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DIFFERENTIAL EFFECT OF RIGHT AND LEFT HEMISPHERIC LESIONS ON TWO MEMORY TASKS: FREE RECALL OF ITEMS AND RECALL OF SPATIAL LOCATION

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Abstract—The effect of lateralized cerebral damage on free recall of items and recall of spatial location, under intentional and incidental learning conditions, was investigated. Eleven right brain-damaged (RBD) patients, 10 left brain-damaged (LBD) patients, 14 young and 11 elderly normal controls, participated in this study. The overall performance of the control groups was better than that of the patient groups. For all groups, free recall was better under intentional than under incidental learning condition. On recall of spatial location the learning condition had a differential effect on the groups. The RBD group performed better than the LBD group under intentional learning condition, while the reverse was found under incidental learning condition. The young-control group showed an advantage over the elderly-control group under intentional but not under incidental learning condition. The results are discussed in regard to different approaches to the distinction between automatic and effortful memory processes and their lateralization in the cerebral hemispheres.

INTRODUCTION

HASHER and ZACKS [1] proposed that spatial, temporal and frequency of occurrence information is registered in memory by "innate" automatic processes. Unlike "learned" automatic processes, that require massive amounts of practice to become automatic, the "innate" processes are not improved with practice. These processes are claimed to be unaffected by feedback, by individual differences such as age, intelligence, motivation or mood, and to function equally effectively under intentional and incidental learning conditions. A considerable amount of evidence from experiments with normal subjects supports Hasher and Zacks' claim that spatial location (which is the focus of the present study) is encoded automatically [7, 8, 12, 13, 18]. However, other studies failed to support Hasher and Zacks' hypothesis [9, 10, 14].

Recall of spatial location in neurologically impaired population

HASHER and ZACKS [1] allow for the possibility that head-injury might interfere with "innate" automatic processes. SMITH and MILNER [16] reported an impairment in spatial recall, under "true" incidental-learning condition (where the subject does not expect any memory test at all), following right temporal lobectomy (contingent upon extensive removal

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of the hippocampal region). In contrast, patients with right frontal lobectomy performed normally on the same task. VAKIL [19] found that closed-head-injured patients were impaired on recall of the spatial location of words presented on one of four quadrants of a computer monitor. However, when subjects were required to select the original quandrant out of two alternatives, the patient group did not differ significantly from the control group. It is important to note that in both cases, information about the nature of the task did not have an effect, thus supporting one of Hasher and Zacks' criteria for automaticity. HIRST [2] and HIRST and VOLPE [3] explained amnesia in the theoretical framework of "context theory of amnesia". Their claim is that amnestic patients fail to encode the contextual information which is normally used as retrieval cues. Furthermore, in terms of "figure-ground", the "figure"—the focus of our attention—is encoded effortfully, while the "ground"—the context—is encoded automatically. Thus, amnestic patients, according to this model, fail to encode the contextual information via automatic processes. They can process it effortfully, but then, by definition, this information becomes the "figure". In regard to recall of spatial location, HIRST and VOLPE [4] have demonstrated improvement in amnestic patients, but not in normal subjects, under intentional learning condition. This finding was interpreted as a support for their model. Contrary to HASHER and ZACKS' [1] claim that spatial location is encoded automatically under both intentional and incidental learning conditions, HIRST and VOLPE's [3, 4] model would argue that spatial location, just as any other information, is encoded automatically only under incidental learning.

Automaticity and lateralized hemispheric damage

In a series of studies, LURIA, SYMERNITSKAYA and colleagues [5, 15] observed that left brain damage (LBD) results in breakdown of controlled, effortful processes (e.g. writing and copying), while right brain damage (RBD) results in impairment of overlearned, automatic processes (e.g. signature). In a different study LURIA and SYMERNITSKAYA [6] compared RBD and LBD groups in performance of a recall task. Here the automatic/effortful dichotomy was defined according to whether the learning condition was incidental or intentional, respectively. The LBD group was more impaired on free recall under intentional learning condition, while the RBD group was more impaired at incidental learning. The studies cited above, although employing different definitions of automaticity, revealed a common laterality pattern, where automatic processes seem to be more affected by right-sided cerebral lesions whereas left-sided lesions seem to affect more the effortful processes.

The purpose of the present study is to compare the performance of LBD and RBD patient groups and two control groups, young and elderly, on recall of spatial location and free recall of words and pictures, under intentional and "true" incidental learning conditions. The basic hypothesis is that the LBD group will be more impaired in tasks involving controlled processes while the RBD group will be more impaired in the performance of automatic tasks. Even if one accepts this hypothesis, the approaches reviewed above wili have different predictions depending on their definition of automaticity. According to HASHER and ZACKS [1], it is predicted that the RBD group will perform better than the LBD group on the free recall task under both intentional and incidental learning conditions. On the other hand, the LBD group will perform better than the RBD group on recall of spatial location, under both learning conditions, since in both conditions spatial location is encoded automatically.

According to HIRST and VOLPE [3, 4] and LURIA *et al.* [6], who assume that information learned incidentally is processed automatically whereas information learned intentionally is processed effortfully, it would be predicted that RBD will perform better than the LBD group in the free recall task as well as in the recall of spatial location under the intentional learning condition. On the other hand, the LBD group will perform both tasks better when learned incidentally.

METHODS

Subjects

Subjects were recruited for the study from among a population of patients admitted to the Loewenstein Hospital for rehabilitation after stroke. To be included, subjects had to answer the following criteria: (1) Brain damage was the result of a CT-proven, single, nonhemorrhagic infarction. (2) The neurologic representation was compatible with a unilateral hemispheric involvement. (3) Negative history of previous stroke or another neurologic disease, psychiatric disorder or alcoholism. (4) Intellectual and linguistic functioning at a level enabling adequate responsiveness to the task requirements.

Eleven RBD and 10 LBD patients were examined. The RBD patients averaged 59.4 years of age, and had in average 10.4 years of education. The LBD patients averaged 54.7 years of age, and had an average educational level of 10.0 years. Individual data of these patients are presented in Table 1(a) and (b).

Table 1. Main clinical data of the right and left brain-damaged group

Patient	Age/Sex	H	Ed	TAO	HP	HA	Neglect	Aphasia
(a) *Right (RBD)*								
G.M.	64/F	R	8	11	++	+	+	–
N.J.	49/M	Lc	12	19	++	–	±	–
H.V.	63/M	R	6	16	++	–/e	±	–
P.P.	49/M	R	12	30	++	UQ/e	+	–
S.B.	57/F	R	12	30	++	–/e	+	–
S.S.	72/M	R	12	30	++	–/e	+	–
B.E.	55/M	R	12	10	++	–/e	+	–
Z.R.	53/M	R	15	32	++	–/e	+	–
B.Y.	58/M	R	6	10	++	+	+	–
A.B.	77/F	R	12	15	++	+	+	–
D.S.	57/M	R	8	10	++	+	+	–
(b) *Left (LBD)*								
V.Z.	54/M	R	12	15	++	–	–	Conduction→Amnestic
A.M.	53/M	R	10	32	–	–	–	Conduction
A.E.	43/F	R	12	10	–	–	–	Motor
S.S.H.	55/M	R	8	4	+	–	–	Dysgraphia
H.S.	32/M	R	10	122	++	–	–	Motor
Z.N.	66/M	R	6	54	+	+	–	Amnestic
R.H.	67/M	R	12	9	–	–	–	Amnestic, mild
Z.Y.	43/M	R	8	20	++	–	–	Motor
L.S.	65/F	Lc	10	10	+	+	+*	Amnestic
E.I.	69/F	R	12	15	++	+	–	Motor mainly

Ed = Education (years); H = Handedness (Lc = Converted left hander); TAO = Time after onset (weeks); HP = Hemiplegia(++)/Hemiparesis(+); HA = Hemianopsia (UQ = Upper-quadrant anopsia, e = extinction upon bilateral simultaneous stimulation); * = Right-sided neglect.

Fourteen healthy young and 11 healthy elderly served as control groups. In the young group mean age was 32.8 years, and mean educational level was 13.2 years. In the group of elderly normal controls mean age was 62.0 and mean educational level was 10.9 years.

Lesion analysis

Reconstructions of the lesions from follow-up CT scans are provided in Fig. 1(a) and (b). To achieve optimal visualization of infarct boundaries, follow-up scans, performed at least 6 weeks after onset, were used (Elscint 2400 CT scanner; slice width—10 mm; Inter-slice distance—10 mm). For each patient, all the slices which demonstrate the infarct, are shown. This provides a clear notion of the three dimensional extent of the lesion, and enables identification of the brain areas involved. Approximately parallel slice reconstructions from different subjects are

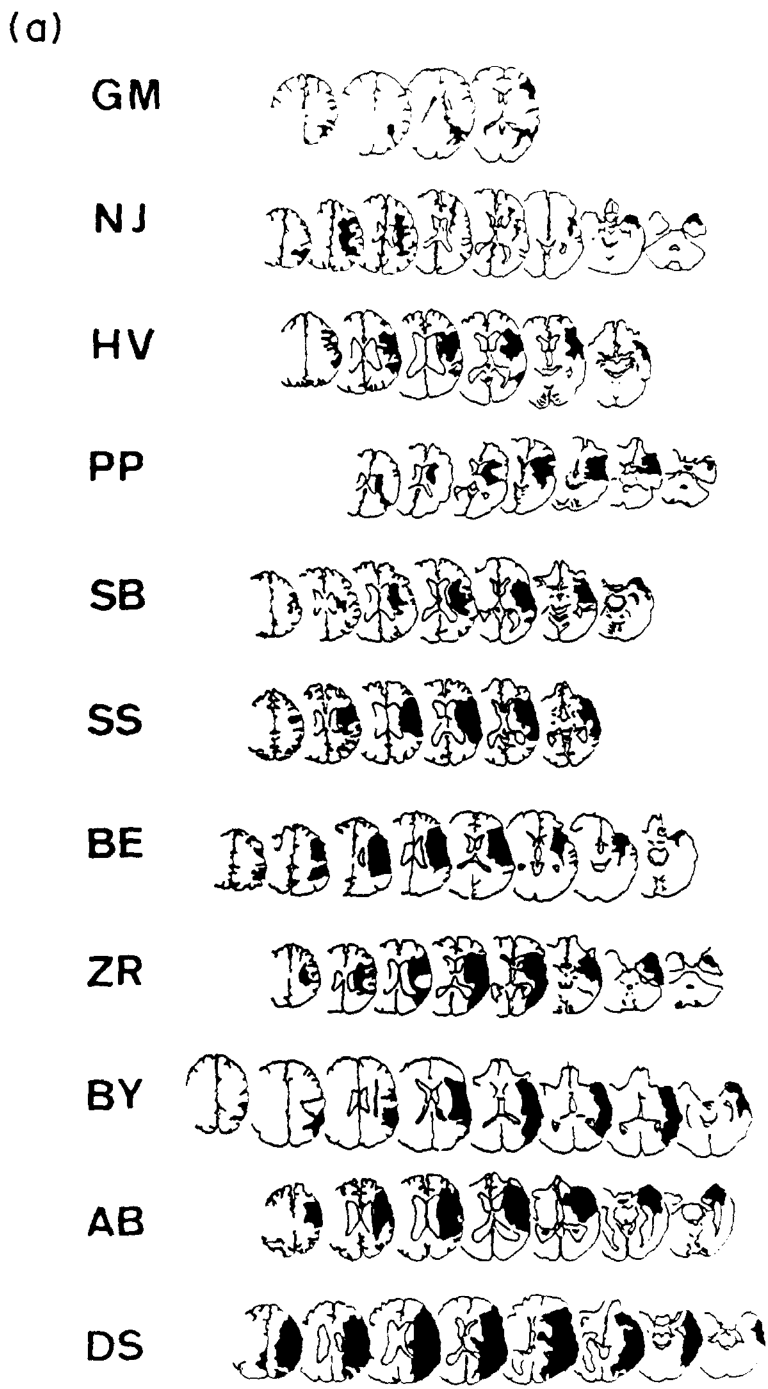

Fig. 1(a).

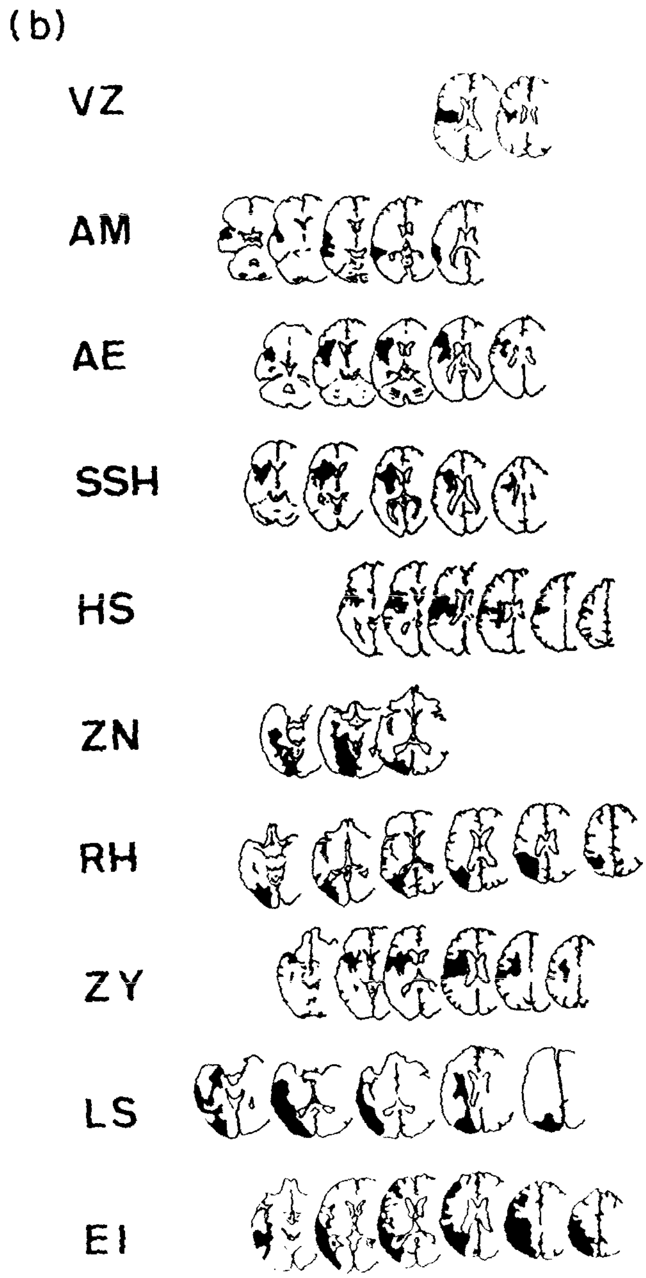

Fig. 1. CT reconstructions from right brain-damaged patients (a) and left brain-damaged patients (b). See text for explanations.

displayed in vertical columns. In all the patients (except for Z.N. of the LBD group) the infarcts are confined to the territory of the middle-cerebral artery. In most of the patients the posterior-dorsolateral aspect of the frontal lobe, the inferior parietal lobule, and part of the temporal lobe are involved. However, in few patients, the lesion involves only one or two of these three lobes (patients R.H., A.M. and V.Z. of the LBD group, and patient G.M. of the RBD group. Patient Z.N. is exceptional in having a demonstrable lesion at the posterior cerebral artery territory, while showing right hemiparesis. The task requirements precluded participation of LBD patients with significant language disturbances. This is most probably the reason why lesion extent in the LBD group is generally smaller than that of the RBD group, as may be seen in the CT reconstructions.

Stimuli

Three sets of 12 boards (19 × 17 cm), each divided into four quadrants, were used. On half of the boards, at each quadrant, a name (in Hebrew) of a familiar object was presented. On the other boards, each of the four quadrants contained a picture of a familiar object, like a car, a bell, etc. All together, 144 stimuli (3 × 12 × 4) were used, half of them words and half pictures.

Testing procedure

Subjects were tested individually in three stages: (1) Incidental learning of words and pictures and their spatial position. (2) Intentional learning of words and pictures. (3) Intentional learning of spatial position. At each stage a different set of 12 boards was used. All subjects were first tested on the incidental-learning task (stage 1). The order of the second and third stages was counterbalanced. A short recess was given after each testing stage.

Incidental learning. As recommended by MANDLER *et al.* [7], "true" incidental learning condition was used. Under this condition the subject should not expect a memory test at all. The subject was told "You are going to be presented with 12 boards—six of them will be with words and six with pictures. Each board contains four words or pictures. You are asked to read the word or name the picture and then to estimate the price of each item". Each board was presented for 20 sec. Following the presentation of the 12 boards, the subject was asked first to recall as many words and pictures as he or she could. Then, an empty board, divided into four quadrants, was presented, and four small cards of words or pictures were given to the subject who was asked to place them in their original positions.

Intentional learning—words and pictures. In this stage administration was essentially the same as in the previous stage, but subsequently only recall and not spatial positioning was required. The instructions provided prior to testing were: "pay attention to the words and pictures presented because you will be asked to recall as many as you can".

Intentional learning—spatial location. At this stage also administration was the same as in the first stage, but here the instructions were to "focus on the spatial position of the words and pictures because afterwards you will be asked to place small cards with these words and pictures in their original positions". After the acquisition phase, spatial positioning of the items was required.

RESULTS

Spatial-location analysis

Figure 2(a) and (b) present the number of pictures and words, respectively, placed in the correct position by the RBD and LBD patient groups, as well as by the elderly- and young-control groups, under both incidental and intentional learning conditions.

MANOVA procedure was used to analyse the effect of group (LBD, RBD, elderly and young) by learning condition (incidental vs intentional) by stimulus (words vs pictures). The former being a "between-subject" factor and the latter two being "within-subject" factors. The three main effects and the interaction between group and learning condition were found to be significant: group $F(3, 42)=16.78$, $P<0.001$; learning condition $F(1, 42)=95.80$, $P<0.001$. The overall performance under incidental learning condition was more accurate than under intentional learning. Stimulus $F(1, 42)=61.87$, $P<0.001$. Overall, subjects relocated the pictures more accurately than the words; group by learning condition $F(3, 4)=95.8$, $P<0.001$. A follow-up analysis using the Duncan procedure revealed that the overall performance of the two control groups was significantly better than that of the two patient groups. Comparison between LBD and RBD showed that LBD performed significantly worse than RBD under intentional learning condition. However, under

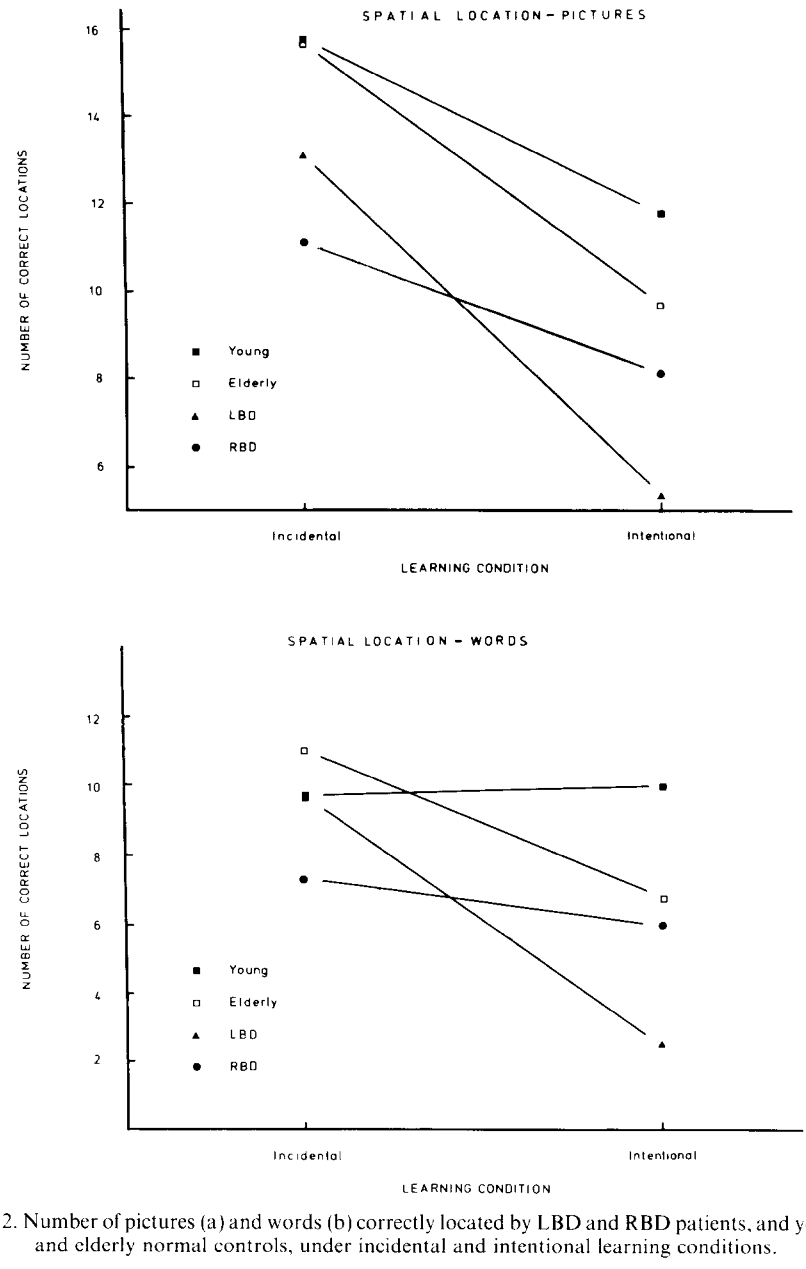

Fig. 2. Number of pictures (a) and words (b) correctly located by LBD and RBD patients, and young and elderly normal controls, under incidental and intentional learning conditions.

incidental learning condition, the RBD group performed significantly worse than the LBD group. The comparison between the two control groups revealed that under intentional but not under incidental learning condition, the young group performed better than the elderly. This pattern of results for the patient and the control groups was the same in both words and pictures.

Recall analysis

Figure 3(a) and (b) present the number of pictures and words, respectively, recalled by the LBD and RBD patient groups, as well as by the elderly and young control groups, under incidental and intentional learning conditions.

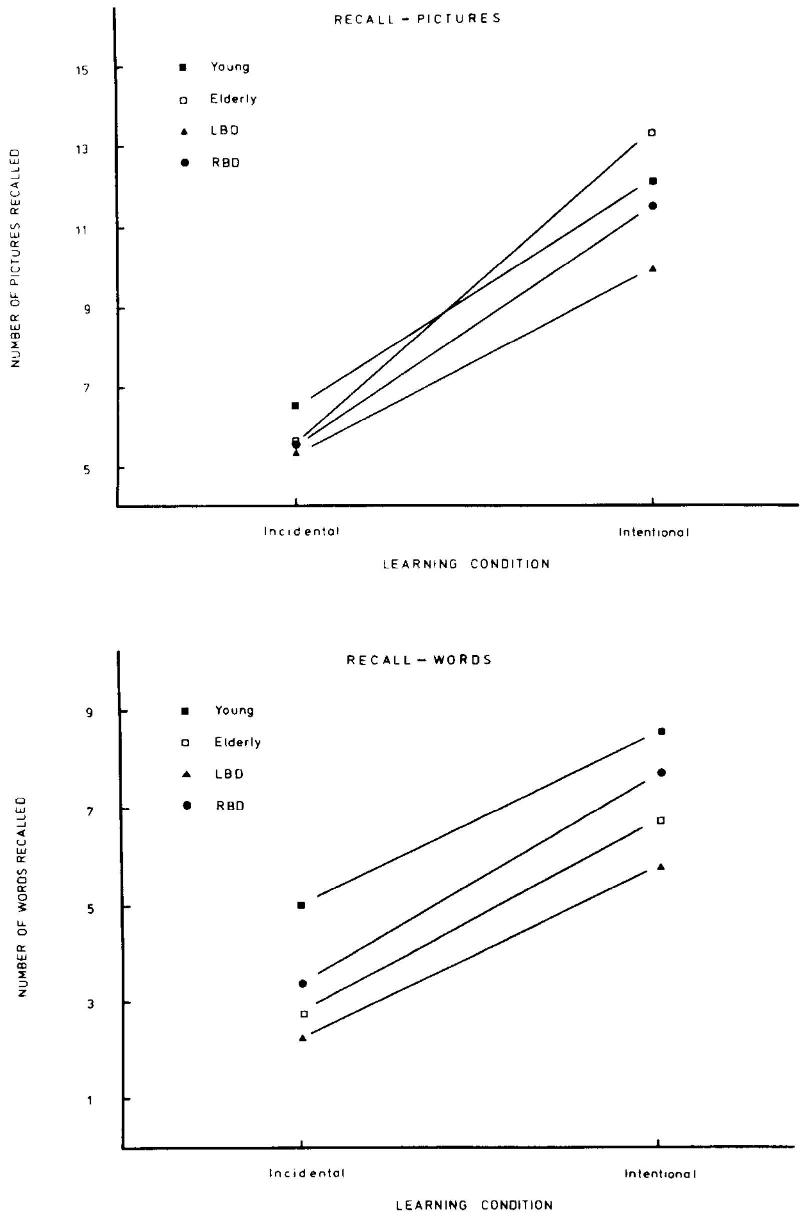

Fig. 3. Number of pictures (a) and words (b) recalled by LBD and RBD patients, and young and elderly normal controls, under incidental and intentional learning conditions.

MANOVA procedure was used to analyse the effect of group (LBD, RBD, young and elderly) by learning condition (incidental vs intentional), by stimulus (pictures vs words). The former being a "between-subject" factor and the latter two being "within-subject" factors. The three main effects (but none of the interactions between them) were found significant. Group $F(3,42)=6.31$, $P<0.001$; learning condition $F(1,42)=114.10$, $P<0.001$. Contrary to the results in recall of spatial location, here the overall performance under intentional learning condition was better than under incidental learning. Stimulus $F(1,42)=77.23$, $P<0.001$. Similar to the finding in recall of spatial location, overall subjects, recall of pictures was better than recall of words. A follow-up analysis, using the Duncan procedure, was used in order to identify the source of the group main effect. The LBD group recalled significantly less than both control groups and less than the RBD group, although this difference did not reach significance. The RBD group recalled significantly less when compared with the young but not with the elderly control group. The young and elderly control groups did not significantly differ from each other.

The superior performance of the RBD group over the LBD group in recall of spatial location under intentional learning conditions, might be attributed to the use of verbal coding (which would be feasible given the use of simple 2×2 spatial arrays), in which RBD patients have an advantage. To assess this possibility, a correlational analysis was conducted between the scores of item recall and recall of spatial location (pictures and words combined) under intentional learning conditions. The analysis was performed separately for each patient group. No significant correlation was found, neither for the RBD ($R=0.26$, $P>0.05$) nor for the LBD ($R=-0.39$, $P>0.05$) patient groups.

DISCUSSION

The basic hypothesis of the present study, is that effortful memory processes are controlled by mechanisms of the left hemisphere, while automatic processes are controlled primarily by the right hemisphere. Findings reported by Luria and colleagues on the execution of "learned" automatisms and on incidental learning [5, 6] support this hypothesis. Recently Vakil *et al.* [20] have found that RBD patients were more impaired in recall of the frequency of occurrence of items, an "innate" automatic process (Hasher and Zacks [1]), while LBD patients were more impaired in recall of the items, an effortful memory task.

The focus of the present study is on the effect of lateralized cerebral damage on recall of spatial location. This task is also claimed by Hasher and Zacks [1] to be processed by innate automatic mechanisms, irrespective of the learning conditions. An alternative approach was presented by Hirst [2] and Hirst and Volpe [3, 4] who claim that any type of information learned incidentally is processed automatically. Assuming that the effortful/automatic dichotomy is lateralized as introduced above, both approaches would predict a relative LBD disadvantage on free recall under intentional learning condition and a relative RBD disadvantage on recall of spatial location under incidental learning condition. Our findings confirm these two predictions, common to both approaches. RBD patients outperformed the LBD group in free recall following incidental learning, and in recall of the spatial location after intentional learning. The basic hypothesis of the present study, relating automatic processing with the right hemisphere and effortful processing with the left hemisphere, is supported in the first case if the effortful/automatic dichotomy is defined according to the type of information, and in the second case if it is defined according to the learning conditions.

In our view, type of information and learning condition interact with each other in determining the degree of effortfulness/automaticity of the memory process applied. In the case of an item-recall task, the items are in the focus of attention, and so processed effortfully, whether they are intended for late recall or supposed to be engaged in a non-memory task. This is why intentionality effect was found in the recall task. Effortfulness of the recall task in both learning conditions is in accord with our postulation that the left hemisphere is dominant in controlling effortful memory processes. As we have seen, LBD patients performed the recall task worse than RBD patients under both intentional and incidental learning conditions. On the other hand the spatial location of an item might be processed either effortfully or automatically, depending upon the learning condition. Usually such information is contextual in nature, being less important (and thus attracting less attention) as compared to other features of the item, pertinent to it's identification. This is why spatial location is processed automatically in normal life situations, as well as under true incidental learning conditions created experimentally. However, under intentional learning conditions, when the spatial location of an item is defined *a priori* as its most important feature, and attention is focused specifically on that feature, then effortful processing takes place. Support for this explanation can be derived from the fact that the young and elderly controls in the present study differed under intentional but not under incidental learning conditions of the spatial location task. The advantage of the RBD group over the LBD group in recall of spatial location under intentional but not under incidental learning conditions, is in accord with our lateralization hypothesis if this theoretical viewpoint is accepted.

Two further comments are in place. In all the testing conditions, pictures were better remembered than words. Since the pictures utilized were verbally codeable, in terms of PAIVIO [11], they were "dually coded" and thus better recalled. In future studies we intend to use also figures which are not verbally codeable. In comparing our results to those of SMITH and MILNER [17], it should be pointed out that Smith and Milner required the recall of the precise position in a 16-object random array, so that verbalization would not have been a feasible method even under intentional learning conditions. The simple 2×2 array used in the present study might enable verbal coding of the spatial location. Thus, the advantage of the RBD group under intentional learning conditions, could be alternatively explained as resulting from inability of LBD patients to use effectively verbal coding of the items' spatial location. However, lack of significant correlation between scores of intentional recall of items and intentional recall of their location do not support this interpretation. Replication of the present study using SMITH and MILNER's paradigm [17] might further clarify the role of verbalization in such a task.

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