Eye Movements and Orienting of Attention in Patients with Visual Neglect

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Abstract

■ The aim of the present study was to assess the relationship between overt and covert orienting of attention in visual neglect patients with parietal and fronto-parietal lesions. Two stimuli were presented at eccentricities of 8° or 20° to the left (LVF) or right (RVF) visual fields and the patient was required to maintain fixation on the central mark and to respond only manually upon the appearance of the stimulus. Neglect patients with fronto-parietal lesion showed a lack of oculomotor control and the presence of leftward eye movements without corresponding attentional shifts. Neglect patients with parietal lesions did not show this phenomenon. They rarely responded ocularly and manually to LVF stimuli, whereas they were unable to inhibit an automatic ocular orienting reaction towards RVF stimuli. When a RVF stimuli triggered both ocular and attentional shifts, the pattern of responses revealed a retinal eccentricity effect. Patients were more accurate to respond to stimuli located at 8° than 20°. In contrast, when a RVF stimuli triggered only attentional shifts, the results showed the attentional gradient effect (Làdavas, 1990). Patients were more accurate to respond to stimuli located at 20° than 8°. Therefore, the results of the present study seem to suggest a functional dissociation of the mechanisms subserving attentional and gaze orienting and a differential role played by the frontal and parietal lobes in overt visual orienting. ■

INTRODUCTION

The aim of the present study was to assess the relationship between overt and covert orienting of attention, that is a selective turning of the eyes towards the stimulus location (overt orienting) and a shift of attention to it (covert orienting).

Patients with visual neglect appear to be good candidates for testing this hypothesis. Hemispatial neglect is characterized by the fact that, even in the absence of sensory or motor deficit, the patients do not report, respond, or orient to stimuli presented in the space contralateral to the lesioned hemisphere. Neglect is often referred to as an attentional disorder. In accordance with this view, many investigators (Posner et al., 1987; Làdavas et al., 1994) have shown that these patients have a specific impairment in the ability to orient attention to left sided stimuli. In the most severe forms of neglect, they also show a failure to make eye movements towards stimuli presented in the contralesional side and a deviation of the eyes towards the ipsilesional side. This rightward deviation of ocular responses is accompanied by the deployment of attention towards the most ipsilesional spatial positions (Làdavas et al., 1990). In this study the authors showed that neglect patients outperformed controls when required to detect stimuli that occupied a relatively right-sided position in the intact visual field.

In the mild form of neglect the uncontrollable gaze deviation towards the right-most extremity of space is associated with increased time for leftward eye movements and for left attentional shift. Chedru, Leblanc, and Lhermitte (1973) found that left unilateral neglect was associated with increased time for leftward eye movements and the degree of asymmetry in eye movement exploration was positively correlated with the degree of unilateral inattention.

These observations support those hypotheses (Rizzolatti et al., 1987; Tassinari et al., 1987; Umiltà et al., 1991), which maintain a very close relationship between the mechanisms underlying covert and overt orienting of attention. Scott, Jeannerod, and Zahin (1966) explicitly maintained that unilateral neglect might be the consequence of an ocular disorder that prevents patients from exploring the contralateral half-space.

On the other hand, these hypotheses are not supported by the observation that several patients with unilateral neglect do not present obvious oculomotor disorders. According to Hécaen (1962), this disturbance is present in about 85% of patients with hemineglect, but Gainotti (1968) and Albert (1973) have observed oculomotor disorders in only 78% and 64% of their neglect patients, respectively. This last observation, i.e., eye deviations and attentional shifts may be separately disrupted, is more consistent with the idea that the two mechanisms may be functionally independent.

The aim of the present study is to test these two hypotheses more directly. Therefore, an experiment was designed in which two stimuli could appear on the left (LVF) or the right (RVF) of a fixation mark, respectively at 8° and 20° on each side. Patients with visual neglect were required to maintain fixation on the central mark and to respond only manually upon the appearance of the stimulus. Three different types of responses can be expected using this experimental paradigm: (1) manual responses without ocular responses (manual responses); (2) manual responses accompanied by congruent ocular responses (manual/ocular responses); (3) ocular responses not accompanied by manual responses (ocular responses). If the channels of information processing associated with the selection of eye movements and manual responses are independent with their own capacity, one can predict little correlation in the pattern of ocular and manual responses. On the other hand, if the selection of responses is carried out within the one limited channel capacity system, considerable correlation between the two responses is likely.

Considering the single channel capacity system, we should expect a similar pattern of results for ocular and manual responses. Patients should manifest an impairment in both ocular and manual responses when the task requires a response to LVF stimuli. This is because it has been shown that neglect patients have an impairment in shifting attention towards the contralesional hemifield (Posner et al., 1987; Làdavas et al., 1994). Due to the deployment of attention towards the most ipsilesional spatial position (Làdavas et al., 1990), patients should be faster and more accurate in responding manually to right (20°) than to left stimuli (8°), when stimuli are presented to RVF. If a right peripheral stimulus compulsorily triggers a right attentional shift and the mechanisms underlying covert and overt attention are the same, a rightward eye movement should also be automatically triggered, although the task required is to maintain fixation at the center. Moreover, ocular responses to RVF stimuli should be faster and more accurate for stimuli presented to the right (20°) than the left (8°) relative position.

The independence hypothesis predicts little correlation in the pattern of ocular and manual responses and, more important, the occurrence of an ocular response without a correspondent attentional shift, as well as the occurrence of an attentional shift without a corresponding ocular response. The last proposition has been largely confirmed by studies showing that attention can be allocated to different parts of the visual field without making overt eye movements (for reviews see Posner, 1980; Umiltà, 1988). In contrast, as far as we know, no one has proved that it is possible to make an eye movement without a corresponding attentional shift. On the other hand, it is known that patients with frontal lesions are not able to inhibit reflex-like orienting movements towards peripheral stimuli (Guitton & Buchtel, 1985). Therefore, in order to study the relationship between covert and overt orienting of attention, neglect patients with frontal lesions seem to be the best candidates for showing a release of eye movements with and without corresponding attentional shifts.

Due to visual neglect, the patients cannot shift attention towards the contralesional direction and, as a consequence, they cannot detect stimuli presented in that visual field. This is because reorienting of attention is necessary before a manual response to peripheral visual stimuli is emitted. Posner (1980) has suggested that an arbitrary response, that is one not automatically triggered by a stimulus, only occurs through the commitment of conscious attention. But, due to the lesion in the frontal lobe, they may be not able to suppress a reflex-like orienting eye movement towards the same peripheral target. Therefore, ocular responses without corresponding manual responses are expected.

In conclusion, the aim of the present study was to assess the relationship between orienting of attention and eye movement by testing neglect patients with only parietal lesions and patients with parietal and frontal lesions.

RESULTS

ANOVAs were performed on mean percentage and latencies of correct manual responses and on mean percentage and latencies of ocular responses. Due to the small number of manual and ocular responses during catch trial conditions (responses never exceeded 2% of the trials), these responses were not analyzed.

Statistical Analyses on Percentage of Manual Responses

Two ANOVAs were performed on the mean percentage of correct manual responses: one for manual responses not accompanied by ocular responses and one for manual responses accompanied by congruent ocular responses. "Incorrect" responses were those in which a response occurred but RT exceeded 2000 ms and those in which the subject anticipated the target or failed to respond. The first two types of errors were very rare and did not exceed 2% of the trials. In each analysis of variance there was one between-subjects factor, the group (neglect patients with parietal lesion, neglect patients with fronto-parietal lesion, and control patients), and two within-subjects factors, the visual field (LVF and RVF) and the retinal eccentricity (20° and 8°). Beside these analyses of variance, pairwise comparisons using the Newman-Keuls method were conducted whenever necessary. The level of significance was always set at 0.05. For the sake of brevity, we will confine ourselves to describing those sources that are relevant for our hypotheses. Sometimes, even a potentially interesting source will be not discussed if it is qualified by the significance of higher order sources.

The first ANOVA was conducted on the percentage of correct manual responses not accompanied by ocular responses (Table 1).

This analysis showed a significant main effect of group ($F(2, 12) = 45.8, p < 0.0001$), with controls being more accurate than neglect patients with parietal and fronto-parietal lesions (100%, 40%, and 9% of responses, $p < 0.01$ in all comparisons). This result pointed out a specific impairment of neglect patients with fronto-parietal lesions in given manual responses without corresponding eye movements. The interaction group × visual field × retinal eccentricity was also significant ($F(2, 12) = 17.04, p < 0.0003$). In LVF condition, neglect patients with parietal lesions were more accurate in responding to stimuli located at 8° (right relative position, RRP) than 20° (left relative position, LRP) (40% vs 28% of responses, $p < 0.05$). In contrast, in RVF condition, they were more accurate in responding to stimuli located at 20° (RRP) than 8° (LRP) (60% vs 33% of responses, $p < 0.05$). This pattern of results demonstrates the well-known attentional gradient effect (Làdavas, 1990): The whole visual field is affected but with a gradient of severity ranging from a maximum in the extreme contralesional hemifield to a minimum in the extreme ipsilesional field. In contrast, neglect patients with frontal lesions did not show any significant difference between responses to stimuli located at 8° and 20° both in the LVF (8% vs 4%) and RVF (16% vs 7%) conditions. Control patients did not show any differences in the pattern of responses (100% of responses in all conditions).

The second ANOVA carried out on the percentage of manual responses accompanied by congruent ocular responses (Table 1) revealed a significant main effect of group ($F(2, 12) = 29.2, p < 0.0001$), with neglect patients with fronto-parietal lesions responding more frequently than patients with parietal lesions and controls (54%, 28%, 0% of responses, $p < 0.05$ in all comparisons).

This type of response was more evident in the ipsilesional than the contralesional visual field in both parietal (46% vs 13% of responses, $p < 0.05$) and fronto-parietal patients (76% vs 32% of responses, $p < 0.01$). The interaction group × visual field × retinal eccentricity was also significant ($F(2, 12) = 50.57, p < 0.0001$). Neglect patients with parietal lesions responded more frequently when stimuli were presented at 8° than 20°, both in LVF (14% vs 12% of responses, p = n.s.) and RVF (59% vs 34% of responses, $p < 0.05$). The same pattern of results was obtained in neglect patients with parieto-frontal lesions both in LVF (41% vs 25% of responses, $p < 0.05$) and RVF (80% vs 72% of responses, p = n.s.) conditions.

Statistical Analysis on Manual Responses Latencies

Due to a large number of omissions in the LVF, only one analysis of variance could be performed, that is on mean manual RT to RVF stimuli. Therefore, there was one between-subjects factor, the group (neglect patients with parietal lesion, neglect patients with fronto-parietal lesion), and one within-subjects factor, the type of manual response (manual responses with and without ocular responses). None of the main factors or interactions were significant or nearly significant. Therefore manual responses with and without ocular responses did not differ significantly both in parietal (504 ms vs 517 ms) and parieto-frontal patients (509 ms vs 486 ms).

Table 1. Mean percentage of responses (manual responses, ocular responses, and manual/ocular responses) as a function of visual field (left and right), and retinal eccentricity (8° vs 20°) for neglect patients with parietal and fronto-parietal lesions.

	Parietal patients				*Parieto-frontal patients*			
	LVF		*RVF*		*LVF*		*RVF*	
	20°	*8°*	*8°*	*20°*	*20°*	*8°*	*8°*	*20°*
Manual responses	28%	40%	33%	60%	4%	8%	16%	7%
Ocular responses	2%	0%	0%	0%	20%	20%	3%	1%
Manual/ocular responses	12%	14%	59%	34%	25%	41%	80%	72%
Total manual responses	40%	54%	92%	94%	29%	49%	96%	79%
Total ocular responses	14%	14%	59%	34%	45%	61%	83%	73%

Statistical Analysis on Percentage of Ocular Responses

Only one ANOVA was performed on the percentage of ocular responses (Table 1), i.e., on the percentage of ocular responses not accompanied by congruent manual responses. Ocular and manual responses have been already analyzed in the previous ANOVA (the second ANOVA).

This analysis is important because the independence hypothesis predicts the occurrence of ocular responses without a corresponding manual response. The analysis revealed that this type of response was manifest only in neglect patients with frontal lesions and mainly in the LVF condition. The interaction group × visual field was significant ($F(2, 12) = 18.6, p < 0.0002$). Neglect patients with fronto-parietal lesions responded more frequently in the LVF than in the RVF (20% vs 2% of responses, $p < 0.01$). This trend was not manifest in neglect patients with parietal lesions (0% vs 0% of responses) and controls (0% vs 0% of responses).

Statistical Analyses on Latencies of Ocular Responses

Three ANOVAs were carried out on mean latencies of ocular responses.

The first ANOVA was performed in order to verify whether the two experimental groups differed in ocular response latencies. This analysis was carried out only on mean latencies to RVF stimuli, due to the large amount of omissions provided in the LVF condition by parietal patients. In it there was one between-subjects factor, the group (neglect patients with parietal lesion and neglect patients with fronto-parietal lesion), and one within-subjects factor, the retinal eccentricity (20° and 8°). Neglect patients with parietal and fronto-parietal lesions did not differ significantly in the latencies of ocular responses (211 ms vs 187 ms), and they were both faster in responding to stimuli located at 8° than 20° (189 ms vs 209 ms, $p < 0.005$).

The second ANOVA was performed in order to assess the pattern of responses in the two visual fields. Because only fronto-parietal patients responded ocularly to both LVF and RVF stimuli, this analysis was confined to this group. It revealed that fronto-parietal patients were slower to respond to LVF than to RVF stimuli (378 ms vs 187 ms, respectively, $p < 0.0007$) and to stimuli located at 20° than 8° (305 ms vs 261 ms, $p < 0.01$).

The third ANOVA was performed in order to verify whether ocular responses accompanied by congruent manual responses were significantly different than those not accompanied by manual responses. Due to the fact that ocular responses not accompanied by manual responses occurred only in the LVF of neglect patients with fronto-parietal lesions, this analysis was confined only to this group. It revealed only a significant main effect of eccentricity (8° vs 20°) without any significant difference between ocular responses (384 ms and 459 ms) and ocular responses accompanied by manual responses (346 ms and 411 ms).

DISCUSSION

The results of the present study show that covert orienting may not be controlled by the neural mechanisms that are in charge of saccade programming. In neglect patients with fronto-parietal lesions two phenomena were observed: a lack of oculomotor control and, even more relevant for the aim of the current study, the presence of oculomotor responses without the corresponding manual responses.

The lack of oculomotor control can be explained by referring to the role of the frontal lobe in controlling orienting saccades. Although the patients were instructed to look at the fixation stimulus, they manifested a strong tendency to make reflexive ocular responses towards the peripheral targets.

Clinical observations suggest that orienting saccades are controlled by neural centers of dorsal convexity of the frontal lobe (Milner, 1982; Guitton & Buchtel, 1985). Patients with lesions of this region have a strong tendency to make reflexive glances towards the visual target and are impaired in their capacity to perform an arbitrary saccade in response to it. It appears that the frontal lobe exerts a control on the saccade emitted by the frontal eye fields and the superior colliculus. It is worth noting that the superior colliculus is thought to be involved in the generation of eye movements toward simple, easily discriminable stimuli. Without a control exerted by the frontal lobe, orienting saccades would occur immediately upon the stimulus presentation. This is exactly the outcome of the present study. Neglect patients with fronto-parietal lesions could very rarely inhibit the automatic orienting reaction of the gaze towards the peripheral stimulus. It is worth remembering that the experimental task required the subject to keep the eyes at the fixation and to inhibit the automatic gaze towards the stimulus. The lack of gaze control was manifested in both visual fields, although it was more evident in the ipsilesional (78% of responses) than in the contralesional visual field (53% of responses). Ocular responses, beside being more frequent in RVF than in LVF, were also faster (187 ms vs 378 ms, respectively).

Automatic orienting of the eyes towards the visual target was mostly accompanied by a corresponding orienting of attention, as proved by the manual detection of the stimuli. However, there were trials in which the patients made oculomotor responses without a corresponding shift of attention, as documented by the absence of manual responses. Ocular responses occurred only after stimulus presentation and were absent in catch trial condition. The lack of manual responses was also accompanied by the denial of visual stimulus presence. When patients were asked the reason why they did not respond manually, they simply answered that nothing had been presented on the display. This pattern of results was evident only in the contralesional visual field and it seems to suggest that a LVF stimulus triggers an automatic saccade but not an automatic shift of attention. Due to the lesion of the parietal lobe, which causes an impairment in the contralesional automatic orienting of attention, the patients were unable to orient attention toward the stimuli. In contrast, they could make a reflexive gaze towards it. These data seem to show that attention and ocular systems may be separately activated by a peripheral stimulus.

The results obtained in neglect patients with parietal lesions also favor the idea that the mechanisms underlying reflexive saccades may be relatively independent of the mechanisms underlying attentional orienting responses. This conclusion is supported by the dissociation found between manual responses and manual/ocular responses. When the patients responded only manually, the results manifest the attentional gradient effect. In contrast, when manual responses were accompanied by congruent ocular responses, the results showed retinal eccentricity effect. When the patients responded only manually, they were more accurate in responding to stimuli located at the rightmost position. This was evident both in RVF condition, where they responded more often to stimuli located at 20°, and in LVF condition, where they responded more frequently to stimuli located at 8°. These results are opposite to those one should expect according to eccentricity effect, at least in RVF condition, and are compatible with the attentional interpretation of neglect. The whole visual field is affected by the attentional deficit, with a gradient of severity ranging from a maximum in the extreme contralesional hemifield to a minimum in the extreme ipsilesional field (De Renzi et al., 1989; Làdavas et al., 1990).

When manual responses were accompanied by congruent ocular responses, the pattern of results is reversed and the results show a retinal eccentricity effect. Both in RVF and LVF conditions, patients responded more frequently to stimuli located at 8° than 20°, although the difference was significant only in the RVF condition.

Again, these results do not support the notion that the mechanisms involved in spatial attention and ocular saccades are basically the same. The identity hypothesis in fact predicts the same effect (attentional or retinal) regardless of whether the stimulus is triggering an ocular response or only an attentional shift. In contrast, the results showed an attentional effect when the stimulus triggered an attentional shift and a retinal eccentricity effect when the stimulus triggered ocular saccades.

In conclusion, the present results do not support the notion that oculomotor programming is at the basis of spatial attention, a point of view mainly known as the "premotor theory" of attention (Rizzolatti et al., 1987; Umiltà et al., 1991). This theory postulates a strict link between covert orienting of attention and the programming of ocular movements. The basic idea is that overt orienting and covert orienting are both controlled by the neural mechanisms that are also in charge of saccade programming. Upon presentation of a stimulus, a motor program for the saccade is prepared, which specifies the direction and the amplitude of the eye movement. This would occur regardless of whether the saccade is actually executed (i.e., overt orienting) or is not executed (i.e., covert orienting).

On the other hand, although appealing, the premotor theory is mostly based on indirect evidence derived from neurophysiological studies showing that those structures that are involved in spatial attention are also involved in motor programming (see reference in Rizzolatti and Gallese, 1988) and on its capacity to explain the "meridian effect," the extra-cost that the subjects pay when visual attention crosses the horizontal or vertical meridian (Rizzolatti et al., 1987; Tassinari et al., 1987; see also Reuter-Lorenz & Fendrich, 1992 for different results). In contrast, the present results are more consistent with the idea that attention is a mechanism related to, but basically independent of, those mediating eye movements (Klein, 1980; Klein et al., 1992; Posner, 1980; Rafal et al., 1989; Posner & Petersen, 1990).

The results of the present study are also informative about the role played by the parietal lobe on oculomotor behavior. A lesion in this lobe seems to disrupt the oculomotor system. Ocular responses to contralesional visual field stimuli are less frequent than in the ipsilesional visual field. This asymmetry can be explained by considering the specific role played by the parietal lobe in programming and executing an automatic gaze orientation. Many studies have shown the existence of an oculomotor area in the parietal lobe and its retinotopic organization (Andersen, 1987; Duhamel et al., 1992). Oculomotor apraxia and abnormalities of visual scanning have been reported in patients with lesions in both parietal lobes (Luria, Pravdina-Vinarskaya, & Yarbus, 1963). This pattern of results is present even in soporose patients with the eyes closed (De Renzi et al., 1982) and during sleep. Doricchi et al. (1991) showed that in patients with neglect the leftward REMs (rapid eye movements) were virtually absent, whereas rightwards REMs were present. Therefore, it is possible to postulate that a lesion in the parietal lobe causes an impairment in gaze orienting towards the contralesional visual field.

However, the disruption of oculomotor behavior in parietal patients could be considered as a consequence of a general disruption of a visual spatial map, and/or the ability to remap space to correct for changes in eye position (Duhamel et al., 1992). If this is the case, one need not postulate a parietal lobe that is specific for oculomotor programming. Such a formulation would, in fact, account for both the attentional and oculomotor deficits following parietal lesions.

METHODS

Subjects

Two groups, selected from the inpatient population of the Fraticini Hospital, were tested: an experimental and a control group. The experimental group consisted of ten neurological patients (5 with parietal lesions and 5 with fronto-parietal lesions), each with a severe left visual neglect and hemiplegia or severe hemiparesis contralateral to the lesion. The side and the site of lesion were confirmed by CT or MRI scans. All were without psychiatric symptoms. A campimetry test was performed to ensure that the patients were without visual field deficits. Based on the results of this latter test, the 10 patients were selected from a larger population of 34 patients with severe left visual neglect. Characteristics of each subject group are outlined in Table 2. The control group consisted of five inpatients without neurological or psychiatric disorders.

The presence/absence of horizontal visual neglect was assessed by a number of tests. In the current study only those that can be easily submitted to a quantitative scoring are presented; others, such as drawing either from memory or from a sample, and reading sentences, will not be discussed. The patient tasks for the quantitative tests were: (1) to cross out "H's" in a structured array of letters (Diller & Weinberg, 1977); (2) to cross out bells in a display of drawings of several objects (Gauthier et al., 1989). Patients who omitted more than 60% of left stimuli in each test were included in the experimental group; among control patients only those who omitted less than 5% of the stimuli on either side were included in the control group.

Apparatus

The apparatus for the presentation of the stimuli consisted of a bar forming an arc of 60 degrees and containing 4 red LEDs located at 8° and 20° on the left and on the right of a fixation mark. The fixation stimulus was a yellow LED located at the center of the display that remained switched on for the duration of each trial (3 seconds). The target consisting of a red LED was shown for 200 ms. The lighting of the LEDs was governed by a controller interfaced with an MS-DOS microcomputer via a serial port. The subject was seated at a distance of 100 cm from the display in a modified dentist's chair with the head mechanically fixed. A button response box was fixed to the right arm of the chair under the subject's right hand and connected to the computer. The computer recorded responses and response latencies, and stored these data on a magnetic disk for subsequent analysis. The signals of ocular responses were recorded by an electro-oculographic technique, using silver-silver chloride electrodes fixed near the inner and outer canthi of the right eye. The signal was amplified, low-pass filtered (50 Hz) and then sampled at 250 Hz and digitized in 12-bit form, by an analog/digital converter. The signal of each measurement was stored on the computer disk for subsequent evaluation. At the beginning of the saccade evaluation, a calibration test was performed. This test was used to correct the nonlinearity between EOG-

Table 2. Summary of clinical data for neglect patients with parietal lesion (PP1–PP5) and fronto-parietal lesion (PFP1–PFP5) (R = Right, F = Frontal, P = Parietal, T = Temporal, D = Deep). Number of correct responses in the clinical tests (cancellation tests) as a function of side (left and right). The number of stimuli on each side was 51 for the letter cancellation task and 18 for the bell cancellation task.

				Cancellation tests			
				Letters		*Bells*	
Case	*Sex/Age*	*Onset of illness(mths)*	*Locus of lesion*	*L*	*R*	*L*	*R*
PP1	M,68	2	RTPD	0	11	0	4
PP2	F,80	12	RPD	0	6	0	5
PP3	M,61	5	RPD	43	51	14	18
PP4	M,64	2	RTPD	1	19	0	12
PP5	M,72	16	RPD	46	51	10	18
PFP1	M,67	14	RFPD	0	23	0	11
PFP2	M,62	12	RFPD	43	50	11	18
PFP3	M,65	55	RFTPD	26	49	5	10
PFP4	F,72	2	RFPD	9	12	0	8
PFP5	M,75	3	RFPD	12	44	0	16

voltage and eye-position changes. The program displayed the eye movements recorded during the calibration and indicated with an arrow the voltage corresponding to each particular position of the eye. The operator could modify from the keyboard the position of such arrows. At the end of the calibration session the program computed and plotted the "calibration curve." This procedure was necessary because the relation between angular eye position and voltage value is not linear for lateral positions. The calibration curve was later used to convert the recorded signals into the corresponding eye deviation expressed in degrees (see Inchingolo et al., 1987 and Buizza & Avanzini, 1983 for the employment of a similar procedure).

Conditions and Procedures

Each trial began with the instruction to look at the central yellow LED, which remained on for the duration of the trial. The patient was aware that the experimenter was monitoring eye movements and he/she was instructed to look at the fixation stimulus whenever an eye shift occurred. When accurate fixation was established, the experimenter initiated the trial from the computer keyboard, an 800 or 1500 ms variable delay elapsed, and a red LED located at 8° or 20° on the left or on the right was switched on for 200 ms. In half of the trials the red LED was not switched on (catch trials). The patient was told that half of the trials were catch trials. The subject was instructed to push the response button upon the appearance of the red light, regardless of its spatial position, without moving the eyes. Reaction times (RTs) were measured from the onset of the stimulus to the appropriate key press. If an eye movement occurred, then both latency and accuracy of the ocular response were calculated.

Each subject attended three experimental sessions that were run on three consecutive days. Each session consisted of four blocks of 30 practice trials and four blocks of 56 experimental trials, with a 10 minute rest period between blocks. The sequence was such that the presentation of the target stimuli in the four different spatial positions was equiprobable, with the restriction that no more than three consecutive stimuli could occur in the same spatial position.

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