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Memory for Temporal Order and Spatial Position Information

Tests of the Automatic-Effortful Distinction

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Summary: Information about the temporal and spatial context of events has been postulated by Hasher and Zacks in 1979 to accumulate in memory via processes that are relatively unaffected by subject variables like age and ability, or task variables such as instructions or practice. These "automatic" processes have been distinguished from "effortful" processes, which *are* affected by these variables. To evaluate these predictions, we tested memory for temporal order and spatial position in groups of young adults recovering from traumatic brain injuries, normal elderly, and normal young adults, using a design that allowed examination of the effects of practice and instructions. Our results indicate that both traumatic brain injury and aging reduce performance on tasks tapping retention of temporal and spatial information if the subject is asked for a relatively precise estimate of the requested information. These effects tend to disappear when estimation tasks are designed, or errors are analyzed, in a way that allows subjects full credit for only partial information about an item's temporospatial context of presentation. The presence of these task and analysis effects that can eliminate existing differences, calls for reevaluation of those studies in which Hasher and Zacks' criteria for automaticity were satisfied. **Key Words:** Effortful—Automatic—Spatial—Amnesia—Judgment task—Brain injury. NNBN 7:281–288, 1994

Several theories have attempted to explain amnesia in terms of a distinction between memory-encoding processes that are "automatic" and those that are "effortful." Effortful processes require the awareness, attention, and control of the individual. In contrast, automatic processes are postulated to require minimal attention or awareness, run to completion without conscious control, and do not normally interfere with concurrent effortful functions (1). Hasher and Zacks (2) proposed that processes governing the encoding of information about the frequency of occurrence and the temporal and spatial context of the occurrences of events, accumulate in memory by automatic processes. They have provided evidence that performance on tasks tapping this information was unaffected by subject variables like age and ability, or task variables such as instructions and practice. Thus, interest in these tasks is directly related to the apparent difference between them and the many effortful recall and recognition tasks that are known to be sensitive to these variables.

In a review paper, Hasher and Zacks (3) summarize a considerable number of studies requiring frequency of occurrence judgments that generally support their position. Evidence establishing the automaticity of memory processes that accumulate temporal and spatial information is less compelling. Zacks and colleagues (4) themselves raised the possibility that temporal order judgment does not satisfy all of their criteria for innate automatic processes. Some studies have supported Hasher and Zacks's claim that temporal order and spatial position information is encoded au-

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tomatically by demonstrating invariances in performance over age and/or instructional conditions (e.g., 5–9). Recent work by Ellis and his colleagues (10, 11) has systematically tested several of Hasher and Zacks' (2) criteria for automaticity of spatial location judgments. In support of Hasher and Zacks (2), Ellis (10, 11) reports that neither intention to learn nor practice improve spatial location judgment. Furthermore, accuracy in spatial location judgment of children from different age groups and college students did not differ significantly in comparison to mentally retarded adults (12, 13). Similarly, intention to learn and the use of different learning strategies did not affect accuracy in temporal order judgment (14, 15). By contrast, other studies have reported results that are at odds with Hasher and Zacks' (2) claim (16–21).

Empirical validation of the automatic/effortful distinction is important because of its role in some theoretical accounts of certain types of organic amnesia. Indeed, these theories are most easily distinguishable by their differing propositions about whether automatic (e.g., 22–25) or effortful (e.g., 26, 27) memory functions are most vulnerable to the injury or disease process creating the amnestic symptoms (for review, see ref. 28). Furthermore, the automatic/effortful distinction is important in the context of the contemporary view that memory is comprised of two separate subcategories, that is, explicit and implicit memory. *Explicit memory* requires effortful and intentional retrieval. On the other hand, retrieval of *implicit memory* is automatic and incidental (29). It is noteworthy that while the automatic/effortful distinction focuses on the *encoding* stage, the implicit/explicit distinction focuses on the *retrieval* stage.

Memory disturbance is the most prominent residual deficit following Traumatic Brain-Injury (TBI) (30, 31). In reviewing the literature, Baddely and colleagues (30) concluded that the pattern of memory deficit shown by TBI is very similar to classic amnesic patients. Both groups of patients show impaired ability to learn new verbal or visual material tested either by recall or recognition methods.

Our previous study (32) indicated that frequency of occurrence judgments are affected by both age and brain trauma. This study will provide similar evidence about the effects of these subject variables on two other putatively automatically mediated task domains.

Two experiments are presented. The first experiment uses two alternative temporal order tests and four alternative spatial position tests, the second a four-alternative temporal and a two-alternative spatial task. Thus, it is possible to evaluate the effects of traumatic brain injury on memory capacity for spatial and temporal information in two task situations across experiments, and to evaluate changes in the response structure of tasks independent of the type of information being tapped. It has been claimed that two alternative forced-choice recognition paradigms provide a better opportunity to observe between group differences in memory capacity, because they reduce or eliminate response criteria effects found in other paradigms (33).

EXPERIMENT 1

Method

Subjects

Twenty young adults (14 male, 6 female) who had suffered brain-injury, at least one year prior to testing, with loss of consciousness (minimum duration of one hour, based on the information recorded by the physician-in-charge), comprised the TBI group. All attended an outpatient rehabilitation program at the Institute of Rehabilitation Medicine of the New York University Medical School. The age of the group ranged from 18 to 49 (mean: 28.7 years; SD: 8.97 years). All had either a verbal or a performance IQ of greater than 80 on the Wechsler Adult Intelligence Scale—Revised (WAIS-R) (34). The patients had no preinjury history of neurological or psychiatric illness and had not used alcohol since injury. All were ambulatory and none was employed at time of testing. All the patients had cognitive impairments sufficient to require participation in a 4-day-per-week program, though none had a language-based deficit sufficient to interfere with understanding the requirements of the tasks. The above characteristics of the TBI group constitute the admission criteria to the rehabilitation program.

The young control subjects consisted of 20 volunteers: 10 males and 10 females. All were undergraduates at Queens College, New York, ranging in age from 21 to 38 years (mean: 26.9 years; SD: 5.16 years). None had a history of alcohol abuse or of significant neurological or psychiatric illness. None had serious medical conditions or were taking medications with known effects on mentation at the time of testing.

Stimuli

Two sets of 52 high-frequency words from the Thorndike and Lorge (35) AA list norms were selected. Each was used to construct two different versions of a 72-item acquisition list. In each of the four different lists, the initial and final four items were fillers used to counteract primacy and recency artifacts. The body of each list consisted of 64 items, divided into four 16-item quarters, each containing ten trials devoted to multiple presentations of four words later used in a frequency of occurrence test (10 trials were devoted to the presentation of four words: one four times, one three times, one twice, and one once). In addition, there were six singly presented words that would later reappear in the temporal and spatial memory tests. Data from the frequency of occurrence judgment task were presented in a previous article (32).

Procedure

Subjects were tested individually. Each was seated before a TRS-80 Color microcomputer with a display screen divided into quadrants by bars 6 mm wide. Each of the words in an acquisition list appeared in the center of one of the quadrants. They were presented at a 5-second rate, printed in uppercase characters 15 mm high. Each quadrant was used equally often in each of the four quarters of a list. Multiply presented words to be subjected to the frequency of occurrence tests appeared only once in any spatial quadrant, and all presentations of each frequency test word occurred in a single temporal quarter of the acquisition list.

After each acquisition list, first temporal order and then spatial position judgments were collected on the same set of 24 singly presented words, six from each temporal quarter of the list, and six from each spatial quadrant of the display screen. Temporal order judgments always preceded spatial position judgments because it was felt that presenting items for a spatial test initially would produce a strong recency artifact on any subsequent temporal order judgments. Since items presented in the temporal test appeared near the center of the screen, no such bias on subsequent spatial position judgments should occur. Half of the subjects in each group made 20 frequency of occurrence judgments on other words from the list prior to the 24 temporal and spatial judgments. For the other half, the frequency judgments followed the temporal and spatial tasks.

After completion of all tests on items from the first acquisition list, a second acquisition list of identical format and structure was presented in order to evaluate the effect of having prior information about the kind of memory test to be employed. Initially, subjects had been *uninformed* about the specific types of memory tests they would encounter, being told only to "pay close attention to what is presented on the screen because later your memory will be tested." Prior to the presentation of the second list, subjects were specifically *informed* that the tests that would follow it "were exactly the same as those used previously, tests of when, where, and how often the words had been presented." Although this variation will be discussed as an instructional manipulation, it is of course confounded with whatever practice and/or fatigue effects operate within the experiment. Since instructions, or changes from incidental to intentional learning conditions or for that matter, practice or fatigue, are not supposed to affect automatic memory functions, performance in the uninformed and informed conditions should be comparable (10, 11).

Memory for temporal order was assessed with a *relative recency task* requiring the subject to indicate which of two words presented for test appeared last in the previous acquisition list. Each subject made judgments on each of 12 pairs of words formed from the words allocated to the temporal and spatial judgment tasks. Three of the pairs contained maximally separated words, one which had appeared in the first and one which had appeared in the fourth quarter of the list. Three pairs contained words from the first and third or the second and fourth quarters, three pairs contained words from adjacent quarters, and three pairs contained words from the same quarter. Test pairs were presented in a horizontal array near the center of the display screen. The most recently presented word appeared equally often on the left and the right side of the test pair. Subjects responded by pointing or by verbalizing the word they had selected and the experimenter entered the selection via the keyboard.

Memory for spatial location information was assessed with a *quadrant estimation task* that required identification of the quadrant in which the item had been originally presented. Each of the 24 words used in the relative recency tests was presented again, one at a time, near the center of the display screen, along with a small facsimile of the quartered screen used to present the original list. Each quadrant of the facsimile was labeled with a letter (*A, B, C,* or *D*), and the subjects indicated their estimates of the original location of each word presented for testing either by pointing or by verbalizing the appropriate letter.

Results

Temporal Task

Average proportion correct scores for each subject group and instructional condition are presented in Table 1.

Both TBI and control subjects found the relative

TABLE 1. *Results of Experiment 1: proportion of trials correct (and standard errors) for two subject groups in a temporal (relative recency) and a spatial (quadrant estimation) task*

Task	Group: Control	TBI
Temporal (2 alternatives)		
Uninformed	.56 (.03)	.55 (.03)[a]
Informed	.55 (.04)[a]	.53 (.05)[a]
Spatial (4 alternatives)		
Uninformed	.33 (.02)	.31 (.02)
Informed	.38 (.03)	.30 (.02)

[a] Performance not significantly better than chance, $p > .05$.

recency task difficult and scores were low in most conditions of the experiment. Multivariate analysis of variance (MANOVA) was used to analyze the effect of group (TBI vs controls) and instructions (uninformed vs informed). The former is a between-subjects factor, and the latter a within-subjects factor. The results showed no effect for instructions or for group and no group by instructions interaction.

Spatial Task

Average proportion correct scores on the quadrant estimation task are also presented in Table 1. In contrast to the temporal judgment task, an analysis of variance reflected a significant effect for subject group, $F(1, 38) = 3.93$, $p < .054$, reflecting the greater accuracy of the controls. No main effect for instructions and no group by instructions interaction were obtained.

Discussion

The lack of a group difference in the temporal judgment task appears to support the view that even individual differences due to traumatic brain injury do not affect performance significantly. However, inspection of Table 1 reveals that the task was quite difficult, with performance at close to chance level (.50). Under these conditions significant group differences are unlikely to emerge. The group differences obtained with the spatial task indicate that the task is like other effortful measures of memory in its vulnerability to brain injury. Direct comparison of the temporal and spatial judgments must be made cautiously, because of the differences of structure between the two tasks (e.g., number of response alternatives).

EXPERIMENT 2

A revised version of the temporal task was developed in an attempt to increase performance level, so that more sensitive estimates of between-group capacity differences and instructional effects could be obtained. The number of response alternatives in the spatial task was reduced to two in this experiment, providing a test comparable in the number of alternatives to Experiment 1. This configuration allows a between-experiment examination of an additional task variable. Tasks with single-item tests and four response alternatives can be compared with tasks employing double-item tests that provide two response alternatives, independent of whether spatial or temporal memory is assessed.

Method

Subjects

New groups of 25 TBI and 25 age-matched control subjects selected by criteria identical to those employed in Experiment 1, and nearly identical in age, participated in this experiment. Group TBI consisted of 19 males and 6 females, ranging in age from 19 to 49 (mean: 28.64 years; SD: 9.34 years). The age-matched young normal controls consisted of 12 males and 13 females, ranging in age from 17 to 39 (mean: 26.72 years; SD: 5.84 years).

To test the age invariance aspect of the Hasher and Zacks (2) formulation, a third group of 25 normal elderly subjects participated in Experiment 2. It consisted of 16 females and 9 males, ranging in age from 55 to 85 (mean: 67.0 years; SD: 8.84 years). All were volunteers at the rehabilitation hospital treating the TBI subjects, and like the young normal controls, none had a history of major neurological or psychiatric disorder, and none took a medication with known effects on the central nervous system at time of testing.

Procedures

The word stimuli used, and the structure and content of each acquisition list used were all identical to Experiment 1. The only difference between the two experiments was the type of test employed for retention of temporal and spatial information.

The revisd temporal judgment task (hereafter the *quarter estimation task*) is a close analog of the spatial quadrant estimation task used in Experiment 1. Each of the 24 test words was presented one at a time, in the center of the display screen. Every subject was required to specify, with a digit between *1* and *4*, the temporal quarter in which each word had been originally presented. Each test item remained present until the subject's response had been entered by the experimenter via the computer's keyboard. Following the temporal test trials, each test item was presented in a *binary choice task*. The display screen was segmented into quadrants as it had been during the acquisition list. Each of the 24 items appeared in its original quadrant and in the quadrant diagonal to it. The subject was instructed to indicate the correct position by pointing. The intent was to make it possible for the subject to respond correctly even with only partial information about the item's original spatial position (i.e., knowing only whether the item appeared left or right, or knowing only whether it appeared at the top or bottom of the screen).

Results

Temporal Task

First, each subject's quarter estimates for all words appearing in a particular temporal quarter were averaged to permit an analysis of variance analogous to the one typically employed on frequency of occurrence and temporal order judgments by Hasher and Zacks (2, 3). In this analysis each subject contributes an average judgment value for the tested words originally appearing in each quarter of the list. The variables in the analysis are subject group (TBI, elderly, and young controls), instructional condition (uninformed and informed), and quarter of presentation (first, second, third, and fourth).

Main effects for subject group or instructional condition would reflect only overall differences in the average magnitude of quarter estimation responses for all tested items. The main effect for quarter of presentation is the measure of accuracy in this analysis. Random responding will result in a flat mean judgment function over quarters. Between-group differences in judgment accuracy (or instructional effects) will be reflected in the interaction of the subject group (or instructional condition) with quarter of presentation.

Table 2 presents the functions relating average judged to actual quarter of presentation for each group. Judged quarter did increase with the actual quarter of presentation, resulting in a significant main effect for quarter: $F(3, 216) = 29.07$; $p < .001$.

The control subjects' quarter of presentation judgments were more accurate than those of the elderly and TBI subjects, whose performance was quite similar in every quarter. This is reflected in a significant group by quarter interaction: $F(6, 216) = 2.76$, $p < .02$. In this analysis no main effect for subject group was obtained. This indicates that, summed over all test items, there was no response bias effect (i.e., no overall difference between groups in the utilization of the four response alternatives) like the one found by McCormack (5). A significant instructions effect was observed: $F(1, 72) = 42.23$, $p < .001$, indicating generally lower (i.e., earlier) estimates on second list for all subject groups.

Analyses based on averaged judgment values are problematic because they may mask differences between groups or between instructional conditions in the consistency of a subject's responses to the items in a particular presentation condition. A second analysis, based on the size of each judgment error, was performed on the quarter estimation data. It is analogous to the one developed for evaluating the size of judgment errors in frequency of occurrence estimation tasks (32).

First, a signed difference score, representing the discrepancy between the judged and the actual quarter of presentation, was obtained for every item. These were then summed over all items appearing in each quarter for every subject. Finally, the summed error scores were corrected for temporal quarter of presentation by dividing each by the sum that would have been observed in a subject responding randomly. This compensates for the fact that greater errors of estimate are possible for items appearing in the first and last quarter than for those presented in the second and third quarters. These corrected scores can range from zero (perfect performance) to one (random responding). Table 3 presents the mean corrected deviation scores for items in each quarter of the list, and the average deviation score, for every subject group. The difficulty of the task, particularly for items near the end of the acquisition list, is reflected in scores that rise to 1.00 in quarter 4 for the TBI and elderly subjects.

Notice, that unlike the analysis based on averaged judgment values, in which between-group difference in judgment accuracy is reflected by the interaction of group by quarter of presentation, the judgment accuracy in the deviation score analysis is revealed in the significant group main effect: $F(2, 72) = 5.16$, $p < .01$, indicating larger judgment errors for the elderly (.893) and TBI (.915) subjects than for the young controls (.805). For all subjects, judgments on items presented in the first quarter were more accurate than those on items from the rest of the list, resulting in a quarter effect: $F(3, 216) = 3.54$, $p < .02$. Judgments made by control subjects were more accurate in the final quarter of the list as well, resulting in a significant

TABLE 2. *Results of Experiment 2: mean judged temporal quarter of occurrence vs actual quarter of occurrence, for both instructional conditions, for each subject group*

	Quarter of presentation							
	1		2		3		4	
	Instructional condition							
Group	Uninfo.	Info.	Uninfo.	Info.	Uninfo.	Info.	Uninfo.	Info.
Control	2.23	1.91	2.82	2.25	2.72	2.45	2.99	2.79
TBI	2.38	2.13	2.39	2.20	2.53	2.47	2.63	2.44
Elderly	2.37	2.15	2.59	2.34	2.68	2.45	2.58	2.47

Uninfo., uninformed; Info., informed.

group by quarter interaction, $F(6, 216) = 2.50$, $p < .05$.

Spatial Task

Average proportion correct scores on the binary choice task for each subject group and instructional condition are presented in Table 4. Unlike the four-alternative quadrant estimation spatial task used in Experiment 1, and the four-alternative temporal quarter estimation data collected on the same words in this experiment, the analysis of the binary choice spatial judgments indicated no main effect for subject group: $F(2, 72) = 1.74$, $p > .10$. In addition, no significant effect for instructions and no interaction of subject group and instructions were observed.

DISCUSSION

In Experiment 1, no differences between groups of TBI and normal subjects were observed on a two-alternative temporal recency task, but reliable differences were obtained on a four-choice spatial quadrant estimation task on the same items. In Experiment 2, the situation is reversed. TBI and elderly subjects were not significantly worse than controls on a two-alternative spatial task, but they were on the four-alternative temporal estimation task (when the analysis was based on the size of the judgment error).

Effect of Instructions

The general failure to obtain benefits of specific instructions about the type of tests to be used supports the Hasher and Zacks (2) formulation and replicates previous findings by Ellis (10, 11). However, the consistent declines in accuracy seen between the uninformed and the informed conditions may mask the benefits of this information in the proactive interference of the first list (and its subsequent tests) on memory for the second. It is also possible that significant improvements might have been observed had the subjects been allowed to prepare for just one instead of three different types of memory tests.

Effects of Number of Alternatives

Comparison of the two experiments indicates that the presence of group differences may be more closely tied to task variables (such as the type of test employed or the number of response alternatives available) than to whether the task taps spatial or temporal information. The two-alternative tasks which used a pair of stimuli in each test (relative recency temporal tests in Experiment 1, and the binary choice spatial

TABLE 3. *Results of Experiment 2: corrected deviation scores for temporal location judgments on words in each quarter of the acquisition list*

	Quarter of presentation				
	1	2	3	4	Mean
Control	.72	.91	.85	.74	.805*
TBI	.84	.90	.92	1.00	.915
Elderly	.84	.95	.78	1.00	.893

* Between-group difference significant, $p < .01$.

TABLE 4. *Results of Experiment 2: proportion of trials correct for three subject groups on the two-alternative spatial location task*

	Group*		
Instructional condition	Control	TBI	Elderly
Uninformed	.60 (.02)	.57 (.03)	.52 (.03)**
Informed	.59 (.02)	.57 (.03)	.56 (.03)

* Between-group difference not significant, $p > .10$.
** Performance not significantly better than chance, $p > .05$.

task in Experiment 2) both failed to reveal between-group accuracy differences, while their four-alternative counterparts (spatial quadrant location in Experiment 1, and temporal quarter location in Experiment 2) both demonstrated statistically significant group differences.

In order to simulate results which might have been obtained from a temporal estimation task with only two response alternatives, data from the temporal quarter estimation task in Experiment 2 were rescored in a post hoc analysis using criteria that gave credit to responses correctly indicating in which half of the list an item had been presented, that is, quarter estimations of *1* and *2* were both correct for any item presented in the first half of the list, and *3* and *4* were correct for any item from the last half. This after-the-fact collapsing of our data into a "binary" response format reduced the group effect to one that only approached statistical significance: $F(2, 72) = 2.72$, $p = .07$. When scoring criteria are relaxed to give credit for partial information, the lower level of retention of temporal information is less easily documented in elderly or TBI subjects. This finding is similar to the disappearance of reliable between-group differences in memory for spatial information in the binary choice task used in Experiment 2, where the response alternatives were arranged to give credit for any partial information about an item's original position that was retained at test. This finding supports our conclusion that the lack of group difference in the binary response format is due to task constraints rather than to floor effect.

In conclusion, the experiments provide evidence suggesting that failures to obtain between-group differences on tasks tapping putatively automatic functions should be interpreted cautiously. Statistically reliable differences reflecting accuracy deficits associated with both increased age and a history of traumatic brain injury were obtained in these experiments for both temporal and spatial judgments when the subject was asked for a relatively precise estimate of the requested information. These differences disappeared when (a) the task constraints, or (b) the data analysis, were relaxed to give subjects full credit for only partial information about an item's temporospatial context of presentation, or (c) when the data were analyzed by frequently used methods that are insensitive to the size of the judgment error or to the subject's consistency of responding. It is important to notice that all of Hasher and Zacks' (2) criteria are defined as a null hypothesis (i.e., lack of age effect, lack of instructional effect, etc.). The presence of these task and analysis effects which can eliminate existing differences, calls for reevaluation of those studies in which Hasher and Zacks' (2) criteria for automaticity were satisfied.

A major contribution of this study is its demonstration of the significant effect of such methodological factors as instructions and number of alternatives on the performance of the control and the TBI groups. Because of the heterogeneity of the TBI group, the contribution of the present study to the understanding of the characteristics of memory impairment following traumatic brain injury is limited.

In a recent study on temporal order judgment, Vakil and colleagues (36), testing a TBI group (very similar to the group used in the present study), reported that under incidental retrieval conditions, more criteria of automaticity were satisfied than under intentional retrieval conditions (e.g., TBI and control groups did not only differ under incidental retrieval of temporal order). This accords with extensive literature focusing on the effortfulness of the *retrieval* stage (i.e., implicit/explicit), rather than the *encoding* stage (i.e., automatic/effortful) of memory. These studies report quite consistantly that explicit, but not implicit, memory is sensitive to effects of age and brain injury (for review, see ref. 37).

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