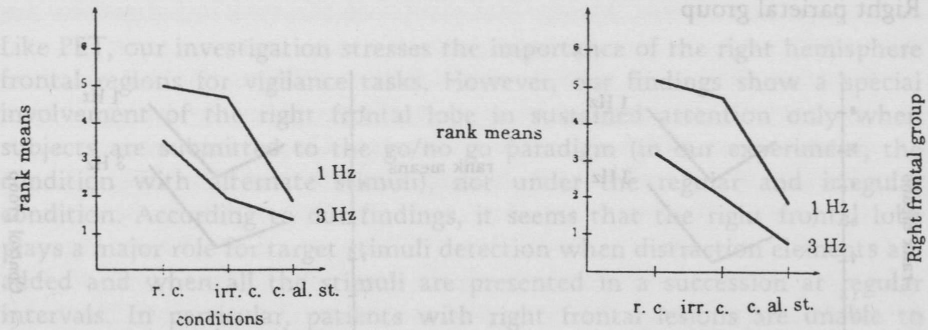
In left frontal, left parietal, right parietal and normal subjects, the performance is significantly better under the condition with alternate stimuli (for visual stimuli: $Z = 4.511$, $p<0.001$; $Z = 4.116$, $p<0.001$; $Z = 4.214$, $p<0.001$; $Z = 4.315$, $p<0.001$; for auditory stimuli: $Z = 3.159$, $p<0.001$; $Z = 3.195$, $p<0.001$; $Z = 3.988$, $p<0.001$; $Z = 4.977$, $p<0.001$), whereas in the right frontal subjects the condition with alternate stimuli gives significantly worse results (for visual stimuli: $Z = 5.752$, $p<0.001$; for auditory stimuli: $Z = 5.517$, $p<0.001$);

The interaction between variables is not significant (for visual stimuli: $Z = 1.497$, $p>0.05$; $Z = 1.357$, $p>0.05$; $Z = 1.349$, $p>0.05$; $Z = 1.253$, $p>0.05$; $Z = 1.133$, $p>0.05$; for auditory stimuli: $Z = 1.177$, $p>0.05$; $Z = 1.006$, $p>0.05$; $Z = 1.164$, $p>0.05$; $Z = 1.053$, $p>0.05$; $Z = 1.226$, $p>0.05$).

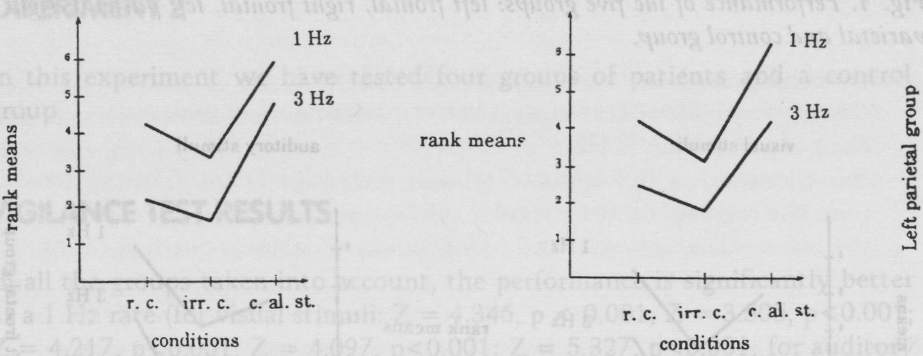
Fig. 1. Performance of the five groups: left frontal, right frontal, left parietal, right parietal and control group.



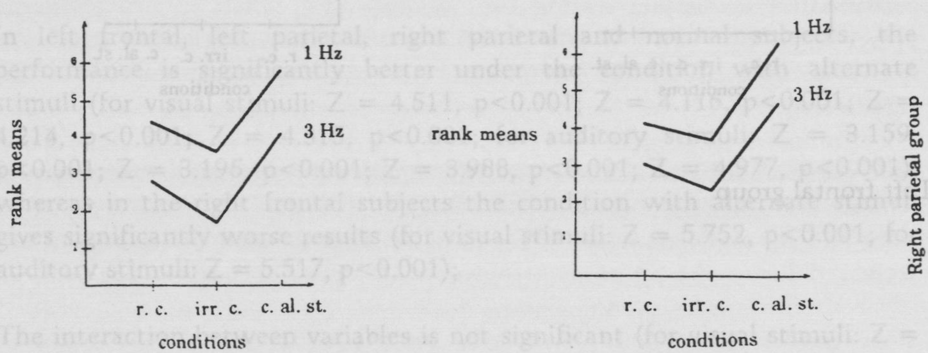
Left frontal group



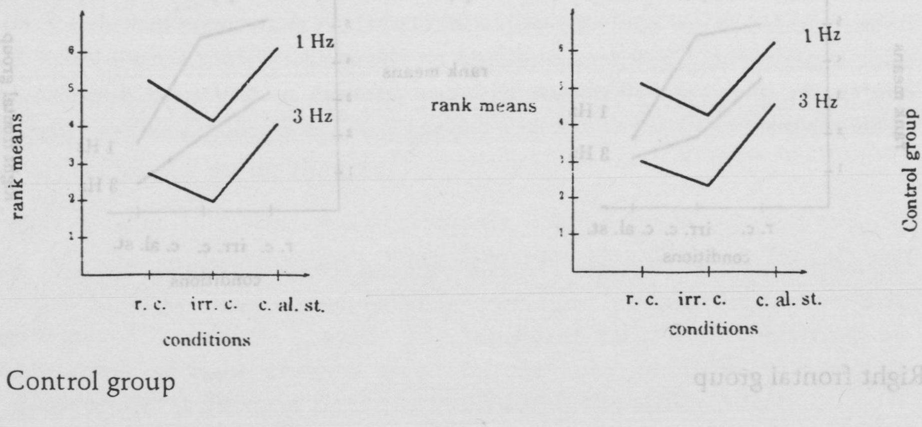
Right frontal group



Left parietal group



Right parietal group



Control group

When we compare all the subject groups, the only significant difference which results from this comparison refers to the condition with alternate stimuli (the results under this condition are significantly worse for the right frontal group).

Neuropsychological test results

In all neuropsychological tests, the performance is significantly worse ($p<0.05$) in the two groups of frontal patients, when these results are compared to those of parietal patients.

DISCUSSION

The results obtained from our vigilance test are similar to those obtained from PET (Positron Emission Tomography) on blood flow in normal subjects and to the data obtained, in the neuropsychological field, from patients with brain lesions. On one hand, our experiment does not show any difference in subjects' performances with reference to visual and auditory vigilance (both in normal subjects and patients with brain lesions). On the other hand, PET shows an increasing blood flow in the same brain regions both for visual and auditory sustained attention. Therefore, a damage to these regions would provoke a disorder of sustained attention both from a visual and an auditory point of view, with no distinction between visual and auditory stimuli.

Like PET, our investigation stresses the importance of the right hemisphere frontal regions for vigilance tasks. However, our findings show a special involvement of the right frontal lobe in sustained attention only when subjects are submitted to the go/no go paradigm (in our experiment, the condition with alternate stimuli), not under the regular and irregular condition. According to our findings, it seems that the right frontal lobe plays a major role for target stimuli detection when distraction elements are added and when all the stimuli are presented in a succession at regular intervals. In particular, patients with right frontal lesions are unable to inhibit the answers evoked by noise stimuli and, consequently, they count all the stimuli they are presented (under the condition with alternate stimuli).

This behaviour was found in eight right frontal patients out of ten, and in two left frontal patients out of nine (the comparison between left and right frontal patients is significant from a statistical point of view, hence the go/no go paradigm gives significantly worse results for right frontal patients). A deficit of this kind was not found in patients with right parietal lesions (PET also shows an increasing blood flow in the right parietal lobe Brodmann's area 7). This maybe explained by the fact that not all the patients belonging to this group were affected by lesions involving that brain region. The importance of bilateral frontal regions when subjects must make a distinction between a signal and a noise was already stressed by another investigation (see Salmaso and Denes, 1982). On the basis of our experiment, we can suggest a superiority of the right frontal regions for this kind of tasks.

In the future, it could be interesting to apply the go/no go paradigm to the irregular condition when intervals between stimuli are different, as well as to the whole tactile modality. Furthermore, it could be interesting to use, in the go/no go paradigm, some target-stimuli physically indistinguishable from other stimuli, but lasting more milliseconds.

In this experiment we could not confirm the findings of Wilkins et al. about a right frontal patients' deficit when they are presented stimuli at low rates (1 Hz) and at regular intervals between the stimuli. In our experiment, their performance (under the regular condition at 1 Hz) is similar to the performance obtained from all the other groups, both from a visual and an auditory point of view. Maybe, the results of the two investigations are different because of:

- a higher number of stimuli to which the patients should draw their attention in the work of Wilkins et al.: the train of stimuli of that investigation (which is longer) includes 22 stimuli, whereas each condition of our vigilance test includes no more than 11 stimuli;
- a sequence effect with reference to the train of stimuli, the rates of stimuli and sensory modalities (Wilkins et al.), whereas in our experiment all the trains of stimuli are randomized, as well as all sensory modalities and both the rates used to present the stimuli (1 Hz and 3 Hz);
- a lack of homogeneity within the group of frontal patients. In Wilkins et al., the group of left and right frontal patients includes also patients with left and right frontal-temporal lesions. Therefore, with reference to the auditory vigilance task, maybe a bad performance of the Wilkins et al.'

patients is due to a lesion in the brain auditory areas, a lesion which would affect a good stimuli detection. In our experiment, as we have already stated, frontal and parietal patients only have unilateral and unifocal lesions.

As we have stated at the beginning, in all the subject groups (except for right frontal patients) the condition with alternate stimuli gives better results, followed by the regular condition and the irregular condition. The trend of results, with reference to the performances under the three aforementioned experimental conditions, is similar at 1 Hz and at 3 Hz, even though a significant difference is found between the performances at low and high rates. The better performance at the 1 Hz rate (the subjects are bound to draw voluntarily their attention to the task) can be explained by taking into account the time between the patient's accident and the moment he/she has been submitted to our test: during this time, a reduction of diaschisis, appearing in healthy brain structures far from the injured area, can occur, and in some patients the reduction, or disappearance, of this phenomenon can improve attention capabilities, that several months before had been impaired by the accident.

We could even say that such a length of time is a factor responsible for improved attention capabilities in these subjects. Consequently, we can affirm, with reference to the Norman and Shallice's model, that a damage, of any kind, to frontal lobes usually does not cause a permanent disorder in the supervising attention system: such a damage still allows a gradual inner strengthening and increases, as time goes by, the patient's capability to select the most appropriate schemes to keep his behaviour under control. However, we must bear in mind that a supervising system functional damage can persist, even after long periods, when the supervising attention system is required to select target-stimuli to which distraction elements are added.

Therefore, according to the data we have obtained, we can not affirm that a damage to frontal lobes can provoke, as time goes by, a total functional block of the Norman and Shallice's supervising attention system; it only causes a selective deficit of some specific functions (in our experiment, the detection of target-stimuli to which noise stimuli are added).

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