

# EVIDENCE FOR A RIGHT HEMISPHERE SUPERIORITY AND FOR A SERIAL SEARCH STRATEGY IN A DOT DETECTION TASK

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## INTRODUCTION

The work on the differences in speed and accuracy of performance between left and right visual fields has led to the general conclusion that perceptual asymmetries provide evidence for an asymmetry of cerebral functions (Milner, 1971; Berlucchi, 1974). In accordance with findings on commissurotomy and brain injured patients, researches with normal subjects show that the task requirements are the prime mediators of hemispheric specialization and that in most people the right visual field (left hemisphere) prevails for linguistic processing while a left visual field (right hemisphere) superiority occurs for visuo-spatial processing (see reviews in Springer, 1977; Moscovitch, 1978). However, the mechanisms by which these perceptual asymmetries are achieved are by no means completely understood and there is still a great deal of uncertainty about the exact nature of the underlying functional asymmetries and the range of cognitive processes over which they apply.

Besides the oldest verbal/spatial distinction, other functional dichotomies have been proposed with respect to differences in hemispheric processing and the left hemisphere has been characterized as an analytic or serial processor while the right as an holistic or parallel processor (Nebes, 1972; Cohen, 1973; Levy, 1974; Patterson and Bradshaw, 1975; Bradshaw, Gates and Patterson, 1976). It should be noted that the holistic mode of processing cannot be assimilated to the parallel mode of processing of the serial/parallel dichotomy (see, e.g., Cohen, 1973; Moscovitch, 1978), since the latter involves the simultaneous analysis of individual features and thus pertains to the analytic processes (Bamber, 1969; Nickerson, 1972).

Some investigators (Cohen, 1973; Gross, 1972; White and White, 1975) have attempted to find evidence for the serial/parallel hypothesis of hemispheric specialization. Unfortunately, the experiments reported were unable

to determine the processing strategies since they have failed to consider the several types of plausible models according to which a stimulus analysis can be performed. There are, in fact, at least four basic models: serial and parallel processes and within each of these types both self-terminating and exhaustive processes (Egeth, 1966; Nickerson, 1972).

As for the range of cognitive processes that are affected by hemispheric functional asymmetries, Moscovitch (Moscovitch, 1978; Moscovitch, Scullion and Christie, 1976) has maintained that the low-order processes concerned with the extraction of simple sensory features are common to both hemispheres. Hemispheric asymmetries can only be found when the stimulus is represented in terms of the higher-order configurational or categorical properties that are typical of the later stages of processing for each hemisphere. While some evidence supports this view (see review in Moscovitch, 1978), other findings (see review in Davidoff, 1977; and again in Moscovitch, 1978) seem to show that the right hemisphere is superior in dealing with simple perceptual stimuli even when there is no apparent spatial component in the task. The present study is addressed to the questions of hemispheric asymmetries in a simple feature detection task and in serial/parallel processing.

## EXPERIMENT I

This experiment aimed at determining whether there were field differences in ability of detecting a low-level sensory feature and to examine the possible involvement of stimulus processing strategies in inducing field differences. The task of manually signalling whether a solid dot is present or not in an array of empty dots certainly taps one of those simple perceptual abilities (Egeth, Jonides and Wall, 1972; Davidoff, 1977) that according to Moscovitch's hypothesis should not yield any field asymmetry. In the present study we used a go-no go response paradigm that is considered a more direct indicator of simple perceptual processes than a two-response paradigm (Egeth, Marcus and Bevan, 1972). Furthermore, in this type of task memory should play only a minor role since the criterion for response is very easy to remember.

Four basic types of models have been proposed in connection with the mode of processing the information contained in a briefly presented display: serial exhaustive, serial self-terminating, parallel exhaustive, and parallel self-terminating (Egeth, 1966; Nickerson, 1972).

Serial exhaustive search implies that each item in the array is compared in turn with the stimulus in memory; only at the end of the process the decision is made whether or not to execute a response. Serial self-termina-

ting search implies that the items are compared one at a time with the stimulus in memory and a response is emitted as soon as a match is found. Parallel exhaustive search means that all items in the display are simultaneously matched with the memory stimulus and only after the last match is terminated the decision is made whether or not to execute the response. Parallel self-terminating search indicates that all possible comparisons are initiated simultaneously but as soon as a match is found the process is terminated and the response is executed.

In the present experiment the dots in the display could be either three or six, arranged in one or two rows of three dots each and included within a rectangular frame. It was reasoned that a serial self-terminating search predicts that response latencies depend on the location of the target (i.e., the solid dot). The lack of such a relationship is clearly compatible with all the three alternative models; however, the serial exhaustive model predicts an increase in response latencies from the three-dot to the six-dot arrays while the two parallel models do not predict such an increase. Thus, we hoped to be able to determine whether the search strategy employed was in series or in parallel. Admittedly, this is an oversimplification since there are other aspects of the above-mentioned models that should be considered, such as whether the order of examination of the elements is fixed or random in the case of a serial model, or whether the processing times for individual elements are constant or distributed in the case of both models (Egeth, 1966; Grill, 1971; Nickerson, 1972). Some of the possible implications of these further distinctions will be discussed later.

### *Material and Method*

#### *Subjects*

Twenty students of the University of Rome (10 males and 10 females) in the age range of 19-25 years took part in the experiment. All subjects completed the Edinburgh Handedness Inventory (Oldfield, 1971) that showed that they were fully right-handed. All had normal or corrected vision, and right eye dominance for sighting. They were paid for participating in the experiment. No subject was accepted for the experiment if one of his/her close relatives was classified as non-right-handed.

#### *Stimulus material*

Eighty-one stimulus cards were prepared (see Figure 1); 48 were positive, that is they contained a solid dot and required a manual response; 33 were negative, that is they did not contain the target and did not require a manual response. Half of the positive stimulus cards consisted of six dots arranged on two superimposed horizontal rows of three elements each. Besides the target there were 5 empty dots. This provided a total of 6 possible locations for the target and

there were 4 stimulus cards for each location. The other 24 positive stimulus cards consisted of only three dots arranged in one horizontal row. This provided 3 possible locations for the target and there were 8 cards for each location. In 12 cards the row coincided with the upper row and in the other 12 with the lower

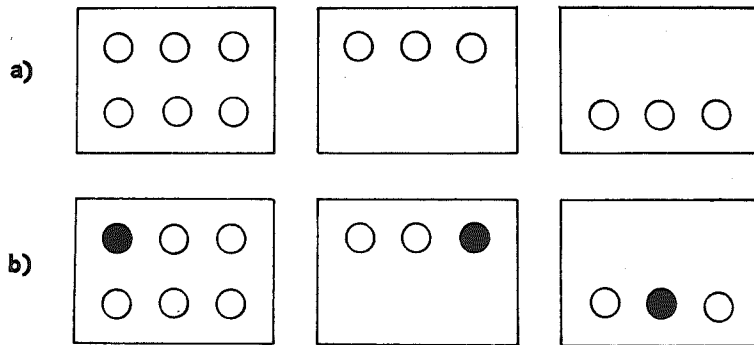


Fig. 1 — Examples of negative (a) and positive (b) stimuli.

row of a two-row card. Of the 33 negative stimulus cards, one third consisted of two rows of 3 empty dots each, one third of only the upper row and one third of only the lower row. In any stimulus card the array of dots was included within the same rectangular frame. Photographic negatives (35 mm) of each card were mounted in slide holders for tachistoscopic projection on a back-projection screen.

### Procedure

The subjects maintained a constant head position by leaning their foreheads against a head-rest and placing their chin on a chin-rest. They faced a translucent screen at a distance of 60 cm. An acoustic signal (800 Hz for 1 sec.) prompted the subject to fixate a clearly marked central point on the screen. Subject's fixation was monitored by one of the experimenters through a camera on a television screen. With this technique a deflection of about 0.5 degrees of visual angle was reliably detected. The experimenter always restored subject's position after any rest or pause. Half a second after the warning signal a slide was back-projected for 116 msec. on the screen, on a level with, and either to the right or to the left of, the central fixation point. The interval between presentations was 5 sec. The stimuli extended from 6.27 to 9.01 degrees of visual angle from fixation or from 5.73 to 9.55 degrees considering the frame. The fixation point was a black spot ( $0.29 \times 0.24$  degrees) drawn with a felt pen on the geometric center of the screen. The dots were white on a dark background. Each dot had a diameter of 0.48 degrees and the distance between two adjacent dots in the same row or in two different rows was 0.54 degrees. The stimulus intensity was 13.0 fL while the luminance of ambient light and fixation field was 6.1 fL and 5.8 fL, respectively. The subjects were instructed to respond by pressing two keys with their right and left index fingers as soon as they detected the solid dot, and to refrain from responding when the target was not present. The keys were on a response panel positioned in front of the subject and in a central position just below the fixation mark on the screen. After the completion of the experiment

for half of the subjects (5 males and 5 females) the two keys on the response panel were inverted in order to counterbalance the key-hand assignment. Pressing the keys stopped two electronic millisecond counters that were started at the beginning of the 116 msec. exposure period. The stimuli were back-projected into the screen through a Kodak Carousel projector equipped with an electronic shutter.

Formal testing began after informal practice trials during which the subjects were acquainted with the experimental situation and learned to fixate the central point of the screen and to press the keys when a target item was detected. Each subject was tested during one session which lasted about 50 min. Each session consisted of 324 trials divided into 2 blocks of 162 trials separated by a 3 min. rest period. Each block comprised two complete series of the 81 stimulus cards. Stimuli were presented in random sequences. The 2 blocks of trials were presented to the right visual field and to the left and the order of presentation was counterbalanced across subjects. The subjects were instructed to press the keys as fast as possible simultaneously with both hands and to try to avoid errors, but were not given any feedback about speed or accuracy with the exception of the practice trials. If a subject made an error, or his/her response latency exceeded an arbitrarily set limit of 1 sec., or if a lateral eye movement was observed during a trial, then these trials were discarded but not replaced. The occurrence of eye movements was very rare (about 0.7% of the trials in the whole experiment) and evenly distributed between the two visual fields. Also the occurrence of response latency longer than 1 sec. was exceedingly rare (about 0.2% of the trials in the whole experiment), and evenly distributed between the two visual fields and the two hands.

### Results and Discussion

A five-way within-subjects analysis of variance was carried out on mean correct RTs. The five factors were hand (right or left), visual field (right or left), number of rows (one or two), position of the row containing the target dot (upper or lower position), and location of the target dot within the row (locations 1, 2 and 3 from the fixation point). Table I shows overall mean RTs as a function of the above-mentioned factors. Four main effects were significant. The left hand (438.5 msec.) proved to be significantly faster than the right (446.9 msec.),  $F = 16.56$ ,  $d.f. = 1, 19$ ,

TABLE I

*Experiment I: Mean Correct Reaction Times (in msec.) as a Function of the Five Main Factors*

Hand***	Left	438.5	Row position	Upper	442.0
	Right	446.9		Lower	443.3
Visual Field**	Left	433.5	Target location**	1	430.4
	Right	451.9		2	447.3
				3	450.3
Rows*	One	438.4			
	Two	447.0			

\*  $p < .025$ ; \*\*  $p < .01$ ; \*\*\*  $p < .001$ .

$p < 0.001$ ; 15 of the 20 subjects showed this trend. Target items were detected significantly faster in the left visual field (433.5 msec.) than in the right (451.9 msec.),  $F = 8.93$ ,  $d.f. = 1, 19$ ,  $p < 0.01$ ; again 15 subjects showed this trend (it should be noted, however, that they did not always coincide with those that showed an advantage for the left hand). Target items were detected significantly faster when they belonged to a one-row display (438.4 msec.) than to a two-row display (447.0 msec.),  $F = 7.59$ ,  $d.f. = 1, 19$ ,  $p < 0.025$ ; 17 subjects behaved this way. The position of the row containing the target did not significantly affect detectability, the average RTs being 442.0 msec. for the upper row and 443.3 msec. for the lower row. Finally, the three different locations of the target produced significantly different RTs: 430.4 msec. for the location nearest to the fixation point, 447.3 msec. for the intermediate location and 450.3 msec. for the location most distant from the fixation point;  $F = 6.83$ ,  $d.f. = 2, 38$ ,  $p < 0.01$ . Three  $t$  tests for correlated means showed that location 1 yielded RTs significantly faster than locations 2 and 3 ( $t = 2.41$ ,  $d.f. = 19$ ,  $p < 0.05$  and  $t = 2.95$ ,  $d.f. = 19$ ,  $p < 0.01$ , respectively) while RTs for location 2 were not significantly faster than those for location 3. None of the interactions reached significance.

A similar analysis of variance performed on number of errors yielded only a significant source of variability, namely the hand main effect: the overall error rate was 2.8% for the right hand and 2.1% for the left hand,  $F = 5.98$ ,  $d.f. = 1, 19$ ,  $p < 0.025$ . The errors were almost exclusively of the false alarm type.

The results clearly show an advantage of the left field/right hemisphere in the detection of the target dot. Furthermore, this observation is corroborated by the finding of an asymmetry in speed of response in favor of the left hand that has direct neural connections with the right hemisphere.

As for the processing strategy used by the subjects, the results seem congruent only with the serial self-terminating model. The significant effect of the number of rows is incompatible with both parallel models since those models assume that the comparison processes are initiated simultaneously for all the dots irrespective of their number. The parallel models do not imply that the comparisons are also simultaneously terminated and different retinal locations might yield different processing times. However, in the present experiment retinal locations are not changed from one-row to two-row displays. The significant location effect is incompatible with both exhaustive models since those models imply that the decision is made only after the processing of every dot, irrespective of its location and of the fact that it is empty or solid. Thus, only the serial self-terminating model seems not to be disproved even if some of its predictions are not satisfactorily met.

A serial self-terminating search implies (a) that response latencies are a linear function of the location of the target (probably with location 1 scanned first and location 3 scanned last in both fields) and (b) that location of the target interact with the number of rows, since a given location should be checked at different times when the number of possible locations increases (e.g., location 1 might become location 4 and location 3 might become location 6). The latter prediction is clearly not supported by the data, while the former is contradicted by the lack of a significant differences in response latency between locations 2 and 3. In fact, the same increase in response latency should be expected when one more comparison is executed, irrespective of the location of the element. However, the order in which the elements are scanned in a serial self-terminating model need not, as already stated, be fixed. If elements are checked serially but in random order and the process is self-terminating, an effect of the number of rows should be anticipated but not a location effect nor an interaction between number of rows and location of the target. Since the dots are checked one at a time, the overall processing time depends on the number of dots, but since the order in which the dots are checked is random, that is, it changes from trial to trial, the location effects tend to disappear. The finding of a significant location effect might be attributed to the fact that the dots were projected into different retinal positions.

So far we have considered the two extreme alternatives of completely fixed (that is invariant) and completely random orders of search. An equally plausible alternative is that the order is neither invariant nor entirely random (Nickerson, 1972). It is conceivable that if, owing to different retinal positions, not all the locations allow an equal discriminability of the dot, the most discriminable location will be checked first. The dot arrays of the present experiment are projected to the same isoresponse time region according to the map outlined by Haines and Gilliland (1973) for a small, white, photopic stimulus; however, it is likely that visual acuity, probably an important determinant of speed of response in detecting the target, varies over this range of locations, decreasing with retinal eccentricity (Lefton and Haber, 1974; Eriksen and Schultz, 1977). In summary, the present experiment has shown an asymmetry in favor of the right hemisphere in a simple perceptual task and has indicated that the processing strategy is best described by a serial, self-terminating, quasi-random model with the most discriminable location checked first.

## EXPERIMENT II

If hand differences in speed of response provide evidence for an underlying hemispheric functional asymmetry, then they might be observable even when the stimuli are projected to the center of the visual field, so that information reaches directly both hemispheres. A serial self-terminating search in perceptual detection or discrimination tasks is not an unusual finding (Egeth, 1966, who supported the random-order version of the model; Bamber, 1969; Nickerson, 1972; Snoodgrass, 1972; Estes, Allmeyer and Reder, 1976; Hoffman, 1978). However, in Experiment I the paradigm was basically an oddity detection task, where the subject was required to search a display to detect the presence of an item different from the rest. With similar paradigms results reflecting parallel processes have been reported (Egeth, 1966; Egeth, Jonides and Wall, 1972; Nickerson, 1972; Cohen, 1973; White and White, 1975) even with stimuli much more complex than those employed in Experiment I (e.g., alphanumeric material or geometrical shapes). Previous studies have suggested the possibility of bringing about a change in processing strategy from a serial to a parallel mode by decreasing retinal eccentricity of the display (Lefton and Haber, 1974) or by allowing the subject an extended period of practice (Grill, 1971). Experiment II addressed the questions of hand differences with centrally presented displays and of the effects of retinal location and practice on information processing strategies.

### *Material and Method*

#### *Subjects*

A new group of 20 right-handed students of the University of Rome (10 males and 10 females) was tested. They were selected in the same way as before.

#### *Stimulus material*

The same stimuli of the previous experiment were used.

#### *Procedure*

The procedure of Experiment I was exactly replicated in the present experiment with only the following exceptions. The stimuli were centrally projected so that the fixation mark fell exactly between the two middle dots when a two-row display was presented. They extend 1.26 degrees of visual angle to the right and to the left from fixation or 1.91 degrees considering the frame. The instructions did not stress the importance of keeping a good fixation as they did in the case of Experiment I. Each subject was tested during two successive sessions separated by a 10 min. rest period for a total of 324 trials. The whole experiment lasted about 60 min. Each session was identical to those described for the previous experiment.



### Results and Discussion

A five way within-subjects analysis of variance was carried out on mean correct RTs. The factors were identical to those of Experiment I with the exception of session (first or second) instead of visual field. Table II shows overall mean RTs as a function of the five factors. Two main effects were significant. The left hand (371.1 msec.) was significantly faster than the right (380.2 msec.),  $F = 26.17$ ,  $d.f. = 1, 19$ ,  $p < 0.001$ ; 16 of the 20 subjects showed this trend. Target dots were detected significantly faster in the case of one-row displays (370.3 msec.), than in the case of two-row displays (381.0 msec.),  $F = 22.35$ ,  $d.f. = 1, 19$ ,  $p < 0.001$ ; 17 subjects behaved in this way. There was no effect of practice, the average RTs being 375.8 msec. and 375.4 msec. for the first and second session.

TABLE II

*Experiment II: Mean Correct Reaction Times (in msec.) as a Function of the Five Main Factors*

Hand***	Left	371.1	Row position	Upper	373.3
	Right	380.2		Lower	374.0
Session	1	375.8	Target location	1	378.0
	2	375.4		2	373.9
Rows**	one	370.3		3	375.0
	two	381.0			

\*\*  $p < .01$ ; \*\*\*  $p < .001$ .

Also the location of the target did not significantly affect detectability: 378.0 msec. for the left location, 373.9 msec. for the middle location and 375.0 msec. for the right location. None of the interactions reached significance. Overall the errors were less than 1% and were not submitted to a statistical analysis.

The finding of a left-hand advantage complements the observation of a similar difference and of an advantage of the left visual field in Experiment I, thus supporting the view that the right hemisphere is superior in detecting the target dot.

In the previous experiment two of the sources of variability relevant in order to explore the issue of the search strategy, that is number of rows and location of the target, were significant. In the present experiment only the former was significant. By following the same line of reasoning previously outlined, we can only reject both parallel models but have to conclude that the data provide support for both the serial self-terminating random-order model and the serial exhaustive model. If we assume that the visual acuity is sufficiently homogeneous over the very limited retinal region

that has been tested in this experiment and keep in mind the conclusions reached for Experiment I, we might decide in favor of the serial self-terminating random-order model. However, there is considerable evidence available to suggest that visual acuity shows definite variations even within this range (Riggs, 1965; Lefton and Haber, 1974; Ericksen and Schultz, 1977).

### GENERAL DISCUSSION

The present study aimed at determining (a) whether the functional specialization of the two hemispheres had a role in a simple perceptual task where no spatial component was involved; (b) what type of processing strategy was used in searching the display; (c) what differences in modes of processing underlie hemispheric specialization of function.

The finding that the detection of dots can be better achieved by the right hemisphere contradicts Moscovitch's (1978) hypothesis that hemispheric specialization of function plays no role at the early stages of analysis when the stimulus is processed in terms of its low-level, sensory properties. This observation is not without precedent since recently other studies have found evidence for a right-hemisphere superiority in dot detection tasks (Anzola, Bertolini, Buchtel and Rizzolatti, 1977; Davidoff, 1977), and Davidoff (1977) and Moscovitch himself (1978) have reviewed several experiments that seem to show that the right hemisphere is specialized for performing other very simple perceptual tasks.

The data of the present study are consistent with two models in which each stimulus element is examined in series but do not yield enough evidence to distinguish between self-terminating and exhaustive processing. In any case, they seem to reject the two basic parallel models and this is an important conclusion since parallel processing should be characteristic of the right hemisphere (Cohen, 1973; Seamon, 1974). This casts some doubt on the usefulness of the serial/parallel dichotomy for explaining differences in hemispheric processes. Experiment I has shown that the same serial strategy is employed in the two visual fields. This finding leads to different conclusions according to the model of functional specialization of the cerebral hemispheres one is willing to accept (Umiltà, Frost and Hyman, 1972; Moscovitch, 1973). If one favors the absolute specialization model, then the conclusion is that the right hemisphere processed in series both the information that had reached it directly from the left visual field and that had been conveyed indirectly through the right visual field and the forebrain commissures. No conclusion is allowed about the search strategy of the left hemisphere. If one accepts the relative specialization model, then the conclusion is that both hemispheres processed in series

the information conveyed through the corresponding visual pathways, but the right did so more efficiently.

### SUMMARY

In Experiment I the subjects manually signaled whether a solid dot was present or not in an array of empty dots presented either in the right or in the left visual field. The dots were either three or six and the target could appear in any of the possible locations. The results showed (a) a left visual field superiority; (b) a left hand superiority; (c) faster responses to three-dot than to six-dot displays, and (d) an effect of the location of the target in the display.

Experiment II exactly replicated the previous experiment with the exception that the stimuli were centrally projected. The results showed: (a) a left hand superiority; (b) an effect of the number of dots in the display. These results can be interpreted to indicate: (a) a right hemisphere specialization in a simple feature detection task without any spatial component; (b) the compatibility of a right-hemisphere advantage with a serial search strategy.

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