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Temporal Segregation Deficit in Visual Perception: A Single Case Study

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Abstract

The patient (LD) presents a visual deficit in temporal segregation. PET scan showed a bilateral hypometabolism in the superior parietal, temporal and occipital cortex. Neuropsychological data revealed that memory, attention and language functions were almost completely preserved. Visual sensory tests showed that visual acuity, depth and colour perception were normal, whereas detection of apparent motion direction, flicker fusion and saccadic eye movements were abnormal. Shape drawing was impaired whereas shape recognition (and naming), with either static or dynamic stimuli, was good. LD failed in tasks requiring integration of elements to produce a whole image (line drawings, degraded and textured shapes). On the other hand, LD's performance was good in tasks not involving spatial integration, such as visual search and letter-by-letter reading. The main finding is that LD failed in tasks requiring temporal segregation. These tasks involved shape recognition when different shapes (Experiment 1a) or different parts of either a word or a shape presented successively on the same retinal locus with (Experiments 2b, 3a, 3b) and without (Experiments 4a, 4b) eye movements. Finally, LD has no problems in tasks (4c) involving temporal integration alone. Taken together, these results suggest damage to a general mechanism involved in temporal segregation.

Introduction

Wundt (Wundt, 1911) observed that events which follow each other are organized and structured by the visual system. This may occur in two different ways. First, to maintain continuity, successive stimuli are integrated into a single unitary percept (Di Lollo and Dixon, 1992; Dixon and Di Lollo, 1994). Second, to allow detection of rapid changes, overlapping retinal images of stimuli sequentially presented are segregated from each other and assigned to distinct objects and events (Breitmeyer, 1984).

There are various examples of human capability to segregate sequential stimuli from each other. One example is the integration across saccadic eye movements. Since each fixation is followed by a period of visible persistence, the contents of two successive fixations should merge into temporally integrated double images. This does not occur in everyday life because of the visual system's ability to keep successive fixations as segregated. Another example is 'aperture viewing' in which the figure moves horizontally behind a stationary vertical slit. The figure is perceived as a whole, although only a narrow strip of it is visible at any single instant on the same retinal locus.

It has been suggested that in many circumstances, the visual system's ability to keep following images as segregated may be due to saccadic suppression of the persistence of leading fixation by trailing fixation. However, saccadic suppression cannot be the only explanation. For example, Rubin and Turano (1992) have shown that reading is possible in the absence of saccadic eye movements and can be as fast as 1171 words per minute when the reading text is presented one word at the time at the same location in the visual field. Moreover, it has been shown that the 'aperture viewing' phenomenon occurs without tracking eye movements and it is not equivalent to seeing the shape with all its parts physically present at the same time as suggested by the retinal painting explanation (Anstis and Atkinson, 1967). Indeed, retinal painting is eliminated in standard motion perception because of tracking.

The visual system's capability of temporal integration and segregation has been recently documented by Di Lollo and co-workers (Dixon and Di Lollo, 1994), using two brief sequential overlapping displays separated by a brief inter-stimulus interval (ISI): the subjects perceive the two

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patterns either as temporally segregated or integrated depending on the presentation time and ISI. A more classical example of integration is the absence of smear with moving objects. While an object moves, its retinal image persists for about 100 ms at each retinal locus; nevertheless the object is perceived unblurred even when it is not tracked (Burr, 1980).

Important suggestions regarding the underlying mechanisms of temporal integration and segregation may come from studying the performance of brain-damaged patients. In this paper we present data from a patient, LD, whose PET scan revealed a bilateral hypometabolism in the temporal and occipital cortex and in the superior lobules of the parietal cortex. The patient showed selective impairment in many tasks involving temporal segregation of visual information. The deficit in processing overlapping successive images was present regardless of whether the images were separated by saccadic eye movements or not.

In attempting to understand LD's deficit, we also hoped to make some inferences on the normal functioning of integration and segregation mechanisms. Several tasks were used. One was apparent movement. A second method was visual temporal integration in which detectability depended on the subject's capability to integrate successive images. A third method was visual temporal segregation, tested with both whole and fragmented shapes. To test temporal segregation with whole images a rapid serial visual presentation (RSVP) technique was used. To test temporal segregation with segmented shapes we used either the 'moving slit' (in which a vertical slit is moved along a static figure) or 'aperture viewing' (in which a figure is moved horizontally behind a vertical slit). In both 'aperture viewing' and 'moving slit', normal observers can perceive the figure as a whole, although only a narrow strip of it is visible at any single instant. We will show that whereas for normal observers object recognition is good in all conditions, LD performed normally in the visual temporal integration task, whereas he failed in all temporal segregation tasks. These results suggest that LD suffers from a deficit in the mechanism responsible for keeping successive images perceptually disjoint.

The patient

The patient, LD, a 72-year-old man, underwent a neuropsychological assessment in November 1991, following an ophthalmological diagnosis of 'Reduction of the visual field' and a MRI report of generalized atrophy of supra- and sub-tentorial cortical structures (see Table 1 for a summary of neurophysiological exams made from 1991 to 1995). Several ophthalmologic examinations failed to find the nature or cause of his visual difficulty. He began having visual difficulty in 1990, when he first noticed he was unable to play bowls any longer and he started having spatial orientation problems; he was able to walk around the rooms in his flat without bumping into objects, but he progressively became insecure and decided to stop going out alone.

Averaged transient visual evoked potentials (VEP) using a counterphase modulated checquerboard pattern, were measured in 1991, 1993, 1994 and in 1995. Measurements consistently showed an amplitude reduction and an increase of both latency and wavelength of the first positive and negative wave which is likely to depend on a desynchronization of visual responses to the transient stimuli. MRI, conducted in 1994, showed no changes from the preceding one. A PET scan in 1994 demonstrated bilateral hypometabolism of occipital and temporal lobe and of superior lobules of parietal lobe (Fig. 1).

Neuropsychological evaluation of basic cognitive functions was conducted in 1991 and repeated during the following years. Performance in the Mini Mental State Exam, which aimed at evaluating the general cognitive functions, was low but constant (20/30 ± 1): he made mistakes mainly in copying drawings, reading and calculation. In 1995, scores in Wechsler Performance IQ and Wechsler Verbal IQ tests were 78 and 119 respectively (subtest scores pooled averages were: general culture 10, comprehension 12, digit span 6, arithmetic reasoning 7, analogies 11 and vocabulary 11; story ordering 3, figures completing 0, cubes arrangement 1, figures assembly 0 and digit symbol combining 0). His speech was fluent without paraphasic errors. LD was very poor in copying drawings and drawing from memory. His performance was within

Table 1. Results of neurophysiological tests

Test	1991	1993	1994	1995
EEG	Normal			
MRI	General cortical atrophy		As before	
PET			Bilateral temporo-occipital and sup. parietal hypometabolism	
VEP[a]	L: normal A: reduced W: increased	L: delayed A: reduced W: increased	L: delayed A: > reduced W: increased	L: delayed A: > reduced W: increased
ERG	Normal		Bilateral reduction of amplitude	

[a] VEPs were measured with transient-patterns; L refers to latency, A to amplitude, W to the wavelength of the VEP. P300 was small and delayed.

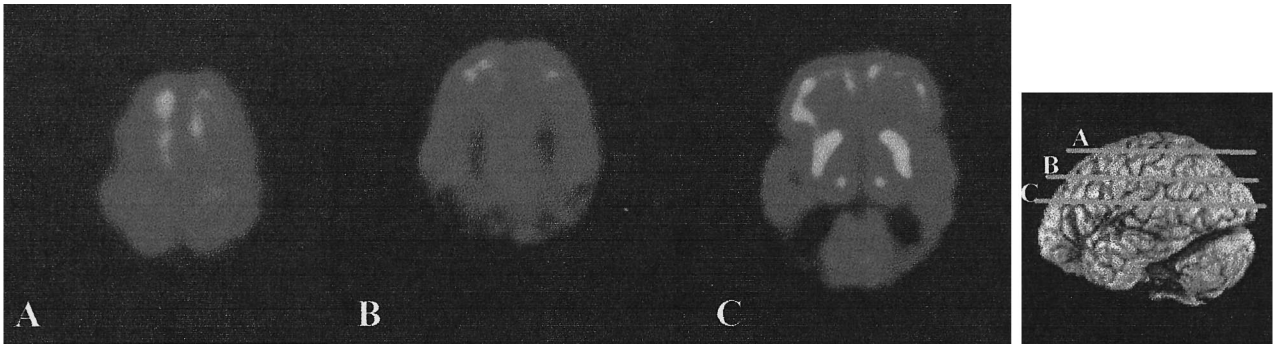

Fig. 1. Horizontal blood flow PET sections obtained from LD, while he was resting quietly with eyes closed. The patient was scanned with infusion of 18F-FDG as the tracer, following intravenous injection of 260 MBq. PET scans, obtained with metabolic tracer, show a severe hypoperfusion in the superior parietal, temporal lobes and in the occipital gyri bilaterally. The reduced metabolism was more evident on the right hemisphere than on the left.

the normal limits in all attention tests administered; he made no errors in a line bisection test. Performance was below normal limits in anterograde memory tests. He was submitted to some short-term memory tasks: repetition of three long sentences was within the normal limits, digit span was 6. Performance on long-term memory tasks was: learning of a list of words $z = -2$ (relative to 10 age-matched controls), incidental memory $z = -1.2$ (relative to 12 age-matched controls).

Visual perception

Sensory functions

Visual acuity

Visual acuity was measured in 1994 by using a gap resolution task similar to the Landolt-C test (Riggs, 1965) with line segments of 3′ wide and 2°10′ (3 minutes of visual angle and 2 degrees and 10 minutes of visual angle) long and separation levels of 0, 13.74″, 17.7″, 23.41″, 27.22″, 29.76″, and 34.92″ (seconds of visual angle). Using a two-alternative forced-choice procedure, thresholds were defined as the minimum separation between the two lines which could be detected 75% of the time, and were within the normal limits (below 1′) for LD and two age-matched controls.

Visual field measurements (in 1991, 1992, 1993 and in 1994) showed a peripheral visual field loss but they were inconsistent and not reliable.

Contrast sensitivity

Contrast sensitivity, which is the reciprocal of contrast threshold, was evaluated for spatial frequencies of 0.66, 1.5, 3, 6, 12, 24 and 49 c/deg. LD's contrast sensitivity (Fig. 2) was normal at all but the highest (48 c/deg) and lowest (0.66 c/deg) spatial frequencies tested. This result indicates that LD did not present the changes in the shape of contrast sensitivity usually associated with peripheral visual field loss (see ERG results in Table 1).

Disparity

We tested LD and two normal age-matched observers with a variety of complex random dot stereograms (a square, a triangle, a saddle-like shape with a ring around it, a spiral staircase, etc.). Each random dot stereogram consisted of anaglyphs defined by two similar images containing random dots with no shape cues. The two images, overlapping and slightly horizontally displaced, were painted, the left in red and the right in green, and viewed with red/green spectacles to allow the component pictures to be presented separately to the two eyes. LD perceived anaglyphs as three-dimensional easily and even better than one of two age-matched controls.

Flicker fusion

A binocular flicker fusion task with a variable flicker rate LED was used. In each of the total 16 trials (four repetition of two fields – left versus right – and two LED voltages – 5 V versus 12 V) the frequency was varied along a

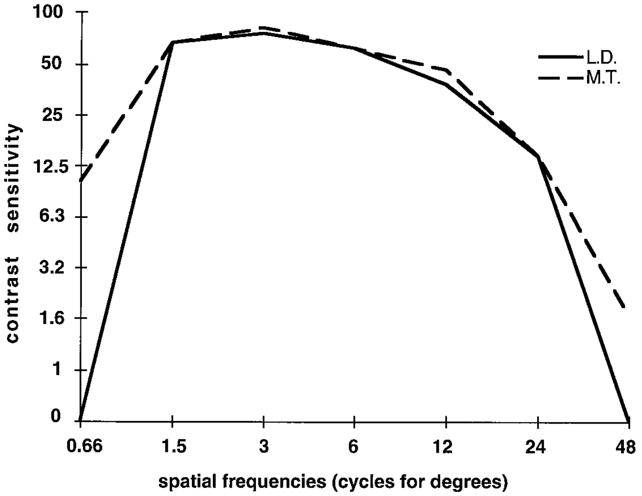

Fig. 2. Contrast sensitivity was evaluated with the Maione–Maffei test (Linea Oftalmologica Angelini) for spatial frequencies of 0.66, 1.5, 3, 6, 12, 24 and 48 cycles per deg independently for LD and control (MT).

continuum either from the lowest to the highest or vice versa. The observer's task was to report when the LED stopped or started flickering. Critical flicker fusion for LD and an age-matched control group of 13 subjects was equal to 31 Hz and 39 Hz respectively (cf. Tagliaro, 1994). Results of a *t*-test show that these values differed significantly ($P < 0.01$).

Motion detection

Observers' ability to detect the displacement direction of a bright spot (0.8′ in diameter) in apparent motion, was measured over a block of 90 trials. The distance between the two spots was varied randomly from trial to trial according to five levels (0, 1′, 2′, 3′ and 4′) for each of two displacement directions. Percentage of correct responses as a function of displacement was measured for LD and an age-matched control subject. Whereas for the normal observer performance increases as the displacement increases, LD's performance was at chance level regardless of displacement. Since frame duration (20 ms), IFI (20 ms) and displacement (from 1′ to 4′) were chosen to produce optimal apparent motion (Braddick, 1980), the former findings are indicative of impairment of motion processing rather than location discrimination. This is also confirmed by the visual acuity experiment which shows that resolution for relative location of two lines is very good (below 1′).

Eye movements

Eye movements were recorded using an infrared device. The stimulus, first used by Pavlidis (1985), consisted of a bright circle with a diameter of 0.5°. The circle successively appeared for 0.5 s, from left to right, then right to left across five locations each separated by 5°. During five cycles of presentation, the observer's task was to gaze at the circle and move his eyes to its new position. Figure 3 shows eye movements recording for LD and a normal age-matched observer. As it appears, eye movement amplitudes (on the vertical axes) and latencies (on the horizontal axes) are very regular in the normal subject and they match the spatial and temporal separations between successive circles. On the other hand an inspection of LD's recording showed that the patient was incapable of moving his eyes at the proper time and position. His eye movements recording shows a pattern characterized by regressions, short saccades, reduced span and anticipatory saccades. This pattern is common in patients with abnormal vision when performing tasks similar to the one we used but also other tasks like reading (Jones and Stark, 1983). LD's eye movement patterns are abnormal and they are indicative of either a primary problem in controlling eye movements or an impairment in the visual input registration. Since these two explanations cannot easily be disambiguated, crucial perceptual tasks not involving eye movements were devised.

To summarize, results of sensory tests show that LD presents normal visual acuity and stereopsis; whereas his performance is abnormal in motion detection and saccadic eye movements, his temporal resolution is low.

Shape detection and recognition

To assess whether LD presents a problem in visual perception we asked him to execute a set of tasks requiring either shape detection or recognition. These tasks were: Efron test (Efron, 1968), Gollin test (Gollin, 1960), Visual Recognition of Textures (Battelli *et al.*, 1997). Figure 4 shows the proportion of correct responses in these sets of shape perception tasks.

The Efron test consisted of a set of pairs of black geometrical shapes (squares and oblongs) that were matched for their surface area and equated for total flux. The subject had to perform a same/different task in which he had to judge the size of the shapes in each pair of squares differing in side according to seven levels (0, 0.2, 0.4, 0.6, 0.8, 1, 1.2 deg). In the second condition the subject was required to judge whether the individually presented shape was a square or an oblong. Performance in task 1 and 2 respectively was 75% and 83% correct for LD and 100% and 100% in two age-matched controls.

In the Gollin test (Gollin, 1960) the subject was presented with the fragmented version of 30 line drawings; if the subject was not able to identify the very fragmented

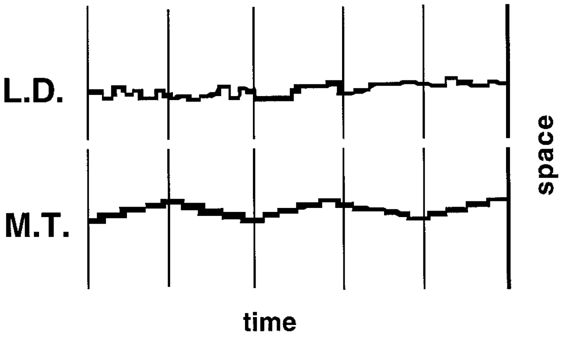

Fig. 3. The amount of displacement of the eyes (ordinate) is shown as a function of time for LD and an age-matched control (MT).

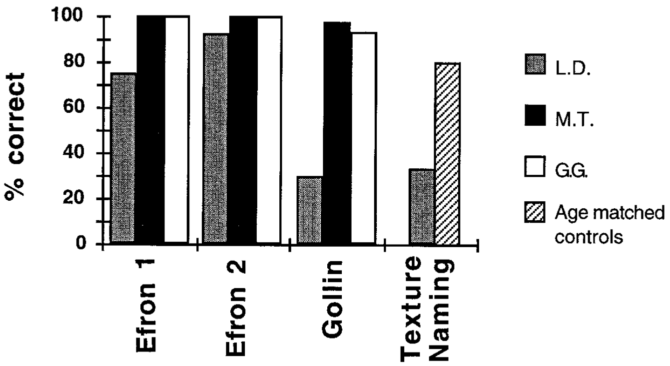

Fig. 4. Percentage of correct responses in four tasks requiring detection and recognition of shapes. Results are recorded for LD, two age-matched controls (MT and GG) for Gollin and Efron, six age-matched control subjects for texture naming.

version he was shown the increasingly complete versions of the drawings across five levels until the object was identified. The proportion of correct responses for LD and two control subjects was 30%, 97% and 93% respectively.

The visual texture naming task consisted of naming visually presented textures with no contour cues (black and white photos: e.g. human skin, wool). The subject was presented with 12 pictures of real textures with an unlimited exposure time. LD's proportion of correct responses was 33%, whereas six age-matched control subjects' proportion was 83%.

Object identification

LD was submitted to a variety of object identification and naming tasks to assess his ability on high-level visual processing.

In naming based on visual or verbal definition, the subject was required to produce a name corresponding to a functional encyclopaedic description of six items for each condition (for example, 'which animal produces honey, flies with two wings and may be dangerous for his jab?') or to a visual description (for example, 'which is the big grey animal with two big ears and a very long nose?'). LD's performance was within the normal range (z score of -0.2 and 0.4 respectively).

In the tactile matching test, the subject had to match one tactile texture with no contour cues to three real objects (12 trials). Proportion of correct responses was normal and equal to 75%, 100% and 100% for LD, MT and GG (chance level in this task is 33%).

In the visual matching task, subjects were asked to match one incomplete part of an animal with four examples of missing parts each belonging to a different animal; for example, the subject had to match the body of a horse with no tail, with four different tails (those of a pig, a dog, a cow and a horse). The 16 stimuli were presented one at a time to LD, who was told to point to the appropriate part for each body. LD performed within the normal limit ($z = -1.49$). He reported 75% correct responses, MT 100% and GG 94% (chance level in this task is 25%).

The proportion of correct responses for LD and two age-matched observers in these tasks is shown in Fig. 5. LD's performance was relatively good, suggesting that the patient could perform object identification and naming tasks. Overall these data show that LD had no major impairment in object identification. Indeed he can name from verbal description ($z = 0.46$) with the same accuracy as naming from visual description ($z = 0.41$).

To summarize, LD presents normal visual acuity; he seems to be able to employ knowledge about objects to identify certain image structures as corresponding to a particular object, indeed he has no major problems in identifying and naming objects. Like patients with apperceptive agnosia he is impaired in some low-level tasks: copying drawings and some shape recognition tasks (Gollin test and visual texture tests), but not in the Efron test, (Benson and Greenberg, 1969; Efron, 1968; Ettlinger, 1956; Warrington, 1985; Warrington and James, 1986). A similar difficulty in identifying shapes with degraded, but not with well defined, contours is a feature of integrative agnosic patients (Riddoch and Humphreys, 1987).

Experiment 1: tasks requiring visual integration of elements in space

In the first experiment we measured LD's performance in shape recognition tasks involving integration of features elements. Two shape recognition tests were used (Experiment 1a: shape naming; Experiment 1b: shape segregation) to investigate the nature of the deficit in the processes involved in shape recognition.

Experiment 1a: silhouettes versus line drawings

Although silhouettes are not inherently easier (normal subjects found them more difficult), they require lower-level processing because of reduced internal detail and they are better recognized than line drawings both in apperceptive agnosic (Marr, 1982; Benson and Greenberg, 1969; Efron, 1968; Ettlinger, 1956) and in integrative agnosic patients (Riddoch and Humphreys, 1987), who are not capable of grouping elements to elaborate the global shape description.

In Experiment 1a we compared LD's performance in naming silhouettes versus line drawings to establish whether he showed an impairment in integrating form information.

Stimuli and method

The Silhouettes condition consisted of 47 black figures and 47 line drawings representing the same figures. In both conditions the observer task was to name the stimulus. The

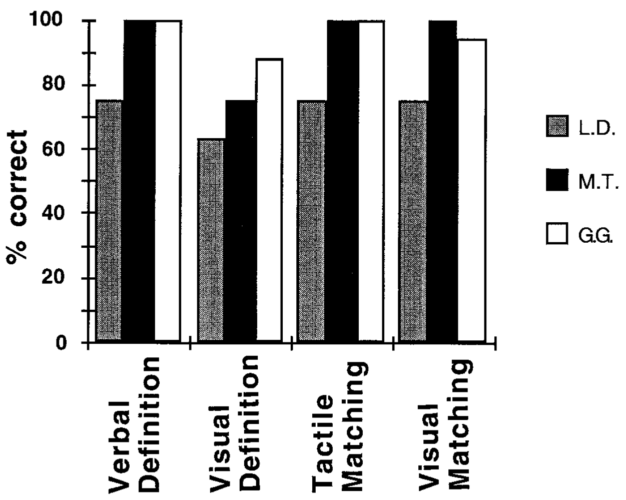

Fig. 5. Percentage of correct responses in four object recognition and naming tasks for LD and two age-matched controls (MT and GG).

pictures were extracted from Snodgrass figures (Snodgrass and Vanderwart, 1980).

Results and discussion

Percentages of correct responses were lower with line drawings (79% versus 44%) for LD but not for two normal observers (100% and 96% versus 92% and 95% respectively). LD's performance was below normal limits ($z = -4.9$ in silhouettes and $z = -15.8$ in line drawings). Moreover, a statistically significant difference among results of the two tests (Chi-test: $P < 0.001$) indicates that different levels of difficulties are involved in the visual recognition mechanisms.

This confirms that the low-level processes involved in simple shape recognition are intact in LD whereas an impairment is likely to be present at the stage of analysis and combination of features to produce a global shape description.

The suggestion that LD suffers from a problem in integration of elementary aspects of the stimulus will be further tested in Experiment 1b.

Experiment 1b: detection of degraded shapes

The result of the Efron test shows that LD is capable of distinguishing a square from an oblong and comparing the size of either two squares or two oblongs. Second, the result of the Gollin test shows that LD's performance is strongly impaired with degraded figures. Boucart and Humphreys (1992) pointed out that a difference between line drawings and structurally fragmented shapes may be due to a difference in the perceptual structure of the stimulus. This question was addressed in Experiment 1b by using degraded Efron shapes.

Stimulus and method

The stimulus consisted of a squared black region (10.5 cm of side) which contained a white rectangle (6.2 × 3.5 cm) with its longer side on either the horizontal or vertical axis.

In the first condition, the stimulus was masked by a random dot pattern and the masking dots were white in the black background and black in the white central rectangle. The number of dots defining the masking pattern was varied according to six levels (0, 7500, 15 000, 22 500, 30 000 and 37 500) for both horizontal and vertical orientation of the central rectangle.

In the second condition, only the non-degraded version of the stimuli was presented. The level of luminance of the central rectangle (Lmin) and of the background (Lmax) was varied according to six levels (within the range of the normal section of the contrast sensitivity function). At each level, Lmax and Lmin matched that of the corresponding level in the degraded condition, as resulted from the phenomenological reports of six naive subjects which were asked to judge 10 repetitions of 10 levels of Lmin/Lmax ratio.

Within two blocks of 39 stimuli randomly presented, three trials were devoted to each stimulus level (either of masking density or Lmin/Lmax ratio) for both vertical and horizontal orientation. The percentage of correct responses was calculated separately for the mask and the luminance condition, for each of 36 stimuli plus three catch trials in which the target was not present.

The stimulus was viewed in normal lighting at a distance of 80 cm. The observers had to perform a two-alternative forced-choice task in which they had to detect the orientation (horizontal versus vertical) of the central rectangle.

Results and discussion

The results are shown in Fig. 6 independently for LD and two age-matched control observers. While normals can perform the task in the degraded and non-degraded condition with the same level of accuracy, LD presented a decrease in performance but only in the degraded conditions. This result is compatible with the hypothesis that LD presents a difficulty in integrating fragmented elements in a whole stable percept.

Experiment 2: tasks not requiring visual integration in space

Coslett and Saffran (1991) and Riddoch and Humphreys (1987) have described patients who presented a deficit in the mechanism which serves to integrate information in the visual field. Nevertheless these patients do not present an impairment in preattentive processes involved in simple search which consists of registering visual information simultaneously presented at different locations in space, because the integration is not required. If LD presented a deficit selective for visual integration of elements in a perceptual whole, he should not present difficulties in tasks

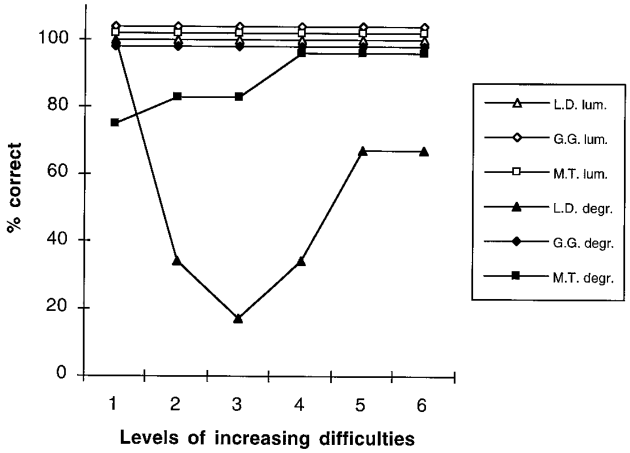

Fig. 6. Percentages of correct responses, for LD and for two age-matched controls (MT and GG), as a function of contour definition (1: maximum definition; 6: minimum definition) in either degraded condition (degr.) and luminance condition (lum.).

which do not require visual spatial integration. Two tasks were designed to check this possibility: parallel visual search and reading through a hole.

Experiment 2a: visual search task

By asking the patient to perform a parallel visual search task we hoped to assess better the level of his visual processing deficit.

Stimulus and method

The task consisted of searching for a line (1.35° long and 0.08° wide) embedded in a background of randomly presented circles (1.2° in diameter). All elements were black presented on a white background on a Macintosh computer screen. The stimulus area was equal to 11.75°×11.75°. The number of distractors (set size) varied according to four levels (3, 5, 7 and 9). In half of the trials the target was present and in the other half it was absent. Within a block of 24 trials, three trials were devoted to each distractor number for both target present and target absent conditions. Exposure duration was varied independently according to four levels (50, 150, 300, 500 ms). Our purpose was to establish how search strategy depended on the interaction between the exposure time and distractors' numerosity (Nakayama and Silverman, 1986). We assumed that if search is not parallel, the percentage of correct responses should decrease as search time decreases, and more so when non-target numerosity was large. On the other hand, if search is parallel, the number of correct responses should be independent of exposure time regardless of non-target numerosity. Moreover, we aimed to compare visual search performance by decreasing exposure duration from 500 to 50 ms, to compare performance when eye movements were possible (500 and 300 ms exposure) with those conditions in which eye movements could not occur (150 and 50 ms).

Results and discussion

Since LD was abnormally slow in responding, reaction times (RT) are not very reliable as a dependent variable. However, RT data for LD are informative about his visual search performance. By analysing RT in the condition with fewer errors (50 ms exposure) it appears that RT are shorter in the present than in the absent condition and they do not depend on non-target numerosity. Indeed, with non-target numerosity of 3, 5, 7 and 9, RT were equal to 932, 1047, 957, 1235 ms in the present and to 2748, 2015, 1668 and 1968 ms in the absent condition. Although RT were slower the trend in the other exposure conditions (150, 300 and 500 ms) was similar indicating that a parallel search strategy was used in this task. In Fig. 7 the number of errors is expressed as a function of exposure time. Results show that LD can perform the simple search task correctly. Two aspects of these results have to be considered. First, since both percentage correct and reaction time do not depend on non-target numerosity at any exposure time, these results suggest that LD's preattentive parallel search mechanisms are intact. Second, results show some improvement in performance (the number of errors of mean RT decrease) as the viewing time is reduced. Since eye movement recording shows that LD's mean and standard deviation of fixation length were long (170 and 63 ms, see Fig. 3), saccades in the two longest exposures are possible for LD and this can explain the duration effect.

Experiment 2b: reading

Results of Experiment 2a show that LD performs well in visual tasks which do not require integration of features in space.

When reading a whole line of text, both integration in space to extract a word out of its constitutive elements and correlation between successive fixations are required. A second task reducing the role of spatial integration in visual recognition is reading through an aperture (2° width). We further tested in Experiment 2b whether a deficit on visual integration is responsible for LD's visual difficulty by comparing LD's performance in normal reading with that in letter-by-letter reading.

Stimulus and method

Black words, laser-printed on white paper, were used. Letter size was equal to 1.7° approximately. All high-frequency words (among the first 2000 most used words of the Italian language) (Thornton *et al.*, 1994) were used and their length was varied from trial to trial according to four levels (1: one letter; 2: two–three letters; 3: four–five letters; 4: six–eight letter words). In the first condition, five words were presented for each length condition. The whole words were presented one at the time with free viewing time.

In the second condition, the letters defining the word were presented in isolation with unlimited viewing time. By using a hole equal to a single letter size, we showed to LD the letters defining the words one at a time (with unlimited exposure time). When all letters were presented, the subject had to say the word he had read.

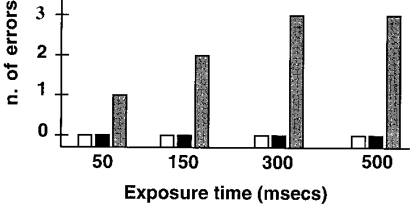

Fig. 7. Number of errors as a function of exposure duration of stimulus in the visual search task is shown for LD and two age-matched controls (MT and GG). Data are shown independently of distractors' numerosity.

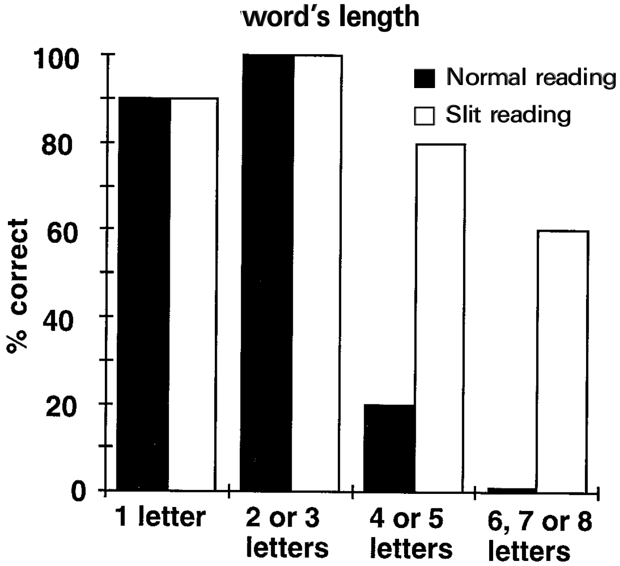

Fig. 8. Percentages of words read as a function of word length are shown in two conditions: with hole (slit reading) and without hole (normal reading). The figure shows LD's results.

Results and discussion

The percentage of words read are shown in Fig. 8, in the two conditions: with and without a hole. In reading whole words with unlimited exposure time, accuracy clearly decreased with increasing word length. In contrast, accuracy was very little affected by word length when reading words one letter at a time through a hole.

These findings suggest that letter-by-letter reading in LD can be due to a difficulty in integrating perceptual elements (letters) in a whole (words). When reading through a hole, word representation is achieved by combining the letters in a word after each of them has been visually recognized in sequence. In these viewing conditions LD's capability in reading words strongly improves.

Experiment 3: visual tasks involving temporal segregation but not spatial integration

The results of Experiments 1 and 2 suggest that a spatial integration problem is certainly present. However, LD presents serious problems in temporal aspects of vision, i.e. eye movements, motion perception and flicker fusion. One important question is how these difficulties in temporal processing affect visual recognition. More precisely, one may ask whether difficulty in low-level temporal processing affects performance in higher-level temporal processing tasks.

In Experiments 3a and 3b spatial integration is not involved whereas eye movements and temporal integration are involved.

Experiment 3a: recognition of moving shapes

In Experiment 3a we tested LD's ability to recognize moving shapes. The shapes used were silhouettes like those used in Experiment 1a, which were easily perceived in static viewing. Since the patient presents a deficit in the perception of motion as well as in eye movements, performance is likely to be reduced.

Stimulus and method

Six stimuli were used: two geometrical shapes (a square and a circle), two letters (an A and a V) and two figures (a cat and a horse). Figures were filled (as in Silhouette of Experiment 1a). Stimulus area, that is the area within which the stimulus was presented, had an average width and height of approximately 3.5° and 2.5°. Three independent stimulus velocities were used (0, 1° and 2° per second). In each condition, all six stimuli were presented in random order and the observer's task was to name the shape moving along a 20° horizontal path.

Results and discussion

Performance in this task was 100% correct. These results suggest that LD is capable of recognizing both static and moving silhouettes. Both psychophysical (Anstis, 1980; Braddick, 1980) and neurophysiological (Mikami *et al.*, 1986; Manning *et al.*, 1988) studies have shown that the motion task in Experiment 3a involves different mechanisms from that activated in the low-level motion task which we have used to test sensory functions in our patient. Results in Experiment 3a provided further neuropsychological evidence on this point by showing a dissociation between these two motion tasks. We suggest that a difficulty in detecting low-level motion does not interfere with higher-level recognition of moving shape.

Experiment 3b: moving slit

To test LD's capability for temporal segregation, we presented the shapes behind a slit and moved either the slit ('moving slit') or the shape ('aperture viewing'). In the psychophysical literature, the 'aperture viewing' condition in which eye movements are not important to the phenomenon is used more than the 'moving slit' condition in which eye movements have to be taken into account. In normal viewing, in both conditions the stimulus is perceived as a whole although only a narrow strip of it is visible at any single instant (Casco and Morgan, 1984).

LD has been tested in the 'moving slit' and in the 'aperture viewing' in two sessions, 15 days apart (Experiments 3b and 4a respectively).

Stimulus and method

The same six stimuli used in Experiment 3a were used in this experiment. To simulate the appearance of a slit moving over the figure, only the parts of the figure falling within a notional slit were laterally displaced in succession. Slit height was equal to 4° and its width varied independently according to three levels: 3′, 8′ and 11′. Sweep length was fixed and equal to 6.6°. Each stimulus sweep consisted of a sequence of 70 frames, and approximately half of them contained stimulus features. Frame duration was equal to 200 ms. Velocity depended upon frame duration and was equal to 0.5° per second. Since the number of frames and the length of the stimulus trajectory was always the same, the amount of slit displacement from one frame to the next was kept constant to maintain velocity fixed in all slit conditions, and was equal to 5.6′. In this way there is some overlapping between frames mainly in the largest slit width.

The task was to name the shape. If the subject could not recognize the shape after the first sweep, the sweep was repeated up to three times before the next shape was presented. The order of presentation of the shapes was randomized.

Results and discussion

Results are shown in Fig. 9. LD responded at chance level at all windows (chance level in his task was 16.6%). This shows that LD was almost incapable of recognizing the shape regardless of slit width. Since subjects in this task have to track the moving window, the eye movement deficit in LD may have caused his performance to fall. To check this possibility eye movements were abolished in Experiment 4, which consisted of three temporal correlation tasks.

Experiment 4: visual tasks involving temporal segregation alone

Poor performance in some shape recognition tasks (Experiment 3b) may depend on an eye movement deficit. Why should an eye movements deficit cause performance to fall in LD? If we assume that LD's eye movements deficit also includes saccadic suppression, these results suggest a difficulty in keeping perceptually segregated successive images which fall on the same retinal locus. This could explain impairment in Experiment 3b and, if eye movements were involved in Experiment 1, a deficit in saccadic suppression could also explain difficulties in Experiment 1 because it causes integration and masking between images successively foveated. Reduced saccadic suppression increases masking and 'visual crowding' (Burr *et al.*, 1994).

However, visual crowding is often also perceived when the images overlap (as in masking by structure) and eye movements are not involved. Visual crowding is therefore an index of a difficulty in perceptual situations in which disjunction between following images is required regardless of whether eye movements are involved or not.

The question of which mechanism is responsible for perceptual visual segregation, either saccadic suppression or temporal segregation, is an interesting one, which has not yet received a clear answer in the psychophysical literature. This question was addressed in Experiment 4a and 4b by assessing whether impaired performance in a temporal correlation task is caused by a deficit in eye movements or by a difficulty in temporal segregation.

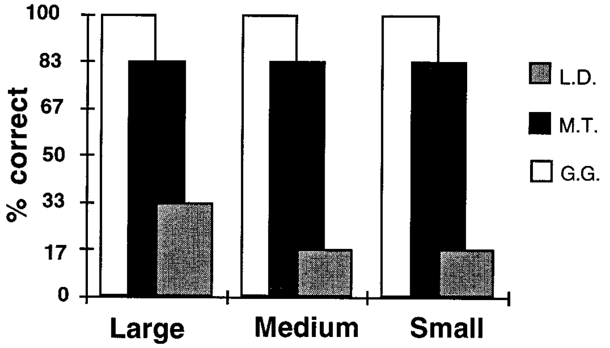

Fig. 9. The figure shows the percentages of correct responses for three slit width conditions of the moving slit task independently for LD and two age-matched controls (MT and GG).

Experiment 4a: aperture viewing

In this experiment we used the technique called 'aperture viewing' in which the figure moves horizontally behind a stationary vertical slit. As in Experiment 3b, in normal viewing the figure is perceived as a whole, although only a narrow strip of it is visible at any single instant. In the 'aperture viewing' phenomenon, eye movements do not account for the phenomenon (Morgan *et al.*, 1982; Casco and Morgan, 1984) and Morgan's data showed that shape identification does not improve at large velocities and therefore eye movements are neither necessary nor sufficient for the perception of the whole shape moving behind a slit.

Stimulus and method

Stimuli were the same as those used in Experiment 3a and 3b. To simulate the appearance of movement behind a slit, a vertical strip in the centre of the screen was defined as the area in which the pattern was to be made visible, and in each frame only the parts of the figure falling within a notional slit were displayed. Slit height and width and sweep length were the same as in Experiment 3b. To increase stimulus velocity, 35 frames were used so that 12′ of the whole sweep was visible in each frame. Not all frames contained stimulus features.

In this experiment, a psychophysical procedure consisting in a modified method of limits was used. Frame duration varied from 100 to 250 ms in independent trials. Since sweep length was fixed, stimulus velocity varied with frame duration and was equal to 1.6°, 1.3°, 1.1°, 0.94° and 0.8° per second. Each stimulus velocity level was presented three times. The experiment consisted of 18 blocks (three windows × six shapes) of 15 trials and in each block a different shape randomly chosen was presented. Using the psychophysical method of limits, absolute thresholds, defined as the velocity at which the shape could be recognized in 50% of the trials, could be measured. The observer task was to name the shape when he could perceive it.

Results and discussion

Results are shown in Fig. 10; these show that the number of shapes identified by LD increases as slit size is increased. The percentage correct is above chance at all but the smallest window conditions. This indicates that the patient can perform the task provided that a part of the shape large enough was seen in each frame. Since in normal observers slit size (from 4.5′ to 9′) has no effect (Morgan *et al.*, 1982), LD's results suggest that he performs the task by identifying static features at each frame. Moreover, thresholds were defined as the stimulus velocity at which the stimulus could be recognized in 50% of the trials and LD reached it only when the stimulus moved slowly (0.8° per second), whereas the age-matched control subjects' threshold was at a velocity of 1.6° per second. This finding is the opposite to that predicted by the retinal painting explanation which requires fast sweeps to allow all the parts of the shape to persist together on contiguous retinal locations.

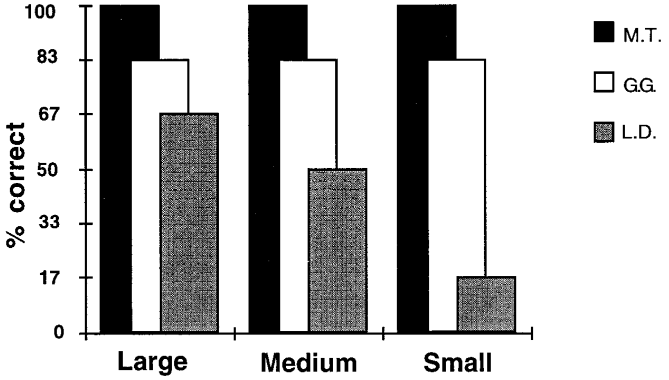

Fig. 10. Percentage of identified shapes as a function of window size for LD and two age-matched controls (MT and GG).

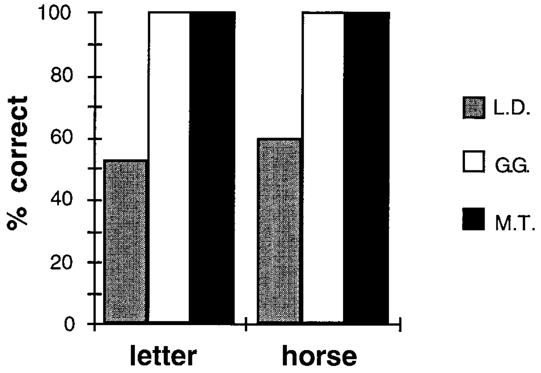

Fig. 11. Percentage of correct recognition of two stimuli (letter A and a horse) in RSVP for LD and two age-matched controls (MT and GG).

Experiment 4b: rapid serial visual presentation

In Experiment 4b we attempted to distinguish whether either eye movements or temporal segregation deficits affect shape recognition performance in LD. This was done by using a rapid serial visual presentation (RSVP) technique. In this technique, eye movements are abolished because stimuli are presented always on the same retinal locus. If LD's visual problems were related to a difficulty in temporal segregation the deficit should persist.

LD's performance in recognizing a target consisting of either a letter (the letter 'A') or a shape (a horse silhouette) in reduced viewing time condition was compared with that obtained when the same target was preceded and followed by a forward and backward mask using RSVP.

Stimulus and method

The experimental condition consisted of two blocks of 30 trials randomly presented; in each trial three stimuli (during 100 ms) were displayed. A letter 'A' (4°30′ × 4°30′) and a 'horse' (3° 30′ × 7°) were the targets and a random dot stimulus (4° 30′ × 7°) was the non-target. Half of the trials contained the target preceded and followed by a random dot pattern which created forward and backward masking respectively. On the other trials the non-target was preceded and followed by the two masks. Two separate blocks were presented, one for each stimulus target. In a preliminary control condition 30 stimuli were presented alone for 33 ms with an interval of 5 s between presentations; after each trial the subject was required to report if a target or a non-target was presented.

Results and discussion

Results are shown in Fig. 11. In contrast to the control, who performed 100% correct, LD was not able to perceive the target presented with a backward and forward masking stimulus (performance was at chance level with both targets: 53% of correct with 'A' and 60% of correct with 'horse'), whereas he could distinguish the target and the mask when presented alone (100% correct).

These results clearly show that LD fails in perceptual tasks requiring temporal resolution between images presented on the same retinal locus, despite the fact that eye movements are not involved. Low temporal resolution, as shown by flicker fusion performance, may explain the deficit. A temporal resolution difficulty may well explain LD's difficulty in keeping perceptually segregated successive overlapping images. If these images are not segregated they mask each other and produce visual crowding.

Experiment 4c: temporal integration

If LD presents a deficit in visual temporal segregation tasks, the hypothesis is that he should not have difficulty in tasks requiring temporal integration. We tested this by using a stimulus similar to that used by Di Lollo and Dixon (1988).

Stimulus and method

Stimuli consisted of 24 pairs of squared matrices of 8 × 8 small white or black squares. Each squared matrix was the reversal of the other and measured 4° 20′ in side. In half of the stimuli one of the two matrices did not reverse one small square. Observers normally match all the small squares in the unique white square on the black background by overlapping in extremely rapid sequence the two matrices of each pair. Observers normally see a hole in the position where a little square is not reversed.

During the experiment the observer sat in a dimly lit room. Stimuli were displayed sequentially on a screen monitor. In each stimulus the two matrices were separated by an inter-frame interval (IFI). Two blocks of 12 stimuli were presented: in the first block the possible hole position was fixed, in the second block the hole position was randomly varied. In each block the stimuli with and without hole were randomly presented. The observer had to report whether the hole was present or not. The matrix duration was 100 ms and IFI varied in independent blocks according to five levels (250, 125, 83, 66 and 50 ms).

Results and discussion

Results show that LD can easily execute this task in both fixed and random target position (see Fig. 12). This result demonstrates that the difficulty with successive overlapping images occurs only when they need to be perceptually disjoined. Thus performance is very good when the task requires perceptual integration in time. Moreover, these results are also important because they show that LD could perform normally at least in that visual field region required by this test. This suggests that LD's deficit is not related to his visual field defects.

General discussion

We have described and quantified visual acuity, contrast sensitivity, stereopsis, eye movements, motion detection, flicker fusion, perceptual segregation through textures, shape recognition and identification, temporal segregation and integration in a patient with bilateral temporo-occipital and superior parietal hypometabolism. The patient had normal contrast sensitivity, depth perception, visual acuity, simple detection and recognition of static and dynamic shapes. He was impaired in apparent motion detection, eye movements, copying drawings, drawing from memory, and identification of either degraded or texture-defined shapes.

Results have shown that shape detection was still possible with shapes of low contrast, providing that contour detection was not impaired. Shape naming was possible with silhouettes but not with line drawings and was not impaired by image motion. Parallel visual search was possible and improved at short exposures. Furthermore, the patient was only capable of letter-by-letter word reading. Letter recognition was good in normal viewing but impossible in rapid serial visual presentation. Finally, LD was incapable of perceiving a shape moving behind a slit regardless of whether eye movements were involved or not but was quite good in tasks requiring temporal integration in time. These results suggest a specific deficit in a mechanism involved in temporal processing of visual information.

Implications for accounts on visual agnosia

Two sets of LD's data are also consistent with the idea that the patient presents a deficit specific for tasks requiring integration of elements in a perceptual whole. First, he is impaired in the Gollin test, degraded shapes detection, texture detection and perception of line drawings. These tasks are sensitive to the level of recognition in relation to segregation or perceptual degradation. Second, the patient does not present a problem in tasks which do not require grouping of elements into a whole shape (visual search and reading with a hole).

These results all suggest that LD presents a difficulty in integrating features into a single unitary percept. The difficulties both in line drawings with respect to silhouettes and in fragmented shapes requiring grouping

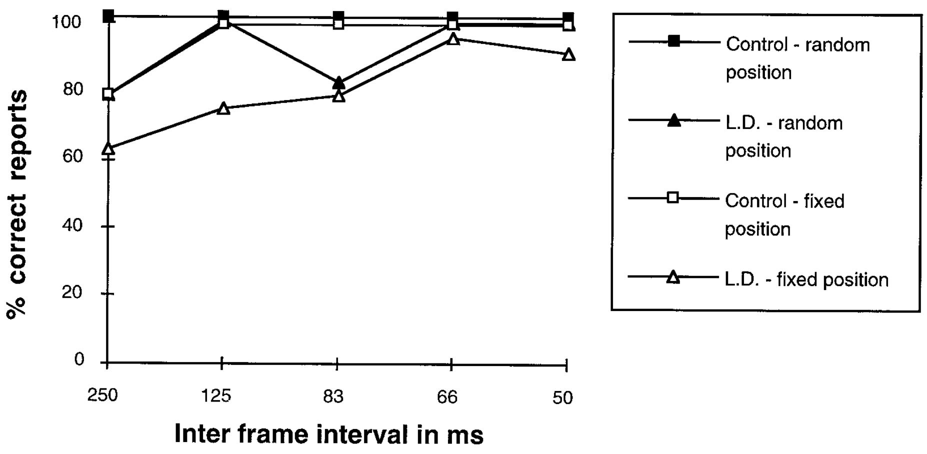

Fig. 12. Percentage of correct reports in two temporal integration tasks (with fixed and random hole position in 24 squared matrices pairs) for LD and one age-matched control. Correct reports are shown as a function of inter-frame interval.

via collinearity are similar to those of integrative agnosic patients who can discriminate single components of an object but are unable to integrate these components into a meaningful percept. For example, from the analysis of LD's errors in identification of silhouettes it appears that LD fails in those figures with few informative contours (bus, mouth, lemon, kite, cap, pen, carrot, celery). The difference between stimuli with few and many informative contours is significant in both silhouettes (Chi-test $P < 0.001$) and line drawings (Chi-test $P < 0.001$). From his verbal report it appears that LD has to rely on informative contour features ('it is not an animal because it has no legs'; 'it has a tail but a squared body'; 'I don't understand, it has a point therefore it is an arm'). This suggests that LD has to rely on informative features for recognition and he is impaired with line drawings because informative features are somehow masked by internal details (Humphreys *et al.*, 1994).

There are, however, important differences between integrative agnosic patients and LD. Differently from integrative agnosic patients, LD is impaired in copying objects and he is not affected by reduced exposure conditions. Numbers of errors in recognition of line drawings do not depend on exposure time. Moreover, LD is impaired in visual functions such as eye movements, direction of motion and flicker fusion.

Similarly, LD's perceptual difficulties are not similar to those of patients suffering from simultanagnosia. Unlike simultanagnosic patients, LD is able to see more than one object at a time. Moreover, differently from simultanagnosia, LD's deficit cannot be interpreted in terms of impairment in the aperture of an 'attentional window'.

LD's difficulty does not depend on attention deficit

It has been suggested that visual difficulties may often depend on a deficit in visual attention mechanisms. First, the mechanism underlying parallel to serial focusing of visual attention, which serves to integrate information from different visual feature maps, may be impaired (Arguin *et al.*, 1994). However, from the analysis of LD's reading errors it appears that they are mainly due to letter confusibility (P was read as R, T as H, F as E or T, V as M or N). Moreover, flanking and letter migration errors were not produced as would be expected if a deficit of the mechanism underlying parallel to serial focusing of attention was present. Second, LD's pattern of errors in reading indicates that his perceptual difficulty is not due to an attentional deficit similar to that responsible for attentional dyslexia (Shallice and Warrington, 1977). Indeed, differently from LD, attentional dyslexics can read single words correctly but cannot name their constituent letters. LD's performance is more similar to letter-by-letter readers who have a perceptual deficit (Shallice, 1988; Arguin *et al*., 1994).

Another attentional mechanism which can affect perception is that which shifts the spotlight of selective attention from one site in the visual field to another (Posner, 1980). Although spatial attention has not been tested directly, it is unlikely that a deficit in spatial attention by itself can explain LD's impairment, because he was strongly impaired in many tasks in which the shift of spotlight of selective attention was not required. Indeed, impaired performance in the Rapid Serial Visual Presentation task and aperture viewing, in which information is presented in fovea, clearly shows that LD's difficulty with multielement display was not due to a spatially based visual attentional problem. Finally, it has been suggested that an attentional mechanism deficit which could affect perception is one which allows one to bind information acquired in different fixation and stored in some abstract form in a visual short-term buffer (Coslett and Saffran, 1991). This cannot be an explanation for LD's deficit, mainly because his reading performance is better while reading through a hole when the binding operation mediated by a temporal attentional window is required. Thus, a deficit in attentional mechanisms cannot explain the impairment.

Eye movements cannot explain LD's deficit

Another possibility is that LD's perceptual difficulties depend on his abnormal eye movements. Saccadic eye movements are normally employed to change the locus of fixation. This usually occurs during the inspection of a static scene or when a new object is suddenly introduced in the periphery of the visual field. To search and inspect the visual field sequential static foveations are required (Breitmeyer, 1984). Since viewing time was unlimited, tasks in Experiment 1a and 1b involve inspection of contours and this requires integration of elementary aspects of the stimulus from one fixation to the other.

Some findings are easily explained in terms of eye movement deficits. Performance in Experiment 2a confirms this suggestion, where visual search slightly improves when the exposure time is too short to allow involuntary eye movements which are likely to occur in LD.

Moreover, eye movements deficit could also explain the improvement obtained in reading through a hole. Indeed, since LD's perceptual span is abnormally small (Rayner, 1983; Rayner *et al*., 1980) and the letters we used are very large, this may explain the difficulty in reading long words (if we assume that eye movements are involved) and the tendency to read letter-by-letter.

The impairment in tasks of Experiment 1a and 1b is more difficult to explain in terms of an eye movement deficit, although this explanation cannot be ruled out. Indeed, since LD has a primary problem in controlling eye movements, this causes an increase in forward, regressive and anticipatory eye movements with very simple patterns (Fig. 3). This increment is likely to become more serious with complex patterns and it may account for LD's impaired performance with fragmented forms. In these tasks, an anomaly in eye movement mechanisms may produce two effects: it may increase response time for recognition, if it only consists of a reduction of perceptual span, and it may increase errors in visual recognition if the anomaly is extended to saccadic suppression. It has been shown that, if saccadic suppression is not good, temporal resolution is low and masking between successive fixations may occur. Masking between successive fixations could be a general explanation of LD's perceptual difficulties.

Although this explanation is not ruled out, results of Experiment 4 suggest that it cannot be the only explanation of LD's deficit. The results of Experiments 4a and 4b cannot be explained on the basis of an eye movement deficit because the stimulus is presented in the fovea. Thus, the explanation that LD's difficulty depends on a deficit in the mechanism activated during saccadic eye movements which allows one to perceive a stable and unmasked image (Bridgemann *et al.*, 1994) is not supported by some of our findings. We have shown that LD fails in dynamic vision tasks, regardless of whether eye movements are involved or not, and the explanation of LD's difficulty may be independent of an eye movements deficit.

Temporal segregation deficit can be based on low-level temporal processing deficit

An alternative explanation relies on the concept of temporal integration and segregation in vision. The results of Experiments 3 and 4 show that LD presents a selective deficit in temporal processing. Sensory tests show that motion detection is impaired and flicker fusion is low.

These low-level deficits may be related to those in temporal segregation tasks. When processing a rapid sequence of stimuli, the visual system must satisfy two conflicting requirements. Sequential stimuli must be integrated into a single unitary percept, to maintain perceptual continuity. Temporal integration prevails whenever two stimuli occur sufficiently close in time that they cannot be perceptually segregated. On the other hand, to detect rapid changes, sequential stimuli must be segregated one from the other. Stimuli that are coded as extensive are integrated and those that are coded as disjoint are segregated. If coding of the temporal relationship between contiguous stimuli is inefficient, stimuli which should be perceived as segregated appear instead perceptually integrated. Perceptual effects of segregation and integration are therefore governed by the reciprocity rule.

The problem of reciprocity between integration and segregation has been approached in different ways. Low-level explanations consider temporal correlation between successive stimuli to be dependent on temporal summation (Barlow, 1957; Roufs, 1972) and visual persistence (Loftus and Hanna, 1989; Di Lollo and Dixon, 1988). Visual persistence, which is the reciprocal of temporal resolution, is increased in LD and this could explain LD's difficulty in keeping successive images as segregated. However, since a cortical correlate of visual persistence cannot be denied (Duyens *et al.*, 1985), and since the neural deficit of the patient is, at least in part, cortical, peripheral mechanisms may not be the only contributor to LD's perceptual difficulty.

Many of our findings are consistent with the view that LD presents a problem in temporal segregation. Di Lollo and co-workers (Di Lollo *et al.*, 1994; Dixon and Di Lollo, 1994) have described a more centrally based mechanism responsible for the reciprocity between temporal integration and segregation. According to these psychophysical studies, integration occurs when the visual responses to successive stimuli overlap in time. Instead, segregation occurs when the two visual responses are disjoint. According to this model the reciprocity between temporal integration and segregation depends on both the relative duration of the stimuli and the interval between their onsets. These two parameters will affect the interval between the peaks of the neural responses: when this interval is short, integration will be perceived, when it is long the stimuli will appear as segregated. Temporal correlation between the responses to successive stimuli is carried out in time within a centrally based 'sliding temporal window' (Dixon and Di Lollo, 1994) or within a 'psychological travelling moment' (Allport, 1968; Poppel, 1970). The temporal dynamics of the window may depend on the period of cortical oscillations of visual responses synchronized with external stimulus (Engel *et al.*, 1992). The period of oscillations determines the scan duration or the duration of the 'travelling moment or window'.

The final issue is whether LD's perceptual impairment can be related to a deficit in a centrally based temporal correlation mechanism responsible for the temporal correlation of elementary response to physical stimuli.

The neural basis of temporal correlation deficit

A rather speculative hypothesis is that modifications in P100 are due to desynchronization of neural signals, which in turn produces a deficit in temporal correlation of neural response to successive stimuli. When signals are not synchronized, the signal duration of temporal responses from all units stimulated varies from one unit to another and this increases the duration of overall response. This may be reflected in VEPs which show increased duration, slowed latencies and reduction of amplitudes in P100. Because of desynchronization, if the stimulus onset asynchrony is short enough, the responses to successive patterns may overlap in time. Thus the two images may appear temporally integrated rather than segregated as the task would require when (as in LD) the interval between the neural responses is shortened as a consequence of increased duration of neural response to each successive pattern.

The temporal deficit explanation, however, accounts for a deficit in perceptual grouping only if the grouping operation is not made at a glance but involves eye movements. In the neurophysiological literature, however, many data suggest that some aspects of temporal response to the elements in the image are important in the grouping operations.

A quite speculative possibility is that the temporal processing deficit may affect grouping of local form information. Previous neuropsychological work on this perceptual problem (Riddoch and Humphreys, 1987) has been carried out within the framework of 'binding by convergence' neurophysiological hypothesis. It is assumed that at an early stage of processing, cortical areas are retinotopically organized (DeYoe and Van Essen, 1988). This organization gradually gives way to a largely non-retinotopic mapping at higher levels in the hierarchy, and the receptive field properties of cortical neurons concurrently increase in size and complexity owing to convergence and divergence of connections from cells in lower areas. This produces binding which underlies perceptual grouping. Once the elementary features of a scene have been represented, some grouping operations must be performed to identify those neurons responding to the features of a particular object to segregate the activity of neurons responding to the features of the objects or to the background. The implementation of units that receive converging inputs from cells whose responses require integration may allow this type of binding. The activity of such cells would then represent either elementary features, or, at higher levels of processing, a particular constellation of elementary features. Finally, by iteration of this operation, units could be created that respond with high selectivity to single perceptual objects.

Recent neurophysiological experimental data suggest that binding by convergence is probably not the only strategy for the association of distributed neuronal responses. It has been suggested, therefore, that selection could be achieved by the synchronization of activity among a distributed population of neurons rather than by solely increasing their discharge rate. In summary, the hypothesis predicts that the discharge of neurons undergoes a temporal patterning and becomes synchronous if they participate in the encoding of related information. This synchronization is thought to be based on a self-organizing process that is mediated by a selective network of corticocortical and corticothalamic connections. Thus, distributed groups of coactive neurons that code, at high levels, a constellation of features corresponding to a perceptual object, would be identifiable as members of an assembly because their response would contain episodes during which their discharges are synchronous. Correlated firing should occur between cells in different columns within an area to enable the linking to spatially disparate but related features. The question is whether the level of desynchronization as it appears from VEP can be responsible for impairment in binding operations by means of synchronization mechanisms. This would explain LD's difficulties in figure–ground segregation and the impairment in recognizing objects from texture. However, this question goes beyond the aim of this study, and further studies are required in which the 40 Hz component of EEG is analysed in grouping tasks. However, our results address this issue because they first show that impairment in grouping of local features may be directly associated to a low-level temporal deficit problem.

To summarize, we have demonstrated that LD has a specific temporal segregation deficit functionally separated from other deficits that may determine subtypes of visual agnosia. Given the present level of specification of temporal processing models the precise nature of the patient's impairment is not clear. Both a deficit in temporal segregation (due to long persistence and low temporal resolution) and a deficit in temporal correlation between successive responses caused by desynchronization of neural responses may account for LD's temporal processing difficulties. Our data do not point to a choice between these two explanations. However, since we have discussed the quite speculative possibility that VEPs' desynchronization may reflect the impairment in correlation mechanism on which both spatial integration and temporal segregation may be based, we suggest that this could be the basis of LD's perceptual difficulties in both these tasks. Since the relationship between grouping difficulty and desynchronization has never been addressed before in the neuropsychological literature, further studies are necessary to establish whether or not these two aspects of visual responses are related.

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Temporal segregation deficit in visual perception: a single case study

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Abstract

The patient (LD) presents a visual deficit in temporal segregation. PET scan showed a bilateral hypometabolism in the superior parietal, temporal and occipital cortex. Neuropsychological data revealed that memory, attention and language functions were almost completely preserved. Visual sensory tests showed that visual acuity, depth and colour perception were normal, whereas detection of apparent motion direction, flicker fusion and saccadic eye movements were abnormal. Shape drawing was impaired whereas shape recognition (and naming), with either static or dynamic stimuli, was good. LD failed in tasks requiring integration of elements to produce a whole image (line drawings, degraded and textured shapes). On the other hand, LD's performance was good in tasks not involving spatial integration, such as visual search and letter-by-letter reading. The main finding is that LD failed in tasks requiring temporal segregation. These tasks involved shape recognition when different shapes (Experiment 1a) or different parts of either a word or a shape are presented successively on the same retinal locus with (Experiments 2b, 3a, 3b) and without (Experiments 4a, 4b) eye movements. Finally, LD has no problems in tasks (4c) involving temporal integration alone. Taken together, these results suggest damage to a general mechanism involved in temporal segregation.

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Primary diagnosis of interest

MRI report of generalized atrophy of supra and sub-tentorial cortical structures

Author's designation of case

LD

Key theoretical issue

- Temporal coding

Key words: eye movements; temporal segregation and integration; spatial integration; dynamic viewing

Scan, EEG and related measures

EEG, MRI, PET, VEP

Standardized assessment

Neuropsychological evaluation, visual sensory evaluation

Other assessment

Lesion location

- Bilateral superior parietal, temporal and occipital cortex

Lesion type

Hypometabolism

Language

English