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Visual Feature Integration with an Attention Deficit

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Treisman's feature integration theory proposes that the perception of illusory conjunctions of correctly encoded visual features is due to the failure of an attentional process. This hypothesis was examined by studying brain-damaged subjects who had previously been shown to have difficulty in attending to contralesional stimulation. These subjects exhibited a massive feature integration deficit for contralesional stimulation relative to ipsilesional displays. In contrast, both normal age-matched controls and brain-damaged subjects who did not exhibit any evidence of an attention deficit showed comparable feature integration performance with left- and right-hemifield stimulation. These observations indicate the crucial function of attention for visual feature integration in normal perception. © 1994 Academic Press, Inc.

INTRODUCTION

Evidence from psychophysics, neurophysiology, and neuropsychology has converged in demonstrating the existence of independent visual pathways, each specialized for the processing of a particular stimulus dimension, such as color, motion, or location (Anderson, Essick, & Siegel, 1985; Cavanagh, 1988; Cavanagh, Arguin, & Treisman, 1990; Kaas, 1989; Livingstone & Hubel, 1988; De Yoe & Van Essen, 1988; Zeki, 1978; Zihl, von Cramon, & Mai, 1983). However, representing the environment as the set of independent properties which are present in the visual field is only the first step in visual analysis. A specification of how these features combine to constitute particular objects is also required. Indeed, visual

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objects are constructed from conjoined properties rather than a disparate collection of features.

Treisman and her collaborators have suggested a dynamic process for the integration of separately encoded visual features (Treisman, 1985; Treisman, 1988; Treisman & Gelade, 1980; Treisman & Sato, 1990; Treisman & Souther, 1985). They propose that features are encoded preattentively in a spatially parallel manner by representations which are specialized for the processing of particular stimulus properties. The integration of the constituent features of an object is said to result from the allocation of attention to the location occupied by that specific stimulus. Without attention, it is assumed that visual features may not be integrated properly and thus that erroneous feature combinations, called illusory conjunctions, may be perceived. For example, when shown a red square and a blue circle, a subject may report seeing a blue square and a red circle.

In the typical paradigm used to study illusory conjunctions, several colored shapes are presented under exposure conditions which are assumed to prevent subjects from attending to each item individually. Under these conditions, erroneous combinations of properly encoded features (i.e., illusory conjunctions) are perceived with a frequency which is above chance level (Cohen & Ivry, 1989; Eglin, 1987; Ivry & Prinzmetal, 1991; Lasaga & Hecht, 1991; Prinzmetal, 1981; Prinzmetal, Presti, & Posner, 1986; Treisman, 1985; Treisman & Paterson, 1984; Treisman, & Schmidt, 1982; Treisman, Sykes & Gelade, 1977; Virzi & Egeth, 1984).

Results indicating that subjects do perceive illusory conjunctions support the separability of feature representations. However, such observations in themselves remain neutral about the role of attention in feature integration. Indeed, it is possible that illusory conjunctions result from the failure of some process other than attention. The demonstration for the role of attention in visual feature integration requires that attentional manipulations be shown unambiguously to have an effect on the rate of illusory conjunctions perceived.

Several attempts at providing such evidence have been reported in the normal literature (Briand & Klein, 1987; Prinzmetal et al., 1986; Treisman, 1985; Treisman & Schmidt, 1982). In each of these studies, the effect of an attentional manipulation (valid vs. invalid spatial cuing of the stimulus location or presence vs. absence of a concurrent task) was shown to be greater in conditions intended to measure feature integration performance than in conditions measuring the encoding of single features. This evidence appears congruent with the role of attention in visual feature integration. However, in a detailed discussion of these experiments, Tsal (1989) maintains that, due to methodological problems, their results are inconclusive. Thus, Tsal (1989) pointed out that the observations from the studies reported by Treisman (1985; Treisman & Schmidt, 1982) are difficult to interpret because either the attentional manipulation or the comparison between feature encoding and feature integration conditions were confounded with other changes in experimental parameters; in particular, stimulus exposure duration and the memory requirements of the task. As well, Tsal (1989) argued, from a detailed examination of the data reported by Prinzmetal et al. (1986), that the attentional manipulation they used may have affected not the perceptual sensitivity to feature conjunctions, but rather may have led to a response bias on the basis of which their effects can be explained. Finally, Tsal (1989) presented arguments according to which the conditions thought to measure feature encoding and feature integration in the Briand & Klein (1987) report may actually have differed only on the number of features which needed to be considered for an accurate performance, without any requirement for feature integration in either condition.

To examine the effect of attention on feature integration, another alternative is to study brain-damaged individuals who suffer from a deficit in allocating attention to a part of visual space. This has previously been attempted by Riddoch & Humphreys (1987) and by Eglin, Robertson & Knight (1989) in patients with visual hemispatial neglect, who show an impairment in attending to the visual field that is controlateral to their lesion (De Renzi, 1982; Jeannerod, 1987). Both studies used visual search tasks where the target differed from distractors by a particular conjunction of features (e.g., target = red circle; distractors = red squares and green circles). The index used as to the effectiveness of feature integration in the intact and attention-impaired visual hemifields of brain-damaged patients was the rate with which response times increased as a function of the number of distractors presented along with the target. More specifically, the effect of the number of distractors on response times served to make inferences about the time required to integrate the constituent features of each individual item. These two studies failed to demonstrate an impairment of feature integration for stimuli presented in the contralesional visual field of brain-damaged subjects with visual hemispatial neglect. Thus, in these patients and in both reports, the rate of increase of response times with the number of items displayed did not differ significantly as a function of the hemifield where the target was located.

Eye movements, which were not controlled in the studies conducted by Riddoch & Humphreys (1987) and by Eglin et al. (1989), may have been responsible for these negative results. Thus, it is possible that, in some instances, their subjects preferred to view contralesional displays through their ipsilesional hemifield since their strategy would allow faster responses. This problem is accentuated by the fact that many of the patients examined by Riddoch & Humphreys (1987; two out of three cases) and by Eglin et al. (1989; four out of seven cases) suffered from a verified or probable visual field defect.

More recently, Cohen & Rafal (1991) have studied feature integration in a left brain-damaged patient with an attention deficit for right-hemifield stimulation. In order to divert their subject's attention from the conjunction task, which involved the perception of colored letters presented in the left or right visual hemifield, these investigators also displayed a pair of digits at fixation. The subject was first required to report the identity of one of the central digits, and then to respond to the lateralized stimuli. Under these conditions, the brain-damaged patient studied by Cohen & Rafal (1991) showed more frequent illusory conjunctions with right-hemifield than with left-hemifield stimuli, thus suggesting a correlation between spatial attention and feature integration. However, their result has also been reported for normal subjects. Indeed, Eglin (1987) used a procedure similar to that of Cohen & Rafal (1991) in neurologically intact subjects. She showed that processing digit distractors led to an increase of illusory conjunctions for right-hemifield stimulation relative to stimuli shown in the left hemifield in these normal subjects. Eglin's (1987) result mirrors that reported by Cohen & Rafal (1991) for their patient. It is therefore difficult to determine whether the right-hemifield increase in illusory conjunctions in the patient resulted from her attention deficit or, as was the case with normals, from the distractor task. Cohen & Rafal (1991) did not present any data from control subjects to allow an assessment of the normal hemifield differences in illusory conjunctions in their experiment.

In the present experiment, we used illusory conjunctions to examine the role of spatial attention in the feature integration process in brain-damaged patients with a visual attention disorder. Precautions were taken to avoid the methodological difficulties which were present in the previous experiments that attempted to assess the relationship between attention and feature integration. Our results show extremely high rates of illusory conjunctions for stimuli presented at locations to which brain-damaged subjects have trouble attending, whereas other brain-damaged patients not affected by an attention impairment show normal feature integration performance.

METHOD

Subjects. Eight left brain-damaged subjects[1] (mean age of 64 years) and 10 age-matched controls (mean age of 71 years) were studied. Several inclusion as well as exclusion criteria

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[1] Six right-brain-damaged subjects were also examined. However, only one of them could be assessed satisfactorily since the others tended to fall asleep after a few minutes into the experiment. This is probably related to the vigilance problems which are frequently associated with right-brain lesions (De Renzi & Faglioni, 1965; Heilman, 1985; Posner, Inhoff, Friedrich & Cohen, 1987) and the right-hemisphere superiority of normal individuals in vigilance tasks (Heilman & Van Den Abell, 1979; 1980). The right brain-damaged subject who could be tested showed no evidence for an attention impairment and, in the illusory conjunction task, performed similarly to the left brain-damaged individuals with no attention deficit. Since he is the only subject with a right brain-lesion in our sample, his results will not be reported.

were applied for subject selection in order to control for potential artifacts. Inclusion criteria were: 1, right handedness, as assessed with the Edinburgh Handedness Inventory (score between +80 and +100; Oldfield, 1971); and 2, brain lesion of vascular origin, a first occurrence of brain-damage, with a unique lesion lateralized to one hemisphere, as assessed by a CT-scan examination (applies only to brain-damaged subjects). Exclusion criteria were: 1, reduced and uncorrected visual acuity; 2, ocular disease such as glaucoma or cataracts; 3, color vision anomaly, as assessed by Ishihara's isochromatic plates (Ishihara, 1964); 4, visual field deficits, as assessed by campimetry (applies only to brain-damaged subjects); 5, visual hemineglect (applies only to brain-damaged subjects); and 6, an aphasia that may impair the understanding of instructions (applies only to brain-damaged subjects).

In order to assess attentional functions, all subjects had previously been tested on visuo-spatial cuing tasks (Jonides, 1981; Posner, Snyder, & Davidson, 1980; Posner, Walker, Friedrich & Rafal, 1984; 1987). Of the brain-damaged subjects, three (VAD group—for visual attention deficit) showed results that differed from those of the normal controls. VAD subjects had much longer RT's to contralesional than ipsilesional targets at short temporal intervals (50 and 150 ms SOAs) following a spatial cue that indicated the hemifield in which the target would occur on 80% of the trials (valid cues). This occurred in the following cuing conditions: (a) a central cue (arrowhead at fixation) that was valid or (b) invalid, or (c) the peripheral onset of a square at an invalid location. The hemifield asymmetries observed in these conditions were much reduced or absent at longer SOAs (600 and 1000 ms) between cues and targets.

This pattern of results indicates a deficit in allocating visual attention to contralesional stimulation in the VAD subjects (Morrow & Ratcliff, 1988; Posner et al., 1984; 1987; Posner, Inhoff, Friedrich, & Cohen, 1987). In contrast to VAD subjects, the other brain-damaged subjects (nVAD group) showed performances that were similar to those of the normal controls and which did not differ as a function of visual hemifield. The attention disorder of the VAD patients did not appear to be associated with a particular site of brain damage but the average volume of the lesions observed in these patients was about four times larger than that seen in nVAD subjects. These same VAD subjects were retested here to determine whether illusory conjunctions are related to deficits of visual attention.

Materials and stimuli. The experiment was controlled by an Amiga microcomputer and stimuli were displayed on an RGB monitor located at a distance of 57 cm from the subjects. Subjects rested their head on a chin rest. A two-button computer mouse was used for response production. The experiment was run in a dimly lit room.

The stimuli presented were lateralized to the left or right visual hemifield. An ocular fixation control was used to ensure that the stimuli were displayed to the proper visual field. This was achieved by the use of a pupil and corneal reflection tracking system (ISCAN, model RK-426) linked to the control computer. This tracking system analyses video images obtained from a black and white camera equipped with an infrared filter. An infra-red source served for illumination. Trials began only when the subject fixated his eyes on a central fixation point. If, during a trial, the subject shifted his ocular fixation toward the array of stimuli (displayed left or right of fixation) so that the distance between ocular fixation and the centermost stimulus was under 2.0° of visual angle, that trial was immediately terminated and run again later in the session. An average of 2.8% of trials were eliminated this way.

A white fixation stimulus (luminance of about 61 cd/m^2; CIE coordinates, x = 0.29, y = 0.32) was shown at the center of the display screen between trials. It was made of a 0.2° dot surrounded by a 1.3° empty circle. Subjects were instructed to keep their eyes directed toward the fixation location as much as possible throughout the experiment.

To test illusory conjunctions, four colored forms were briefly presented at random locations to the left or right visual hemifield on each trial. The forms used were: circle (2.0° in diameter), triangle (2.5° wide × 2.1° high), concave-sided quadrangle (2.5° wide × 2.3° high). The colors of the stimuli were: red (luminance of about 11 cd/m^2; CIE coordinates, x = 0.64, y = 0.33), green (luminance of about 9 cd/m^2; CIE coordinates, x = 0.33, y =

0.58), or blue (luminance of about 6 cd/m^2; CIE coordinates, $x = 0.14$, $y = 0.06$). The target subjects had to search for was a red circle. The minimum distance separating the centers of any of stimuli presented was of 3.2° horizontally and 4.0° vertically. The minimum distance between any of the stimuli presented and the fixation point was of 5.6°. Stimuli were presented on a black background.

The exposure duration of the stimuli was established for each subject during the 35 practice trials that immediately preceded the experimental session. This was done according to the following staircase procedure. During the five practice trials, stimulus duration was fixed at 400 ms. From the sixth practice trial, each trial on which the subject gave a correct response was followed by a reduction in exposure duration. Inversely, each trial on which the subject made an error was followed by an increase in display duration. Initially, the value by which stimulus duration was either increased or decreased was set at 134 ms. Afterward, each time a correct response was followed by an error and each time an error was followed by a correct response, this value was halved. The minimum and maximum possible exposure durations were 150 and 600 ms, respectively. The average exposure duration was of 205 ms for the control group, of 247 ms for the nVAD group, and of 273 ms for the VAD subjects.

Procedure. Subjects had to indicate whether a prespecified target defined by a conjunction of shape and color (red circle) was present in the display. They were informed that they could take their time to make their response and had up to 10 s after the onset of the stimulus display to do so. Subject pressed the button on the right of the computer mouse to indicate that a target was present and pressed the button on the left to indicate it was absent. On each trial, subjects were given an auditory feedback as to the accuracy of their response (high-pitch sound, correct; low-pitch sound, error).

Three conditions determined the distractor items presented on a trial (Fig. 1). In the shape-absent and color-absent conditions, none of the distractors was of the target-shape (circle) or of the target-color (red), respectively. In the conjunction condition, a subset of the distractors was of the target-shape while another had the target-color. The target was present on 40% of the trials and absent in the remaining 60%. The experiment was run in a single 240-trials session which was immediately preceded by a 35-trials practice session. The dependent variable was accuracy.

RESULTS

The frequency of illusory conjunctions is one of several measures of errors in the search task and it is derived from the rates of false alarms

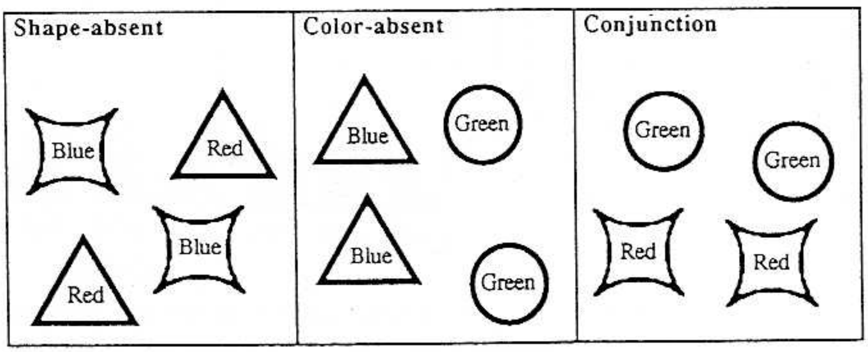

FIG. 1. Examples of displays on target-absent trials in the shape-absent (left), color-absent (center), and conjunction conditions (right). The target to be detected was a red circle.

for the various target-absent conditions. The basic error rates in each distractor condition of the target-present and target-absent trials will be discussed first. Illusory conjunction results will then be presented.

Figure 2 presents the average error rates for each group and each distractor condition on target-present trials (misses). Separate analyses of variance with group and hemifield as factors were applied to the error rates observed in each of these distractor conditions. These analyses showed no main effect or interaction for any of the distractor conditions.

The average false alarm rates for each group and distractor condition are shown in Fig. 3. These observations were subjected to separate ANOVA's for each distractor condition, with the factors of group and hemifield. Analysis of these error rates in the shape-absent condition indicated a main effect of group [$F(2, 15) = 8.2$; $p < 0.005$], but no main effect of hemifield [$F(2, 15) < 1$]. The main effect of group can be seen in the left part of Fig. 3, with the nVAD group showing slightly higher error rates than the normal controls, and the VAD group showing more frequent errors than the nVAD subjects. It should be underlined however that this effect does not involve hemifield differences in the error rates on shape-absent trials. Error rates in the color-absent condition showed no main effect of group [$F(2, 15) = 12$; n.s.] or hemifield [$F(1, 15) < 1$], but an interaction of group × hemifield [$F(2, 15) = 4.3$; $p < 0.05$]. Simple effects of this interaction showed no significant effect of hemifield for any of the subject groups (Controls: [$F(1, 15) < 1$]; nVAD: [$F(1, 15) = 3.1$; n.s.]; VAD: [$F(1, 15) = 2.8$; n.s.]). It seems that the group × hemifield interaction that occurred on the error data in the color-absent condition resulted from the fact that the nonsignificant hemifield differences observed in the nVAD and VAD group were in opposite directions (see middle part of Fig. 3). Finally, the analysis of error rates in the target-

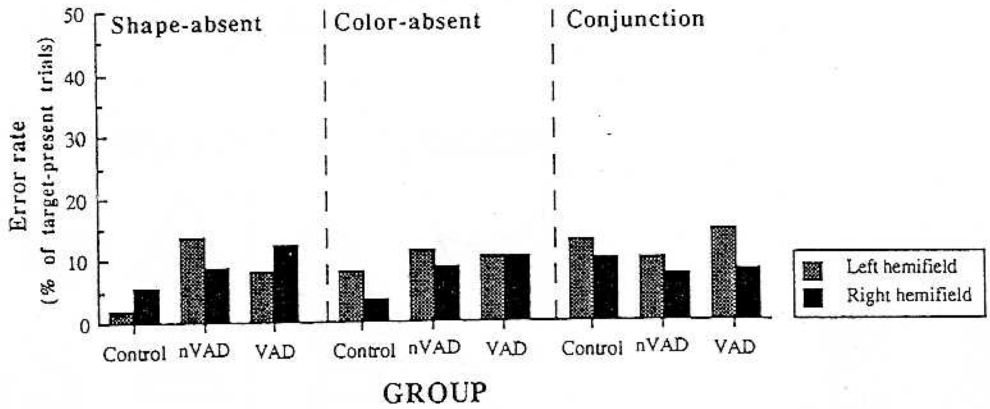

FIG. 2. Average error rates (misses) observed in each distractor condition on target-present trials; shape-absent (left), color-absent (center), and conjunction (right). Each graph presents the results for each group of subjects (control, nVAD, and VAD) and each visual hemifield (left and right).

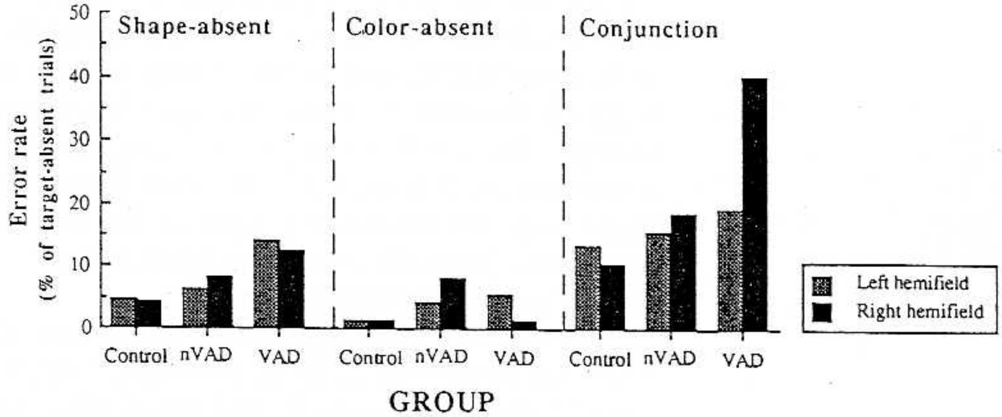

FIG. 3. Average error rates (false alarms) observed in each distractor condition on target-absent trials. Conventions are the same as in Fig. 2.

absent conjunction condition showed no main effect of group [$F(2, 15) = 2.9$; n.s.], but a main effect of hemifield [$F(1, 15) = 28.9$; $p < 0.001$] and a group × hemifield interaction [$F(2, 15) = 28.5$; $p < 0.001$]. Simple effects of this interaction showed a significant effect of hemifield for the VAD group [$F(1, 15) = 45.1$; $p < 0.001$], with more than twice as many errors with right-hemifield displays than with left-hemifield ones. No significant effect of hemifield was observed in the control [$F(1, 15) = 4.3$; n.s.] and nVAD groups [$F(1, 15) = 1.8$; n.s.].

To summarize, the error data on target-absent conditions has indicated, for all groups, that accuracy when one of the two target features was absent in the distractor (shape-absent and color absent) was similar for left- and right-hemifield displays. In the conjuction condition, performance again did not differ between the hemifields in the control and nVAD groups. In marked contrast however, a very large error rate was observed in the VAD group with contralesional (right-hemifield) stimulation relative to ipsilesional (left-hemifield) displays. This latter result indicates that contralesional conjunction displays constituted a special difficulty for the VAD group and thus points to a feature integration impairment. In particular, the high error rate shown by the VAD group with right-hemifield conjunction displays suggests that they often wrongly combined the circular shape of one distractor with the red color of another (illusory conjunction), thus leading to the erroneous perception of the target. This proposition needs to be assessed more formally however, by establishing the frequency with which each group perceived illusory conjunctions with left- and right-hemifield displays. Indeed, false alarms in the conjunction condition may occur not only from illusory conjunctions, but also from the misperception of one feature (e.g., seeing a triangle as being a circle). The rate of illusory conjunctions may be determined on the basis of the false alarm data from the various distractor conditions used in the present experiment.

False alarms in the shape-absent and color-absent conditions (feature errors) indicate the frequency of erroneously perceiving the target-shape or the target-color, respectively, when it was not presented. False alarms in the conjunction condition (conjunction errors) may result either from a feature error or from an illusory conjunction. The rate of conjunction errors that result from a misperceived feature (feature error) can be predicted from the false alarm rates in the shape-absent and color-absent conditions. Any additional false alarms in the conjunction condition are counted as illusory conjunctions.

Thus, the rate of illusory conjunctions was inferred by subtracting the estimated proportion of trials on which a subject would misperceive either or both the target-shape and target-color (determined from the shape and color feature errors) from the rate of conjunction errors. Specifically, the rate of illusory conjunctions was calculated separately for each subject and each visual hemifield (Fig. 4) according to the following formula:

$$p_{(ic)} = p_{(co\text{-}e)} - [1 - (1 - p_{(f\text{-}e)})(1 - p_{(c\text{-}e)})]$$

where $p_{(ic)}$ = proportion of trials on which an illusory conjunction was perceived; $p_{(co\text{-}e)}$ = proportion of false alarms in the conjunction condition–conjunction errors; ($p_{(f\text{-}e)}$) = proportion of false alarms in the shape-absent condition–shape errors; ($p_{(c\text{-}e)}$) = proportion of false alarms in the color-absent condition–color errors.

An analysis of variance applied to the illusory conjunction rates with group and hemifield as factors indicated no main effect of group [$F(2, 15) < 1$] but a significant main effect of hemifield [$F(1, 15) = 37.4$; $p < 0.001$] as well as a group × hemifield interaction [$F(2, 15) = 51.0$; $p < 0.001$]. No hemifield effect in the proportion of illusory conjunctions was seen in the control [$F(1, 15) = 4.2$; n.s.] or the nVAD groups [$F(1, 15) < 1$]. However, a very large hemifield difference in the rates of illusory conjunctions was observed in the VAD group [$F(1, 15) = 102.2$; $p <$

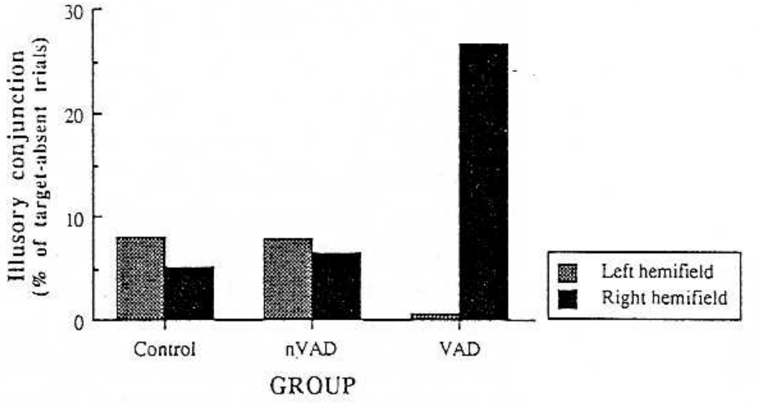

FIG. 4. Average illusory conjunction percentages observed for each group (control, nVAD, and VAD) and each visual hemifield (left and right).

0.001], with a higher rate of illusory conjunctions perceived with right-hemifield (contralesional) than left-hemifield (ipsilesional) displays. The rate of illusory conjunctions perceived with right-hemifield stimulation was 5.2 and 4.2 times higher for the VAD subjects than for the control and nVAD subjects, respectively.

DISCUSSION

The main result of the present experiment is the massive hemifield asymmetry in the rate of illusory conjunctions perceived by the VAD subjects (Fig. 4). Two facts indicate that this asymmetry is not the result of a deficit in encoding single features, but rather results from a deficit in integrating these features. First, as can be seen in Fig. 3, VAD subjects showed roughly comparable rates of feature errors with left- and right-hemifield stimulation, as did the control and nVAD groups. This latter result thus shows that the attention deficit suffered by VAD subjects dissociates from any impairment of feature encoding. Second, in the calculation of illusory conjunctions rates, any potential effect of feature errors has been removed, as can be seen in the formula presented above. Moreover, the feature integration deficit of the VAD group may not be explained by a non-specific effect of brain damage on feature integration. Indeed, the nVAD subjects, who also suffered from brain damage, showed a similar feature integration performance with left- and right-hemifield displays.

Our observations thus indicate a clear correlation between the deficit suffered by VAD subjects in allocating visual attention to contralesional items and a disorder in integrating the constituent features of these stimuli. There are reasons to believe that this relationship is not merely circumstantial. First, the most important result observed in the VAD group refers to a difference between hemifields in the rates of illusory conjunctions perceived. Hence, this observation may not be attributed to a hypothetical subject bias but rather to the attention deficit which served, a priori, to define the subject groups. Second, in a case-by-case analysis, the smallest hemifield difference in illusory conjunction rates in any VAD subject is of 20.4% while the largest hemifield difference in any nVAD subject is of 7.7%. This clearly underlines the dissociation in feature integration performance between subjects with an attention disorder and those without.

Another point which deserves mention is the lack of an hemifield difference in error rates in the VAD group on target-present trials with conjunction displays (Fig. 2, rightmost panel). Indeed, given their severe feature integration deficit for contralesional stimuli, as demonstrated by their illusory conjunction rate with these displays, one might be led to also expect poor performance from the VAD group in the conjunction condition on target present trials. It must be noted however that a feature integration impairment may operate in two opposing ways on target-present trials. On the one hand, the deficit may involve problems in integrating the constituent features of the target, making its detection more difficult. This effect will thus tend to increase the number of target-absent responses on target-present trials. On the other hand, the integration deficit may involve a loss of localization for the features displayed, leading subjects to erroneously conjoin distractor features so that they form a percept that corresponds to the target. Hence, this will tend to increase the number of correct responses on target-present trials, although for the wrong reason. These two antagonist effects may have cancelled each other out in the target-present trials or, alternatively, one may have been somewhat stronger than the other.

From the observations reported here, we suggest that a reduction in attention allocation to the stimuli presented does not affect the encoding of their constituent features, but results in a massive deficit in integrating these features. By extension, this implies that feature encoding is a preattentive process but that attention provides a critical contribution to the feature integration operation in normal perception, as held by Treisman's feature integration theory. The special role of spatial attention in the feature integration process may be due to the fact that the constituent features of an object (i.e., shape, color, etc.) all have one property in common, namely their location. Hence, attentional selection of an item on the basis of its location may allow the rapid and simultaneous access to the features that share this location (Koch & Ullman, 1985).

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