Neuropsychologia, Vol. 29, No. 10, pp. 981–992, 1991.
Printed in Great Britain.

0028-3932/91 $3.00+0.00

DIFFERENTIAL EFFECT OF RIGHT AND LEFT HEMISPHERIC LESIONS ON TWO MEMORY TASKS: FREE RECALL AND FREQUENCY JUDGEMENT

E. VAKIL,*†‡ S. GALEK,* N. SOROKER,§ H. RING§ and Y. GROSS*

*Psychology Department, Bar-Ilan University, Ramat-Gan, Israel; †The National Institute for the Rehabilitation of the Brain-Injured, Recanati Rehabilitation Center, Tel-Aviv, Israel; and §Loewenstein Rehabilitation Hospital, Ra'anana, Israel; Sackler School of Medicine, Tel-Aviv University, Tel-Aviv, Israel

(*Received* 18 *April* 1990; *accepted* 4 *April* 1991)

Abstract—We investigated the relationship between lateralized cerebral damage and two memory tasks; free recall and frequency judgement. Free recall is considered to be processed effortfully while frequency judgement is considered to be processed automatically (HASHER and ZACKS [9]). Nine right brain-damaged patients (RBD), nine left brain-damaged patients (LBD) and nine control subjects participated in this study. It was hypothesized that RBD would show an advantage over LBD on the free-recall task, whereas LBD would show an advantage over RBD on the frequency-judgement task. In accordance with our hypothesis, free-recall was more impaired in LBD than in RBD. In the frequency-judgement task, an effect of laterality of lesion was found in high (4–6) and low (0–1) frequencies, but not in the medium (2–3) frequencies. The anticipated LBD advantage was shown in judgement of the high frequencies, but unexpectedly RBD performed better than LBD in low frequencies. The results are discussed in terms of the relationship between effortful and automatic memory processes and cerebral lateralization.

INTRODUCTION

THE DISTINCTION between automatic and effortful processes has long been recognized in psychology. The most basic differentiating characteristic is that automatic processes make minimal demands on attentional capacity, whereas effortful processes require attention and awareness [16, 22, 24, 25]. HASHER and ZACKS [9] introduced a further distinction between "learned" and "innate" automatic processes. "Innate" automatic processes, unlike "learned" ones, are unaffected by either subject variables (e.g. age, mood or ability) or task variables (e.g. instruction, practice or strategy). According to HASHER and ZACKS [9], three tasks fulfill the criteria of "innate" automatic processes: encoding of frequency of occurrence, temporal order and spatial location. Encoding of frequency of occurrence has been most widely studied over the last decade (for a review, see [10]), and different models have been offered to explain its underlying mechanisms. HASHER and ZACKS [9] and other researchers [12, 29] suggest that upon repeated presentations, an automatic mechanism registers the frequency of occurrence of an event. HOWELL [13] offered an alternative model in which frequency judgement is accomplished by an intentional, effortful strategy of mentally counting the repeated presentations of each item.

NAVEH-BENJAMIN and JONIDES [15, 21], who tested and criticized many of Hasher and

‡Address all correspondence to: Dr Eli Vakil, Psychology Department, Bar-Ilan University, Ramat-Gan, 52900, Israel.

Zacks' criteria for "innate" automatic processes, noted that "frequency estimates were reasonably accurate, even under conditions yielding the poorest relative performance" (p. 239 [15]). GREENE [6], summarizing various findings in a recent review, indicates that there is strong evidence supporting Hasher and Zacks' hypothesis that intentional learning would not yield better performance than incidental learning of frequency of occurrence [3, 4, 21]. However, the assumption of a lack of individual differences made by HASHER and ZACKS [9] has not been well supported [2, 5].

HASHER *et al.* [11] summarized the findings in regard to frequency judgement as an "innate" automatic process as follows: "When these other dimensions or criteria of automaticity have been investigated in relation to encoding of event frequency, the typical finding has been one supporting the automaticity view: The process of encoding frequency information appears to be largely impervious to the vicissitudes of competing demands, old age and depressed mood; it is also largely impervious to benefits typically associated with practice, with explicit preknowledge of what will be tested, with superior intellectual ability, and with the greater sophistication about memory of older compared with younger children" (pp. 83–84). Thus, HASHER and ZACKS' [9] claim that frequency of occurrence is encoded automatically is well supported.

Automatic processes in neurologically impaired populations

(*a*) *Frequency judgement*. HASHER and ZACKS [9] speculated that damage to the central nervous system might interfere with automatic encoding in memory, this being the sole exception to their criterion of lack of individual differences. They remark that "automatic processes should be functioning under all conditions of consciousness, except perhaps where brain damage has occurred" (p. 372).

The neuropsychological literature provides only limited information about the anatomical basis of the automatic memory processes. GROBER [7] found that LBD patients with aphasia did not differ from control subjects in their ability to judge frequency of occurrence. Unmedicated Parkinson's disease patients studied by WEINGARTNER *et al.* [31] also performed as controls in the frequency-judgement task. By contrast, HUPPERT and PIERCY [14] found that Korsakoff patients performed worse than controls on a task that combined frequency of occurrence and temporal judgements. VAKIL [30], TWEEDY and VAKIL [28] and LEVIN *et al.* [17] found that closed-head injured patients performed worse than control subjects on a task requiring judgement of frequency of occurrence. SMITH and MILNER [27] found that frequency judgement is specifically impaired following right frontal-lobe lesions but not following left or right temporal lesions.

(*b*) *Overlearned activities*. Early studies by Luria and his colleagues addressed the issue of automaticity and lateralized brain damage with regard to "learned" automatic processes. LURIA *et al.* [19] reported two patients with left parieto-occipital lesions whose automatized writing (e.g. signature) remained intact, although their writing and copying abilities were impaired. A later report by SIMERNITSKAYA [26] describes two patients with right hemisphere lesions. In these patients slow writing and copying were preserved, but they could not write automatically. In a later study by LURIA and SIMERNITSKAYA [18], 15 patients with left temporo-parietal lesions and 15 patients with comparable lesions of the right hemisphere were compared. Two memory tasks were employed: (1) free recall following intentional learning and (2) free recall following incidental learning. The left brain-damaged group (LBD) was more impaired on the intentional learning task, while the right brain-damaged group (RBD) was more impaired on the incidental learning task. On the basis of this study and other clinical observations, LURIA and SIMERNITSKAYA [18] concluded that left hemisphere damage results in the breakdown of the more conscious, voluntarily controlled processes, while right brain damage results in the impairment of the incidental, automatic processes.

The aim of the present study is to evaluate the effect of right and left hemispheric lesions upon two memory processes: (1) free recall of verbal material; and (2) frequency judgement of the same material. These two tasks are taken respectively as representatives of "effortful" and "automatic" memory processes. Following Luria and his colleagues' observations with regard to "*learned*" automatic processes, it is hypothesized that frequency judgement, thought to be an "*innate*" automatic process [9], would be more affected by right cerebral damage whereas free recall, being an effortful memory process in nature, would be more affected by left cerebral damage.

METHOD

Subjects

Subjects were recruited for the study from among a population of patients admitted to the Loewenstein Hospital (Israel) for rehabilitation after stroke. To be included, subjects had to meet the following criteria:

(1) Brain damage was the result of a non-haemorrhagic infarction, as evidenced by a computerized tomographic scan (CT), performed during the acute stage.

(2) Follow-up CT, performed 6 weeks or later after onset, revealed a cortical subcortical hypodense area, compatible with the occurrence of a single infarction limited to one hemisphere.

(3) Neurologic representation compatible with a unilateral hemispheric involvement.

(4) Negative history of previous stroke or other neurologic disease, psychiatric disorder or alcoholism.

(5) Intellectual and linguistic functioning at a level enabling adequate responsiveness to the task requirements.

Eighteen patients were examined, nine right brain-damaged and nine left brain-damaged patients. The RBD patients' mean age was 59.8, and their educational level averaged 10.3 years. In the case of the LBD patients, the mean age was 50.7 and their educational level averaged 9.2 years. Clinical data for these patients are provided in Tables 1(a) and 1(b).

Table 1(a). Main clinical data for right brain-damaged group

Patient	Age	Sex	H	Ed	TAO	HP	HA	Neglect	Aphasia
GI	68	M	R	12	6	++	-	-	No
MY	66	M	R	4	7	++	-	-	No
LM	69	F	R	4	12	++	?	+	No
KH	56	F	L	12	12	++	-	+	No
PP	49	M	R	14	22	++	-	+	No
ZR	53	M	R	15	23	++	+	+	No
OY	49	F	L	8	11	++	-	-	No
MA	53	M	L	12	15	++	-	-	No
KM	75	M	R	12	21	++	?	+	No

Lesion analysis

Reconstructions of the lesions from follow-up CT scans are provided in Figs 1(a) and 1(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; interslice 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. Images from different subjects, approximately paralleling each other, are displayed in vertical columns.

In all but one patient, the infarcts are confined to the territory of the middle cerebral artery. In the RBD patient M.A., involvement also extends to the territory of the anterior cerebral artery. The temporal lobe is involved in all

Table 1(b). Main clinical data for left brain-damaged group

Patient	Age	Sex	H	Ed	TAO	HP	HA	Neglect	Aphasia
OZ	65	M	R	8	9	+	-	-	No
AM	53	M	R	10	11	-	-	-	Conduction, mild
BB	44	M	R	8	6	+	-	-	Amnestic, mild
GM	50	M	R	15	7	-	-	-	Conduction
HS	32	M	R	10	4	++	-	-	Motor
ZY	43	M	R	8	7	++	-	-	Motor
FD	61	M	R	8	24	++	-	-	Motor mainly
SA	55	M	R	8	8	++	-	-	TrCor Mixed
SB	53	M	R	8	19	+	-	-	Motor mainly

Ed = education (years); H = Handedness; TAO = time after onset (weeks) HP = hemiplegia (++) or hemiparesis (+); HA = hemianopsia (++) or quadrantanopsia (+); ? = probable visual-field defect (uncertain, because of aphasia or neglect); TrCor = transcortical.

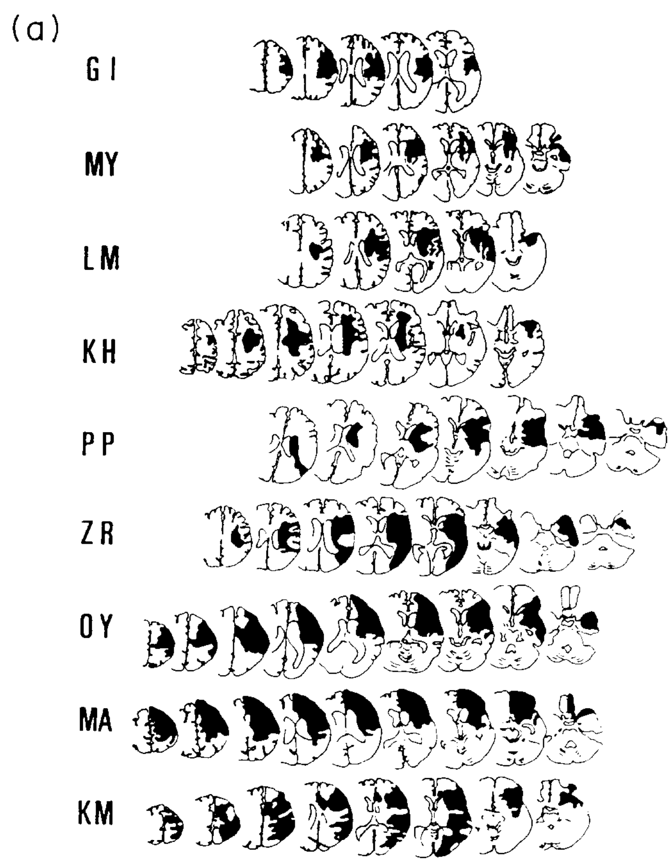

Fig. 1(a).

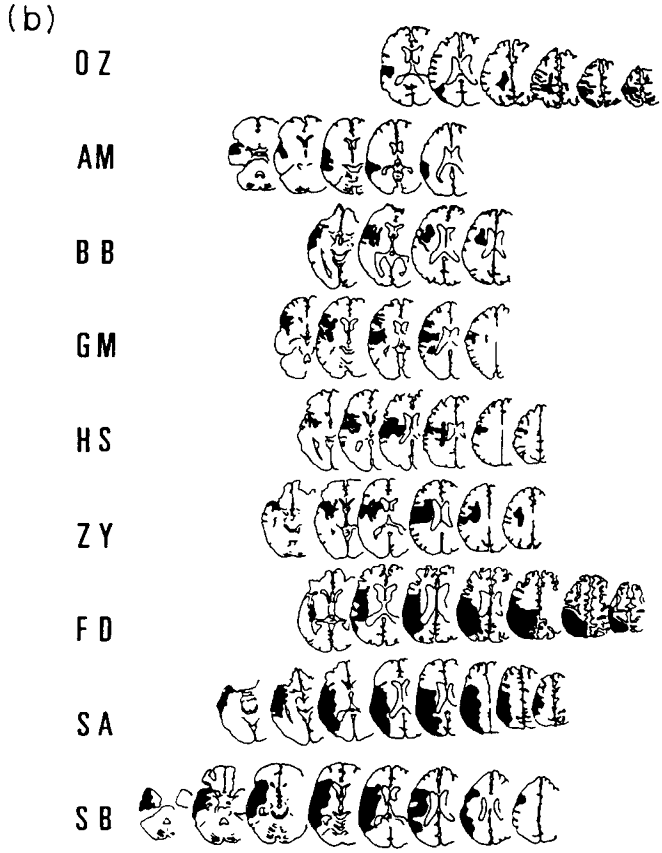

Fig. 1(b). CT reconstructions from (a) right hemisphere-damaged patients, and (b) left hemisphere-damaged patients.

patients, and in most of them portions of the parietal lobe are also involved. In all RBD patients, the lesion involves the dorsolateral aspects of the frontal lobe, at least in its posterior regions. The frontal lobe is involved in all but two patients (O.Z. and A.M.) of the LBD group.

The task requirements precluded participation of LBD patients with significant language disturbances. This is the most probable explanation of the fact that lesion extent in the LBD group is generally smaller than that in the RBD group, as may be seen in the CT reconstructions. Nine healthy control subjects participated in this study. Their mean age was 26.4, and their educational level averaged 14.6 years.

Stimuli

Three sets of 24 high-frequency Hebrew words were used to construct three different versions of a 69-item presentation list. In each list, the initial and final three items were fillers used to counteract primacy and recency artifacts. The body of each list consisted of 18 target words. Sixty-three words were presented from one to six times each, using three words for each frequency. Fifteen additional words were used in the testing stage.

Testing procedure

Each subject was seated in front of an IBM-compatible personal computer. Words, printed in upper case characters 15 mm high, appeared one at a time in the centre of the screen for 3 sec. Judgement of *frequency* of occurrence was tested in two stages: incidental and intentional learning conditions.

Incidental learning. Subjects were asked to "pay close attention to what is presented on the screen because later your memory will be tested". Following the acquisition phase, subjects were asked to recall as many words as possible from the list presented. Then the 18 words which constituted the body of the list, with the addition of 15 novel foils, were presented in the centre of the computer screen, one at a time, in random order. Subjects were asked to estimate the number of times each word had been previously presented, from one to six times, or zero if the word had not been presented at the acquisition stage.

Intentional learning. The procedure was identical to the previous condition except that prior to presentation of the acquisition list, subjects were informed explicitly which tests would follow. Frequency judgement and word recall were tested on different word lists. In half of the cases, frequency judgement was tested first, while in the other half word recall was tested first. In testing frequency judgement, subjects were instructed: "Following presentation of the list you will be asked to estimate the number of times each word has appeared, from one to six, or zero if it has not appeared previously". When word recall was tested, subjects were instructed: "Following presentation of the list you will be asked to recall as many words as you remember".

The word lists assigned to both conditions were counterbalanced. Obviously, the incidental learning condition always had to precede the intentional learning condition. This variation in instructions is, of course, confounded by whatever practice and/or fatigue effects operate within the experiment.

Both learning conditions of the frequency judgement are regarded as intentional learning conditions, with respect to the word-recall task.

RESULTS

Frequency analyses

Two different scores were used to evaluate performance on the frequency of occurrence task.

Mean score. This is the most widely used scoring method for frequency judgement, and was used in the original paper by HASHER and ZACKS [9]. In this method, each subject contributes one score, which is the mean judgement value for every presentation frequency. For example, if the three words that appeared four times were judged to appear three, four and five times, the mean score for this particular subject is four. Thus, the subject received a perfect score for inaccurate judgement. This scoring system indicates the extent to which mean judged frequency increases with actual presentation frequency. However, the major disadvantage of this method is that it is insensitive to the amount of variability in an individual's judgement about the items in a particular frequency, as illustrated by the above example (for a more detailed discussion, see [30]).

Absolute deviation score. This scoring method has been used previously and found to be more sensitive than mean scores in detection of group differences. In a study by VAKIL [30], in which frequency judgement of three groups (closed-head injured patients, elderly and controls) was compared, by analysing the results using mean judged frequency, no group effect was detected. However, when absolute deviation scores were used, a group effect emerged, indicating that all groups differed significantly from each other. In this scoring procedure the sum of the unsigned differences between each item's actual and judged frequency is computed. Using the previous example, the absolute deviation score in this case would be $|4-3|+|4-4|+|4-5|=2$, while a perfect performance (judgement of four for each one of these words) would have yielded a zero deviation score. Thus, this example demonstrates that the deviation score reflects inaccurate judgement better than the mean score.

The next two sections will describe the results obtained using the two different scoring systems.

Mean score analysis. Figure 2 presents the mean judged frequency as a function of the actual frequency for the three groups. Since preliminary analysis indicated that performance under the two learning conditions (incidental vs intentional) did not differ significantly, the results of these conditions were combined. MANOVA procedure was used to analyse the effect of group (LBD, RBD and controls) by frequency (0–6), the former being a between-subjects factor and the latter a within-subjects factor. The results indicate a main effect for group [$F(2, 24)=14.43$, $P<0.001$] and for frequency [$F(6, 144)=128.43$, $P<0.001$]. The

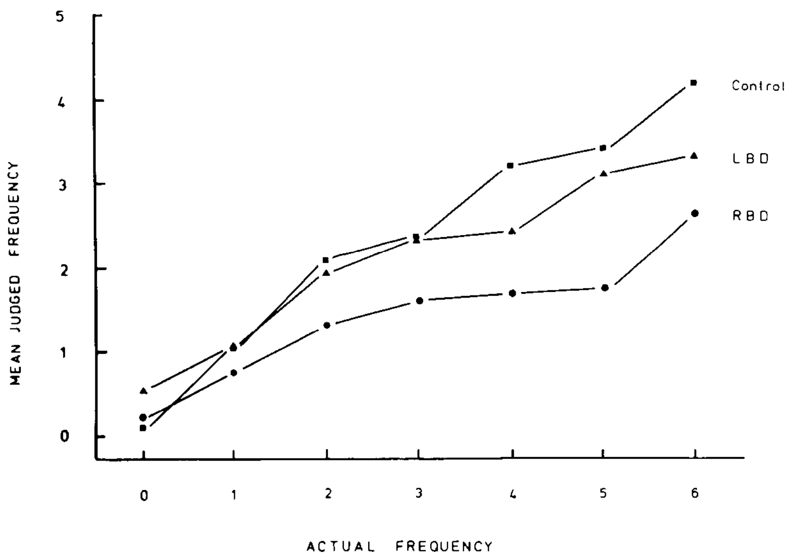

Fig. 2. Mean judged frequency scores, as a function of the actual frequency, for RBD, LBD and control groups.

group by frequency interaction was also found to be significant [$F(12, 144)=5.06$, $P<0.001$]. A follow-up analysis using the Duncan procedure indicated that the control group was more accurate than the two patient groups. When the two patient groups were compared, in spite of the seemingly small difference in accuracy, statistically, LBD performed significantly worse (mean = 0.55) than RBD (mean = 0.21) and control groups (mean = 0.16) when frequency = 0. When frequency = 1, the groups did not significantly differ from each other, and from frequency 2 to 5, the LBD group was more accurate than the RBD group. The advantage of LBD over RBD when frequency = 6 did not reach significance.

Absolute deviation analysis. Figure 3 presents the absolute deviation scores as a function of the actual frequency (notice that because the score reflects deviation from the correct answer, the higher the score, the worse the performance). As in the mean score analysis, results of the two learning conditions (incidental vs intentional) were combined, since the difference in performance between the two conditions did not reach significance. MANOVA was used to analyse the effect of group (LBD, RBD and controls) by frequency (0–6), the former being a between-subjects factor and the latter a within-subjects factor. Both main effects and the interaction between them were found to be significant: group [$F(2, 24)=38.92$, $P<0.001$]; frequency [$F(6, 144)=73.11$, $P<0.001$]; and group by frequency [$F(12, 144)=5.82$, $P<0.001$]. A follow-up analysis using the Duncan procedure revealed that the overall performance of the control group was better (lower absolute deviation score) than that of the patient groups. Comparison between LBD and RBD showed that for items with frequency of occurrence 0 (0.55 and 0.21, respectively) and 1 (1.04 and 0.67, respectively), in spite of the seemingly small difference in accuracy, statistically, LBD performed significantly worse than RBD (higher absolute deviation score). For frequencies 2 and 3, the two patient groups did not differ significantly. For frequencies 4–6, RBD were less accurate than LBD (when frequency = 6, the difference did not reach significance). For simplification of these results, the range of frequencies from 0 to 6 was divided into three categories: low frequencies (0–1),

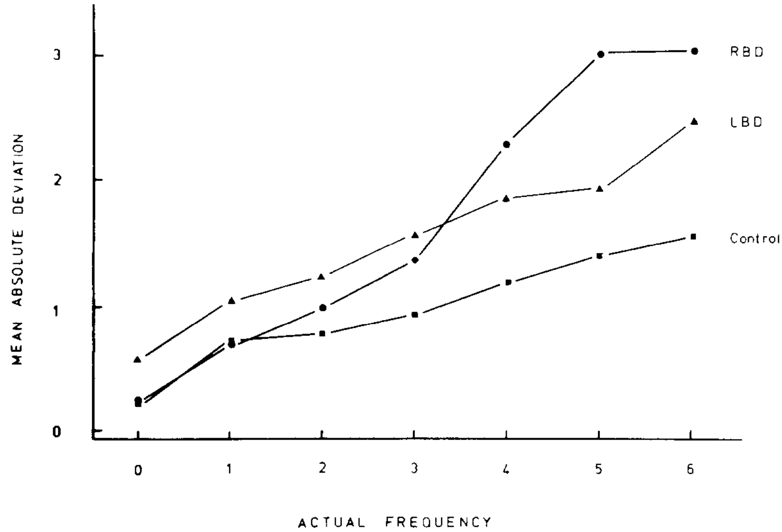

Fig. 3. Absolute deviation scores, as a function of the actual frequency, for RBD, LBD and control groups.

middle frequencies (2–3) and high frequencies (4–6). MANOVA was used to test the effect of group (LBD, RBD and controls) by frequency (low, middle and high), the former being a between-subjects factor and the latter a within-subjects factor. Both main effects and the interaction between them were found to be significant: group [F (2, 24) = 38.92, P < 0.001]; frequency [F (2,48) = 229.75, P < 0.001]; and group by frequency [F (4, 48) = 13.54, P < 0.001]. The Duncan procedure was used for follow-up analysis. Results clearly indicate better RBD performance at the low frequencies as opposed to better LBD performance at the high frequencies. The two groups did not differ significantly at the middle frequencies.

In a preliminary analysis, all patients, regardless of lesion side, were divided into two groups according to lesion size. Group main effect was not significant when frequency judgement was measured. Thus, the differences between LBD and RBD performance cannot be attributed to the generally larger lesions in the RBD group.

Recall analysis

In both learning conditions of the *frequency*-judgement task, word recall was learned under intentional learning conditions; the results were therefore combined. This decision was also supported by a preliminary statistical analysis, finding that the recall under both conditions did not differ significantly.

Figure 4 presents the number of words recalled by each group as a function of the actual frequency. MANOVA was used to analyse the effect of group (LBD, RBD and controls) by frequency (1–6), the former being a between-subjects factor and the latter a within-subjects factor. Both main effects were found to be significant: group [F (2, 24) = 19.39, P < 0.001]; and frequency [F (5, 120) = 11.69, P < 0.001]. As can be seen in Fig. 4, the three groups recalled more words at the high frequencies than at the low frequencies. The interaction between the two did not reach significance. The group main effect was followed by a Duncan procedure which revealed that the three groups are significantly different from each other. The control group recalled the highest and LBD the lowest number of words.

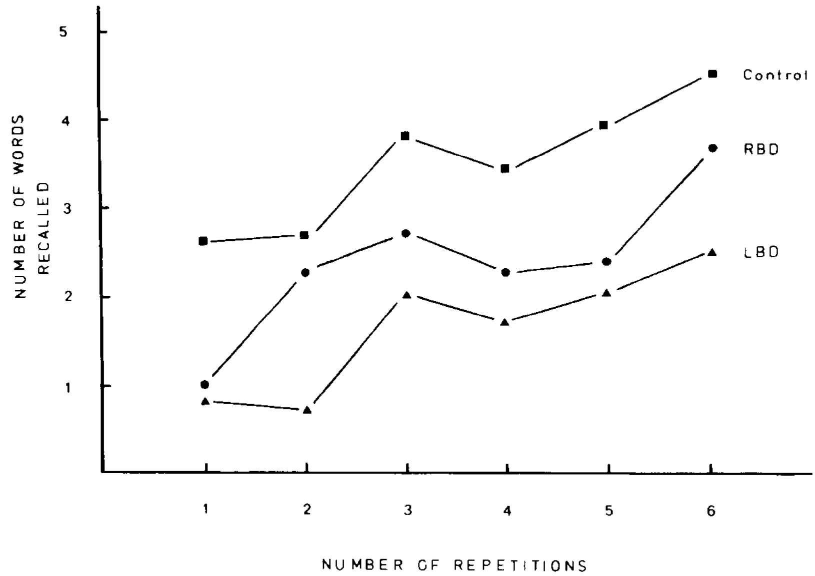

Fig. 4. Number of words recalled by each group, as a function of the actual frequency.

DISCUSSION

The primary objective of the present study was to investigate the relationship between lateralized cerebral damage and impairment of effortful vs automatic memory processes. Following LURIA's work with colleagues [18, 19, 26] on "learned" automatic processes and lateralized brain damage, it was hypothesized that LBD patients would be more impaired than RBD patients in effortful memory processing, while RBD patients would be more impaired than LBD patients in automatic memory processing. Free recall was used as a measure of an effortful memory process, while frequency judgement, based on HASHER, ZACKS and their colleagues [9, 11], was used as a measure of an automatic memory process.

The findings of the present study, regarding the effortful memory task of word recall, are in accord with previous findings that LBD patients are more impaired than RBD patients in recall of verbal material [20].

Two different scoring methods were used in the analysis of frequency-judgement performance: mean judged frequency and absolute deviation. We used mean judged frequency since it is the most commonly used score [9, 10, 32]. Absolute deviation score was used because, as previously noted, it is a more sensitive measure of frequency judgement; thus, the discussion will focus mainly on the results yielded by this scoring method.

Some similarities and some differences emerged in the comparison of results obtained by the two scoring methods. Using either method, intentionality did not have an effect. Thus, for the purpose of subsequent analyses, we combined the frequency judgement of both intentional and incidental learning. This finding further supports HASHER and ZACKS' [9] conclusion that frequency of occurrence is encoded automatically. Both methods also show a superior performance of the control group over the two patient groups. This reconfirms findings of previous studies showing an impairment in frequency judgement following cerebral injury [17, 28, 30].

The most important contribution of this study derives from the comparison between LBD and RBD patient groups in judgement of frequency of occurrence. In this comparison, the two scoring methods are quite different. As may be seen in Fig. 2, results obtained using mean judged frequency scores indicate that RBD patients performed better than LBD patients only when frequency = 0; at all the other frequencies (1–6), LBD patients performed better than RBD patients; and the advantage did not reach significance at frequencies 1 and 6. These findings (except when frequency = 0) support our original hypothesis, that RBD patients will be more impaired in the performance of the frequency judgement.

The results obtained using absolute deviation scores are more complicated. As can be seen in Fig. 3 there is no overall advantage of one patient group over the other. At the low frequencies (0–1) RBD patients performed significantly better than LBD patients, at the high frequencies (4–6) the situation was reversed, and at the middle range (2–3) the groups did not differ significantly from each other. This pattern of results was unexpected, since frequency judgement is usually regarded as a single and uniform task, irrespective of the actual frequency. However, upon reconsideration, we found the pattern very revealing. It would appear that with judgement of low frequencies, one is confronted essentially with a recognition rather than a frequency-judgement task, despite the fact that in all studies of frequency, 0–1 were regarded as measures of frequency. Thus, assuming low frequency judgement is a verbal-recognition task, LBD patients in particular are expected to be impaired, as in the case of a word-recall task [20]. By contrast, judgement of high frequencies apparently requires a totally different cognitive process than mere recognition of whether a stimulus was previously presented or not. This process is found to be particularly impaired in the RBD patient group. The middle frequency range is a transition segment on which neither group showed an advantage.

The breakdown of RBD and LBD scores on different segments of the frequency-judgement task indicates to us that this task is actually composed of different segments which are processed differently. This finding is not predicted by HASHER and ZACKS' model [9, 10] who have regarded frequency judgement as a "single" task which is automatically processed. We would like to offer a tentative interpretation to explain our results. Since low and high frequencies are processed differently and we have good reasons to claim that low frequencies are processed effortfully, then only high frequencies are processed automatically. This contradicts Hasher and Zacks' assertion that the whole range of frequencies are processed automatically.

This interpretation of the findings might help to resolve some of the theoretical debates regarding frequency judgement's underlying process. Some of the disagreements focus on whether frequency judgement is effortful [13] or automatic [9, 12, 29]; others deal with the question of whether frequency judgement and recognition utilize the same mechanisms [1, 8] or totally different ones [23]. Possibly, these different claims arose from the supposition that frequency judgement is a single uniform process, and/or from research designs which inadvertently gave greater weight to one of at least two kinds of processing (high frequency and low frequency) which comprise frequency judgement.

Although frequency judgement has been investigated for over a decade, it is quite remarkable that our findings are the first to differentiate between the processes inherent in the judgements of low and high frequencies. We believe that the present finding was made possible by that fact that our research paradigm used two subject populations, cognitively impaired in different ways, whereas past studies examined a single population type, either normal or uniformly impaired. The fact that this type of paradigm can yield such fine differentiations strengthens the contention that research in cognitive neuroscience can make significant contributions to the understanding of normal cognitive processes.

With regard to the original hypothesis advanced in this paper, the specific prediction of an overall advantage for RBD patients on the recall task was confirmed. The second hypothesis, expecting an overall advantage for LBD patients on the frequency task, was partially fulfilled. However, if one accepts our interpretation of low frequency judgement as an effortful task and high frequency judgement as an automatic task, then the results fit the hypothesis reasonably well. LBD patients were more impaired on the effortful tasks, recall and recognition (i.e. low frequencies). RBD patients, however, were more impaired on automatic frequency judgement (i.e. high frequencies). These results illustrate how the two cerebral hemispheres are involved in the processing of what is regarded as a "single" task.

In conclusion, the fact that RBD patients performed worse than LBD patients on judgement of high frequencies, despite being a verbal-memory task, indicates two things: first, that judgement of high frequencies is performed differently from regular verbal-memory processes; second, low and high frequency judgement require different cognitive processes, and can no longer be regarded as parts of a single task. On the basis of our findings, we would like to propose that judgement of low frequencies should not be considered a frequency-judgement task, but rather a recognition task using effortful processing. On the other hand, high frequencies are processed automatically. This interpretation requires further investigation. In particular, separate analyses of normal subjects' judgements of low and high frequencies must be carried out.

Further research is also required to establish the relationship between lateralized hemispheric activity and the distinction between effortful and automatic processes in memory. RBD and LBD patients should be compared on performance of other automatic tasks, both those "learned" and those claimed by Hasher and Zacks to be "innate" (e.g. temporal order and spatial location).

Finally, this study illustrates the importance of careful selection of patients with CT proven, circumscribed cerebral injury, along with careful analysis of the different possible processes underlying each task, to the understanding of brain behaviour relationships.

REFERENCES

1. BEGG, I., MAXWELL, D., MITTERER, J. O. and HARRIS, G. Estimates of frequency: Attribute or attribution? *J. exp. Psychol.: Learn. Mem. Cognit.* **12,** 496 508, 1986.
2. ELLIS, N. R., PALMER, R. L. and REEVES, C. L. Developmental and intellectual differences in frequency processing. *Devl Psychol.* **24,** 38 45, 1988.
3. GREENE, R. L. Incidental learning of event frequency. *Mem. Cognit.* **12,** 90 95, 1984.
4. GREENE, R. L. Effects of intentionality strategy on memory for frequency. *J. exp. Psychol.: Learn. Mem. Cognit.* **12,** 489 495, 1986.
5. GREENE, R. L. Generation effect in frequency judgement. *J. exp. Psychol.: Learn., Mem. Cognit.* **14,** 298 304, 1988.
6. GREENE, R. L. Memory for pair frequency. *J. exp. Psychol.: Learn. Mem. Cognit.* **16,** 110 116, 1990.
7. GROBER, E. Nonlinguistic memory in aphasia. *Cortex* **20,** 67 73, 1984.
8. HARRIS, G., BEGG, I. and MITTERER, J. O. On the relation between frequency estimates and recognition memory. *Mem. Cognit.* **8,** 99 104, 1980.
9. HASHER, L. and ZACKS, R. T. Automatic and effortful processes in memory. *J. exp. Psychol.: Gen.* **108,** 356 388, 1979.
10. HASHER, L. and ZACKS, R. T. Automatic processing of fundamental information: The case of frequency of occurrence. *Am. Psychol.* **39,** 1372 1388, 1984.
11. HASHER, L., ZACKS, R. T., ROSE, K. C. and SANFT, H. Truly incidental encoding of frequency information. *Am. J. Psychol.* **100,** 69 91, 1987.

12. HINTZMAN, D. L. and STERN, L. D. Contextual variability and memory for frequency. *J. exp. Psychol.: Hum. Learn. Mem.* **4,** 539 549, 1978.
13. HOWELL, W. C. Representation of frequency in memory. *Psychol. Bull.* **80,** 44–53, 1973.
14. HUPPERT, F. A. and PIERCY, M. The role of trace strength in recency and frequency judgements by amnestic and control subjects. *Q. J. exp. Psychol.* **30,** 346–354, 1978.
15. JONIDES, J. and NAVEH-BENJAMIN, M. Estimating frequency of occurrence. *J. exp. Psychol.: Learn. Mem. Cognit.* **13,** 230 240, 1987.
16. KAHNEMAN, D. *Attention and Effort.* Prentice-Hall, Englewood Cliffs, New Jersey, 1973.
17. LEVIN, H. S., GOLDSTEIN, F. C., HIGH, W. M. and WILLIAMS, D. Automatic and effortful processing after severe closed head injury. *Brain Cognit.* **7,** 283 297, 1988.
18. LURIA, A. R. and SIMERNITSKAYA, E. G. Interhemispheric relations and the functions of the minor hemisphere. *Neuropsychologia* **15,** 175 177, 1977.
19. LURIA, A. R., SIMERNITSKAYA, E. G. and TUBYLEVICH, B. The structure of psychological processes in relation to cerebral organization. *Neuropsychologia* **8,** 13 18, 1970.
20. MILNER, B. Disorders of memory after brain lesions in man. Preface: material-specific and generalized memory-loss. *Neuropsychologia* **3,** 317 338, 1968.
21. NAVEH-BENJAMIN, M. and JONIDES, J. On the automaticity of frequency coding: Effects of competing task load, encoding strategy and intention. *J. exp. Psychol.: Learn. Mem. Cognit.* **12,** 378 386, 1986.
22. POSNER, M. I. and SNYDER, C. R. R. Attention and cognitive control. In *Information Processing and Cognition: The Loyola Symposium,* R. L. SOLSO (Editor). Lawrence Erlbaum Associates, New Jersey, 1975.
23. PROCTOR, R. W. The relationship of frequency judgement to recognition. *J. exp. Psychol.: Hum. Learn. Mem.* **3,** 73 81, 1977.
24. SCHNEIDER, W. and SHIFFRIN, R. M. Controlled and automatic human information processing: I. Detection, search, and attention. *Psychol. Rev.* **84,** 1 66, 1977.
25. SHIFFRIN, R. M. and SCHNEIDER, W. Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychol. Rev.* **84,** 127 190, 1977.
26. SIMERNITSKAYA, E. G. On two forms of writing defect following local brain lesions. In *Hemisphere function in the human brain,* S. J. DIAMOND and W. K. BAWMENT (Editors), pp. 335 344. London, 1974.
27. SMITH, M. L. and MILNER, B. Effects of focal brain lesions on sensitivity to frequency of occurrence. *Soc. Neurosci. Abstracts* **9,** 30, 1983.
28. TWEEDY, J. R. and VAKIL, E. Evaluating evidence for automaticity in frequency of occurrence judgments: A bias for bias? *J. clin. exp. Neuropsychol.* **10,** 664–675, 1988.
29. UNDERWOOD, B. J. Some correlates of items repetition in free recall learning. *J. verb. Learn. verb. Behav.* **8,** 83 94, 1969.
30. VAKIL, E. Encoding of frequency of occurrence, temporal order and spatial location information by closed head injured and elderly subjects: Is it automatic?. Ph.D. Dissertation, The City University of New York, New York, 1985.
31. WEINGARTNER, H., BURNS, S., DIEBEL, R. and LEWITT, P. A. Cognitive impairments in Parkinson's disease: Distinguishing between effort-demanding and automatic cognitive processes. *Psychiat. Res.* **2,** 223 235, 1984.
32. ZACKS, R. T., HASHER, L. and SANFT, H. Automatic encoding of event frequency: further findings. *J. exp. Psychol.: Learn. Mem. Cognit.* **2,** 106 116, 1982.