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# Indirect Influence of Modality on Direct Memory for Words and Their Modality: Closed-Head-Injured and Control Participants

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Twenty closed-head-injured (CHI) patients and 28 control participants were tested on recall and recognition of words. In addition, memory for modality (i.e., visual vs. auditory) of word presentation was measured directly (i.e., recognition) and indirectly (i.e., by its influence on word and modality recognition). As predicted, the CHI patients were impaired relative to controls on all of the direct memory tasks; that is, word recall, word recognition, and modality judgment. However, the CHI and control groups did not differ significantly on the magnitude of the modality effect (i.e., facilitation due to correspondence of modality in learning and test). The findings are interpreted in the theoretical framework that distinguishes between item (i.e., words) and source (i.e., modality) memory and between direct and indirect measures of memory.

Memory can be assessed directly (or explicitly) and indirectly (or implicitly). Recall and recognition are direct tests of memory because the person is explicitly asked to retrieve particular information. Indirect memory is inferred from the facilitatory (or inhibitory) effect of performance due to previous exposure to the particular information (Richardson-Klavehn & Bjork, 1988). It is well documented that amnesic patients' memory is impaired when measured directly and preserved when measured indirectly (for review, see Shimamura, 1986).

Similarly, closed-head-injured (CHI) patients have been found impaired on a variety of direct memory tasks, including recall, cued recall, and recognition (Baddeley, Sunderland, Watts, & Wilson, 1987; Levin, 1989; Vakil, Arbell, Gozlan, & Hoofien, 1992). Indirect memory has been assessed in CHI patients to a much lesser degree than in amnesic patients. Just like in amnesia, indirect memory has been found preserved in CHI patients (Mutter, Howard, Howard, & Wiggs, 1990; Vakil, Biederman, Liran, Groswasser, & Aberbuch, 1994).

Schacter, Harbluk, and McLachlan (1984) introduced the distinction between item (or fact) and source memory. Source memory refers to the background information of an item or event, such as its temporal order, spatial location, or modality of presentation (i.e., visual vs. auditory). Several studies have found impaired source memory in patients with frontal lobe lesions (Janowsky, Shimamura, & Squire, 1989). Memory for temporal order, one of the most studied source memory tasks, was found impaired in patients with frontal lobe damage, whereas memory for items was intact (Butters, Kaszniak, Glisky, Eslinger, & Schacter, 1994; Eslinger & Grattan, 1994; McAndrews & Milner, 1991; Shimamura, Janowsky, & Squire, 1990). Findings with regard to the source memory of amnesic patients are inconclusive. According to the contextual-memory deficit theory of amnesia, the item memory impairment observed in amnesia is the consequence of a primary context or source memory impairment (Mayes, MacDonald, Donlan, Pears, & Meudel, 1992; Pickering, Mayes, & Fairbairn, 1989). Other researchers, however, found that the degree of source amnesia was unrelated to item memory impairment (Shimamura & Squire, 1987, 1991).

CHI patients have also been shown to have impaired source memory, such as temporal order (Vakil, Blachstein, & Hoofien, 1991; Vakil & Tweedy, 1994) and spatial location (Vakil & Tweedy, 1994). Similarly, these patients are impaired relative to controls when required to recognize the source of information in a fame judgment task (Dywan, Segalowitz, Henderson, & Jacoby, 1993). However, unlike the findings with frontal lobe patients, CHI patients in these studies were found to have impaired memory for items as well.

In previous studies, Vakil and colleagues have tested item and source memory by using direct and indirect measures of memory in CHI patients. These studies have shown quite consistently that item and source memory in CHI patients was impaired when assessed directly. However, the indirect influence of contextual information on direct memory measures was proportionally similar for the control and CHI groups (cf. Vakil et al., 1991, regarding temporal order judgment; cf. Vakil et al., 1994, regarding frequency judgment; Vakil, Golan, Grunbaum, Groswasser, & Aberbuch, 1996, regarding contextual information).

In the present study we used memory for modality as the specific source information. A change in modality of presentation between learning and test (i.e., modality effect) has

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been found to have a considerable effect on perceptual priming tests such as fragment completion, lexical decision, and perceptual identification (for review see Richardson-Klavehn & Bjork, 1988; Roediger & McDermott, 1993). On the other hand, modality effect was not found when free recall was tested (Blaxton, 1989; Graf, Shimamura, & Squire, 1985). However, results with regard to modality effect on recognition are more mixed (for possible reasons for the variable results, see Roediger & Blaxton, 1987; Richardson-Klavehn & Bjork, 1988). Some studies did find modality effect on memory when measured by recognition (Jacoby & Dallas, 1981; Kirsner, 1974; Kirsner & Smith, 1974), whereas others found no such effect (Hayman & Rickards, 1995; Roediger & Blaxton, 1987).

The correspondence between modality in learning and test is expected to affect item and source memory. This facilitatory effect of consistency in modality presentation, just like other priming tasks, is considered the indirect influence of modality on memory. In light of the previous findings with direct and indirect measures of memory in CHI patients, it is predicted that the CHI and control groups will benefit to the same extent from similarity of modality on the learning and testing conditions. In addition, when measured directly, CHI patients are expected to be impaired on both memory for words and modality.

Table 1
*Demographics of the Head Injured Patient Group*

| Patient | Age (in years) | Sex | H | Ed | TAO | COMA | GCS |
|---|---|---|---|---|---|---|---|
| A.B.H. | 31 | M | R | 16 | 14 | 17 | 8 |
| G.G. | 22 | M | R | 12 | 16 | 7 | 6 |
| Y.H. | 23 | M | R | 12 | 8 | 5 | 4 |
| T.O. | 21 | M | R | 10 | 22 | 35 | 6 |
| A.S. | 20 | M | R | 12 | 20 | — | 8[a] |
| O.S. | 21 | M | R | 12 | 28 | 10 | 5[a] |
| S.M. | 43 | F | R | 10 | 30 | 4 | 6 |
| O.G.R. | 18 | M | R | 11 | 45 | 60 | 6 |
| E.P. | 27 | M | R | 12 | 20 | 14 | 5 |
| T.R. | 20 | M | R | 12 | 6 | 5 | 9 |
| T.S. | 27 | M | R | 12 | 32 | 35 | 4 |
| M.D. | 48 | M | R | 12 | 10 | — | 10 |
| D.A. | 18 | M | R | 10 | 8 | 12 | 6 |
| S.D. | 17 | M | R | 10 | 9 | 21 | 5 |
| R.Y. | 50 | M | R | 11 | 33 | 14 | 6 |
| F.E. | 21 | M | R | 12 | 67 | 60 | 3 |
| A.M. | 19 | M | R | 11 | 31 | 11 | 7 |
| N.O. | 19 | M | R | 11 | 64 | 30 | 4 |
| A.Y. | 29 | M | R | 10 | 29 | 21 | 7 |
| S.S. | 31 | M | R | 19 | 21 | 21 | 7 |

*Note.* Dashes indicate that information was not in medical records. Ed = education (in years); H = handedness; TAO = time after onset (in weeks); COMA = length of coma, in days; GCS = Glasgow Coma Scale, which was recorded on admission to hospital.

[a] Indicates GCS was reconstructed because the patient was intubated and got sedation before being admitted to hospital.

## Method

### Participants

Two groups participated in the present study: a control group (non-brain damaged) and a CHI group. The control group consisted of 28 volunteers (22 men and 6 women) ranging in age from 17 to 49 years ($M = 28.32$). Their education ranged from 8 to 15 ($M = 12.43$) years of schooling. The CHI patients were recruited for the study from a population of patients admitted to the Loewenstein Hospital (Israel) for rehabilitation following a head injury. This group was composed of 20 patients (19 men and 1 women) ranging in age from 17 to 50 years ($M = 26.30$). Their education ranged from 10 to 19 ($M = 11.85$) years of schooling. The groups were not significantly different on age, $t(46) = 0.73$, $p > .10$, or educational level, $t(46) = 0.30$, $p > .10$. Table 1 provides a more detailed description of the patient group including the length of coma, ratings on the Glasgow Coma Scale (GCS), and time after onset. The operational definition applied to indicate the end of coma is "the ability to obey commands, [which] means that a message has been received, understood, and acted upon" (p. 90, Wilson, Shiel, Watson, Horn, & McLellan, 1994; see also Najenson, Groswasser, Mendelson, & Hackett, 1980). The CHI patients were referred to rehabilitation from various neurological services, and data regarding the initial scoring of the GCS were extracted from letters of discharge. All of the letters stated that the GCS was recorded on admission; that is, within the first 6 hours postinjury. All the patients selected for the study were administered a battery of screening tests given by the occupational therapist and the speech pathologist in the hospital department. The Loewenstein Occupational Therapy Assessment battery was administered (Katz, Itzkovich, Averbuch, & Elazar, 1989). This battery includes tests of orientation, visual and spatial perception, visuomotor organization, and thinking operations. Furthermore, an interdisciplinary team in the department had evaluated the patients, who were referred to the study at least 1 month earlier, as being out of posttraumatic amnesia. Thus, patients' intellectual and linguistic functioning was at a level enabling adequate responsiveness to the task requirements on the basis of the tests conducted. Participants in both groups were proficient in Hebrew and had no history of mental illness, alcoholism, or drug use.

### Testing and Procedure

Sixty high-frequency Hebrew words (more than 50/200,000 words) (Balgure, 1968) were used. Forty of the words were applied in the learning phase, and the entire 60 words were applied in the testing phase. Half of the words in each phase were presented visually, and the other half were presented auditorily. Two versions of the list were created: Words presented visually in one version were presented auditorily in the second version, and vice versa. Half of each participant group was presented with one version, and the other half was presented with the other version.

*Learning phase.* Forty words were used. Half of the words (i.e., 20 words) were typed in uppercase form on a 6.5 cm × 6.5 cm sheet of paper for the visual presentation. The second half of the words (i.e., 20 words) were presented auditorily. All 40 words were presented in one trial in pseudorandom order; that is, not more than 3 words were presented consecutively in the same modality. Participants were tested individually. They were told that they would be presented with a list of words, half of which would be presented visually and half auditorily, in random order. They were requested to pay close attention to the words because their memory of the words would be tested later.

*Distractor task.* The Digit Span subtest of the Wechsler Memory Scale—Revised (WMS–R; Wechsler, 1987) was applied as a distractor task immediately following the learning phase and before the testing phase. Here, participants were first asked to repeat a series of digits, ascending in difficulty (digits forward) and were then asked to repeat a different series of digits, this time in the opposite order (digits backward).

*Testing phase.* Participants were first asked to *recall* as many words as possible from the learning phase. The words were recorded by the experimenters (Michal Openheim and Dikla Falck). After the recall task, participants were presented with a list of 60 words that was made up of the 40 words presented in the learning phase and an additional 20 new words. Ten of the 20 words presented originally in visual form were presented visually again, whereas the other 10 were presented auditorily. The same manipulation was conducted concerning the words originally presented in auditory form; that is, 10 of these words were again presented auditorily, whereas the other 10 were presented visually. Half of the 20 new words were presented visually, and half were presented auditorily. As indicated above, the order of presentation was pseudorandom; that is, not more than 3 words were presented consecutively in the same modality. On presentation of each word (i.e., either visually or auditorily), participants were first asked to answer whether the word was new or old (i.e., *word recognition*). They were then asked whether the word was presented visually or auditorily. If a participant judged an old word as new, he or she was corrected and was then asked about the modality of the original presentation (i.e., *modality judgment*). All answers were recorded by the examiner.

## Results

Three memory measures were analyzed in this experiment: free word recall, word recognition, and judgment of modality of presentation. For each one of these measures, a mixed-design analysis of variance (ANOVA) was used to analyze the effect of Group (CHI vs. controls) × Learning Modality (visual vs. auditory), the former being a between-subjects variable and the latter being a within-subject variable.

Table 2
*Mean Number of Words (and Standard Deviations) Correctly Recalled by the Two Groups as a Function of Learning Modality*

| | Learning modality | | | | | |
|---|---|---|---|---|---|---|
| | Visual | | | Auditory | | |
| Group | *n* | *M* | *SD* | *n* | *M* | *SD* |
| Control | 28 | 4.64 | 2.82 | | 4.25 | 2.94 |
| CHI | | 2.40 | 2.09 | 20 | 1.90 | 2.17 |

*Note.* CHI = closed-head injury.

### *Free Word Recall*

Table 2 presents the mean number of words correctly recalled by the two groups as a function of learning modality. The control group recalled more words than the CHI group, $F(1, 46) = 11.54$, $p < .001$. There was no significant advantage of learning the words in one modality over the other, $F(1, 46) = 1.65$, $p = .21$. The Group × Learning Modality interaction was not significant either, $F(1, 46) = 0.02$, $p = .88$.

### *Word Recognition*

Figure 1 presents the number of words correctly recognized by the two groups as a function of modality of presentation in the learning and testing phases. Thus, in this analysis, in addition to the two factors applied above, the effect of testing modality (visual vs. auditory) was evaluated as well. As can be seen in Figure 1, overall, the control group

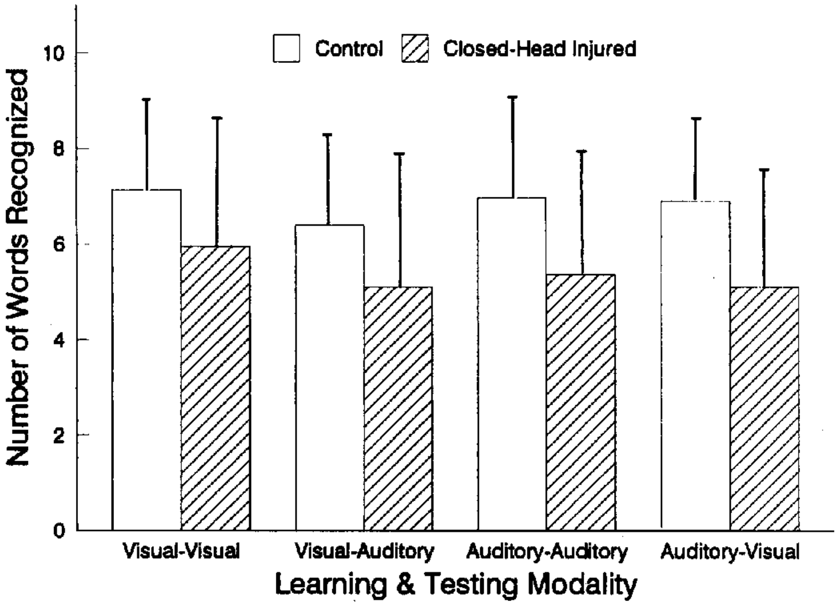

*Figure 1.* The mean number of words correctly recognized by the two groups as a function of modality of presentation in the learning and testing phases. Bars represent standard deviation of the mean.

Table 3
*Mean Corrected Hit Rate (and Standard Deviations) of the Two Groups as a Function of Testing Modality*

| | Testing modality | | | | | |
|---|---|---|---|---|---|---|
| | Visual | | | Auditory | | |
| Group | *n* | *M* | *SD* | *n* | *M* | *SD* |
| Control | 28 | 11.54 | 3.50 | 28 | 11.54 | 3.17 |
| CHI | 20 | 8.05 | 4.17 | 20 | 8.05 | 4.59 |

*Note.* CHI = closed-head injury.

correctly recognized more words than the CHI group, $F(1, 46) = 9.40, p < .005$. There was no significant advantage for modality of presentation, whether in the learning, $F(1, 46) = 0.07, p = .79$, or in the testing phases, $F(1, 46) = 1.38, p = .25$. The only interaction that reached significance was Learning Modality × Testing Modality, $F(1, 46) = 5.03, p < .05$. This result suggests that when the testing and learning modalities corresponded, more words were recognized by both groups, as compared with when there was no such correspondence. None of the interactions with group effect reached significance. The most telling result is the nonsignificant triple interaction, Group × Learning Modality × Testing Modality, $F(1, 46) = 0.11, p = .75$. (Observed power at the .05 level was .05.) In an additional analysis that was separately performed for each group on the same variables (i.e., learning and testing modality), none of the effects for either group reached significance. (Observed power at the .05 level was .13 and .14 for the control and the CHI groups, respectively.) However, this finding should be interpreted cautiously because of the low power of the analysis and because the finding is negative (i.e., a failure to reject the null hypothesis). Thus, these results failed to provide evidence against the claim that both groups benefited to the same extent from consistency in modality of presentation between learning and testing phases.

### *Corrected Hit Rate Scores*

The additional 20 words presented (10 visually and 10 auditorily) in the testing phase enabled us to assess the false-alarm rate of both groups as a function of modality presentation in testing. Corrected hit rate scores were calculated by subtracting the corresponding false-alarm rate scores from the hit rate scores of the words tested visually or auditorily. Notice that the modality of the false-alarm scores was determined by modality in the testing phase because new words were introduced. Thus, visual false-alarm scores were subtracted from the hit rate of words tested visually (regardless of the learning modality), and, similarly, the auditory false-alarm rate was subtracted from the hit rate of words tested auditorily. The only significant finding was the group effect, $F(1, 46) = 15.04, p < .001$. As can be seen in Table 3, the control group scored higher than the CHI group. Modality in the testing phase did not have an effect, nor did it interact with the group effect.

### *Modality Judgment*

Figure 2 presents the number of correct modality judgments made by the two groups as a function of modality of presentation in learning and testing phases. As in word recognition, the control group made more correct modality judgments than the CHI group, $F(1, 46) = 4.29, p < .05$. Overall, there was no significant advantage for either

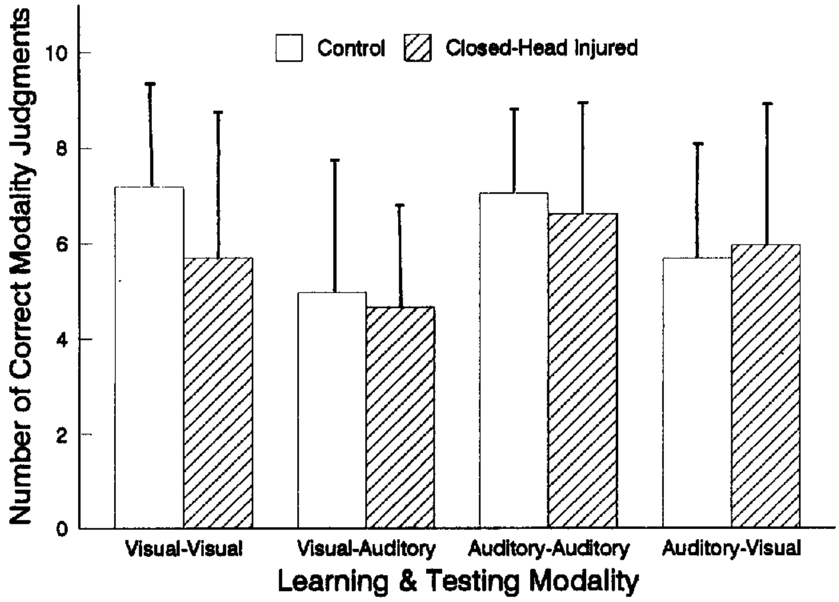

*Figure 2.* The mean number of correct modality judgments made by the two groups as a function of modality of presentation in the learning and testing phases. Bars represent standard deviation of the mean.

modality of presentation, whether in the learning, $F(1, 46) = 1.70$, $p = .20$, or in the testing phases, $F(1, 46) = 2.58$, $p = .12$. The only interaction that reached significance was Learning × Testing Modality, $F(1, 46) = 13.95$, $p < .001$. This result suggests that when the modality in testing and learning corresponded, modality judgments were more accurate for both groups, as opposed to when there was no such correspondence. As with word recognition, none of the interactions with group effect reached significance. The most telling result is the nonsignificant Group × Learning Modality × Testing Modality, $F(1, 46) = 1.76$, $p = .19$. (Observed power at the .05 level was .25.) As indicated above, this finding should be interpreted cautiously because it is a negative finding (i.e., a failure to reject the null hypothesis). Thus, these results failed to provide evidence against the claim that both groups benefited to the same extent from consistency in modality of presentation between the learning and testing phases. When this analysis was conducted for each group separately, none of the effects reached significance for the CHI group. (Observed power at the .05 level was .11.) The Learning Modality × Testing Modality interaction reached significance for the control group, $F(1, 27) = 17.44$, $p < .001$.

To assess dependence of modality judgment on word recognition, we conducted a mixed-design ANOVA to analyze the effect of Group (CHI vs. controls) × Dependence. The dependence effect was determined by comparison of the number of correct modality judgments of words correctly recognized ($M = 17.29$, $SD = 4.54$ and $M = 12.70$, $SD = 5.53$ for the control and CHI groups, respectively) versus number of correct modality judgments of words not recognized ($M = 7.57$, $SD = 3.55$ and $M = 10.20$, $SD = 4.76$, for the control and CHI groups, respectively). As seen in the Modality Judgment section, the control group made more correct modality judgments than the CHI group, $F(1, 46) = 4.29$, $p < .05$. The main effect of dependence reached significance as well, $F(1, 46) = 24.00$, $p < .001$. Overall, the number of correct modality judgments was higher for words correctly recognized than for words not correctly recognized. The Group × Dependence interaction was significant, $F(1, 46) = 8.37$, $p < .005$. To detect the source of interaction, we analyzed the dependence effect separately for each group. Both groups showed a significant dependence effect, $t(27) = 20.16$, $p < .001$ and $t(19) = 10.28$, $p < .001$, for the control and the CHI groups, respectively. Thus, the significant interaction suggests that although both groups showed the dependence effect, this effect was more pronounced in the control group.

Pearson product–moment correlations were conducted as an additional way to assess dependence of modality judgment on word recognition and, more generally, to assess the relationship between source and item memory. Both groups showed a strong relationship between the two item memory measures (i.e., word recall and recognition): $r(28) = .50$, $p < .05$ and $r(20) = .70$, $p < .001$, for the control and CHI groups, respectively. For both groups modality judgment was not significantly correlated with either the number of words recalled or recognized. However, the correlation between modality judgment and word recognition for the control group was close to reaching significance, $r(28) = .35$, $p < .07$.

Table 4
*Pearson Product–Moment Correlations for the CHI Group Between the Memory Measures and the Measures of Severity of Injury*

| Severity measure | Word recall | Word recognition | Modality judgment |
|---|---|---|---|
| | Memory measure | | |
| COMA | −.173 | .217 | .354 |
| GCS | .083 | .155 | −.420 |
| TAO | −.035 | .184 | .556* |

*Note.* CHI = closed-head injury; COMA = length of coma in days; GCS = Glasgow Coma Scale, which was recorded on admission to hospital; TAO = time after onset.
$^*p < .01$.

## *Correlations Between the Memory and Severity Measures*

Pearson product–moment correlations were calculated for the CHI group between the memory measures (i.e., total number of words recalled, total number of words recognized, and total number of correct modality judgments) and the three measures of severity of injury (i.e., length of coma, GCS, and time after onset). As can be seen in Table 4, the only correlation to reach significance was that between the number of correct modality judgments and time after onset, $r(20) = .56$, $p < .001$. This correlation suggests that the longer the injury–test interval, the better the modality judgment.

## Discussion

In accordance with previous reports in the literature, CHI patients' recall and recognition were impaired, as compared with those of the controls (for review see Baddeley et al., 1987; Levin, 1989). In addition, the memory for modality of the CHI patient group was also impaired when measured directly. In Schacter et al.'s (1984) terminology, CHI patients were impaired in item (i.e., words) and source memory (i.e., modality) when measured directly. These findings are consistent with several other studies in which CHI patients were found impaired in both item and source memory (Dywan et al., 1993; Vakil et al., 1991, 1994, 1996). One of the implications of these findings is that the memory impairment that characterizes CHI patients is different from that of frontal lobe patients. Frontal lobe patients are reported to have impaired source memory but to have preserved item memory (Butters et al., 1994; Eslinger & Grattan, 1994; McAndrews & Milner, 1991; Shimamura et al., 1990). These results are more similar to some of the results with amnesic patients in which degree of source amnesia was unrelated to item memory impairment (Shimamura & Squire, 1987). By contrast to direct memory tests, when the indirect influence of modality (i.e., facilitation due to correspondence of modality in learning and testing) was assessed, there were no indications that the control group benefited more than the CHI group from the modality effect. This was true for both item and source memory. Thus, the advantage of the paradigm used in this study is that although all of the memory tests were direct measures of memory (i.e., item and source), they enabled us to assess the indirect influence of modality on these tests. As predicted, the groups were clearly differentiated by the direct but not by the indirect measures. These results are consistent with previous findings with CHI patients when indirect influence of context was measured (Vakil et al., 1991, 1994, 1996).

The analyses of item and source dependence suggest that for both groups, modality judgment was more accurate when the word was recognized as well. This tendency was more pronounced for the control group than for the CHI group. These results might suggest that there is normally a strong relationship between item and source information. That is, when words are remembered, it is more likely that their modality will be remembered as well (notice that this was the sequence of questioning at test). This relationship is weakened following a closed-head injury. The pattern of correlations between the measures of item and source memory further supports the claim that these are two types of memory that under certain conditions can fail independently. Shimamura and Squire (1991) have reported very similar findings in which source memory in normal participants was correlated to fact memory; whereas in amnesic patients, source memory impairment was unrelated to fact or event memory.

As in the study by Dywan et al. (1993), source memory was the only measure related to severity of injury. However, unlike the Dywan et al.'s study, the severity-of-injury measure that significantly correlated with modality judgment was time after onset (i.e., the longer the injury–test interval, the better the source memory) rather than coma duration. Our findings in this regard are not unique; previous studies also did not find coma duration or GCS to be related to the cognitive outcome of CHI patients (Brooks, Aughton, Bond, & Rivizi, 1980). More research is required to clarify the relationship between the different severity-of-injury measures and the different outcome measures.

Finally, it is important to stress that CHI patients are not the ideal patient group to study the brain–behavior relationship. For this reason, the discussion focuses primarily on affected cognitive processes rather than on neuroanatomic implications. To relate the memory processes discussed here to specific brain regions, follow-up studies with a similar paradigm should be applied to test patients who have much more circumscribed damage to brain areas associated with memory, such as the temporal and frontal lobes.

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