

# MEMORY FUNCTION AFTER CLOSED HEAD INJURY: A REVIEW OF THE QUANTITATIVE RESEARCH<sup>1</sup>

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Clinical observation of memory impairment following closed head injury can be found in the 19th century reports of Cooper (1837) and Dupuytren (1839). In this century there has been a proliferation of similar clinical studies (see Symonds, 1937, for a thorough descriptive account of representative cases). More recently, the literature has contained a large number of quantitative studies which measure features of memory as related to closed head injury. In this paper we will review the literature which provides a quantitative analysis of memory function following closed head injury.

In so doing we will exclude from consideration those studies which have not specifically distinguished between patients suffering closed head wounds and those with penetrating wounds (e.g., Hpay, 1971; Tooth, 1947). Also, we will not review studies concerned with the pathophysiology that underlies impaired memory function following closed head injury. Detailed discussion of the biochemical and neurophysiological changes which are thought to be responsible for impairment of memory and other brain functions following closed head trauma can be found in the papers of Courville (1942), Dixon (1962, 1967), Matthews (1965), Ommaya and Gennarelli (1974), and in the volume edited by Walker, Caveness and Critchley (1969).

Symonds (1937, p. 1082) excluded from the class of closed head injuries all cases in which "... a compound fracture might have complicated the clinical picture by introducing the effects either of visible lacerations of the cortex, or of infection. Even in closed injuries, however, we may encounter clinical evidence of coarse focal lesions, for instance, hemiplegia or dysphasia. Such cases, also, I have excluded, my object being to present what appears to be the direct effect of injury upon the cerebral function as a whole." The recent studies that we shall review have not always employed criteria for closed head injury as strict as those of Symonds (1937). Therefore, specific

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effects upon memory function related to possible penetrating damage may sometimes exist in studies which have distinguished between patients with primarily closed and primarily penetrating damage. We believe that the inclusion of some such cases in a sample of "closed head injury" cases will have its main effect by increasing the variability of results within the sample; such a source of variability could be removed in future studies by returning to criteria as strict as those of Symonds (1937).

### POST-TRAUMATIC AMNESIA

In the analysis of memory function following closed head injury, much consideration has been given to the period of so-called "Post-Traumatic Amnesia" (PTA). The term "PTA" refers to a period of variable length following closed head trauma during which the patient is confused, disoriented, suffers from retrograde amnesia, and seems to lack the capacity to store and retrieve new information. In this section we will review literature relating to several aspects of PTA. Since we emphasize quantitative analyses of PTA, the reader who desires a detailed clinical description of cognition and behavior during PTA should consult the authoritative volume by Russell (1971).

#### *Criteria for assessing PTA*

Useful analyses concerning the precise nature of PTA depend on the specification of meaningful criteria for assessing the presence or absence of PTA. In this section we consider the criteria for PTA presence or absence that have been used in the literature.

Although there are instances in the literature of studies concerned with particular aspects of PTA which do not specify the criteria they used to determine PTA presence or absence (e.g., Cook, 1972; Norrman and Svahn, 1961; Phillips, 1954), most investigators report the criteria that they used. Russell (1932) defined PTA as the loss of full consciousness accompanied by disorientation and inability to answer questions intelligently. To determine the termination and extent of this period, Russell depended upon the patient's account of when he "woke up"; that is, the time between trauma and the patient's feeling that he has just "come to" was taken as the duration of PTA. Russell and Nathan (1946, p. 281) modified this criterion: "... the patient is usually able to record the time or date from which he has continuous memory, and this has been used by us for the measurement of the PTA in the cases to be described." They were careful to emphasize that "This duration of PTA will then remain relatively constant and will form a permanent index of the duration, not of unconsciousness, but of impaired consciousness (p. 281)." The criterion for PTA termination of *continuous* memory is an important one, for it indicates a feature of the memory loss associated with

PTA — namely, that it may be sporadic. Periods of PTA may alternate with periods of apparent recovery called “islands” during which memory functions appear to be normal. As Symonds (1942) pointed out, the first appearance of normal memory function following closed head injury may not signal the end of PTA. Rather, it may only represent a temporary return of normal memory to be followed by another period of PTA.

Many investigators have adhered fairly closely to the criterion of the return of continuous memory for PTA assessment specified by Russell and Nathan (Brooks, 1972, 1974a; Richardson, 1963; Smith, 1974). However, there are variations in the PTA criteria used in different studies. Thus while Russell and Nathan (1946) were careful to distinguish between post-traumatic *unconsciousness* and post-traumatic amnesia, interchangeable use of these terms is sometimes found in the literature. For instance, Kløve and Cleeland (1972) used the terms interchangeably in parts of their study, creating confusion about exactly what they meant when they assessed “duration of unconsciousness.”

In several studies, disorientation and amnesia are considered as distinct components of the post-traumatic condition. Moore and Ruesch (1944) measured the duration of post-traumatic disorientation by asking questions concerning time, place, and situation, which were repeated at daily intervals. They did not specify their criteria for assessing amnesia. Although Moore and Ruesch report a good relation between length of post-traumatic disorientation and amnesia, they prefer the use of disorientation duration as a clinical indicator of impaired consciousness, since “... reliable estimates of... (PTA)... duration was attainable only in retrospect after disorientation and other disturbances had entirely cleared (p. 451).” von Wovern (1966) also reported good correspondence between length of post-traumatic amnesia and disorientation, but his criteria are problematic. von Wovern’s criterion for the end of disorientation, which was a note in the hospital records indicating that the patient appeared alert and oriented on a particular day, is not satisfactory since the patient may only be temporarily oriented. Multiple assessments of disorientation seem necessary in order to provide a more accurate index of the duration of disorientation. von Wovern’s criterion for assessing PTA duration — the report of patients upon hospital readmission several years post-trauma of their PTA duration — is not satisfactory, due to the length of time between the presumed end of PTA and the patient’s memory of that time. In fact, von Wovern (1966, p. 373) has noted that “... the patient often maintains that the duration of unconsciousness was much longer than that initially observed and recorded.”

Sisler and Penner (1975) questioned the utility of PTA as a unitary construct, and considered disorientation, anterograde amnesia, and retrograde amnesia as distinct components of PTA. They have provided specific criteria for assessing disorientation: naming of simple objects and identification of

year, month, day of the week, and place. In order to assess duration of anterograde and retrograde amnesia, "...repeated attempts were made to identify valid pre-accident and post-accident memories... (p. 334)." They do not specify their criteria for establishing the validity of these memories.

The literature reviewed in this section indicates that the criteria used for the assessment of PTA vary between studies. This variation limits the usefulness and specificity of statements concerning the nature of PTA, since not all investigators mean precisely the same thing when they use the term PTA. While many investigators consider the criteria for PTA presence to be some combination of disorientation and anterograde amnesia, Sisler and Penner (1975) have suggested that anterograde amnesia, disorientation, and retrograde amnesia should be individually considered as distinct criteria for evaluating the post-traumatic period. A major problem for future study and understanding of PTA concerns the question of which criteria are most appropriate for determining PTA presence or absence: Should disorientation, retrograde amnesia, and anterograde amnesia be assessed independently, and the rather gross term "PTA" be dropped altogether? Should standardized tests of memory be used to assess anterograde amnesia duration, or should the patient's account of the return of continuous memory be used? How frequently should patients be assessed for the presence or absence of the various PTA components? Exploration of these and other questions concerning PTA criteria would be desirable. For the purposes of the present review, we will speak of PTA as that post-traumatic period during which anterograde amnesia and disorientation are present, in keeping with the body of the literature.

### *Onset of amnesia*

Russell (1971) reminds us dramatically of the start of the problem:

The immediate effects of concussion are usually that the individual drops to the ground motionless, often with an arrest of respiration, and at this stage basic reflexes such as the corneal response may be abolished. After respiration returns, restless movements appear and by very gradual stages the patient begins to speak, resist interference, make a noise, and becomes restless, talkative, abusive, and irritable in one way or another. Slowly his speech becomes more intelligible and then as the effect of the trauma wears off he looks around wondering where he is: the period of traumatic confusion is at an end, but he has no recollection of any event that occurred since the injury. Further there is a short period before the injury that he does not remember — the so-called period of retrograde amnesia (R.A.). (p. 1).

This classic description is incomplete with respect to one particular; namely, the time course of the emergence of retrograde and anterograde amnesia. Yarnell and Lynch (1970) questioned four American college football players within several seconds of the occurrence of closed head injury incurred

during play: "The striking finding was that all four players immediately recalled what happened (e.g., 'I got hit') and each of the three questioned could give the signal of the play which led to concussion (e.g., '32 pop'). On re-examination within 3 to 20 minutes all four had lost the immediate pre-traumatic information — e.g. as to the impact and the play (p. 864)." Yarnell and Lynch (1973) have observed similar effects in two additional football concussions.

There are important theoretical implications of the Yarnell and Lynch observations. These findings of delayed amnesic onset suggest that a concussive blow to the brain does not result in failure to *register* information from the preceding few seconds, as had been previously supposed (Williams and Zangwill, 1952). Since the information is available for some time after the trauma, it clearly has been registered. One possible explanation of these observations is that the information has been processed into a short-term store — and that the cases of Yarnell and Lynch are reporting the content of short-term memory — with the closed head injury preventing transfer of this information into long-term memory. Further observations are needed in order to test hypotheses concerning this phenomenon, and to determine the generality of the phenomenon. Also, an intriguing possibility suggested by Yarnell and Lynch (1973) — that the time to amnesia from time of trauma might prove to be a useful indicator of general cerebral dysfunction — should be investigated.

### *Duration of PTA*

Estimates of PTA duration in a given population are likely to vary, since different investigators use different criteria for PTA assessment, and because investigators sometimes do not specify PTA criteria. Also, since the cases which do find their way into the literature consist of a sample with injuries severe enough to merit hospitalization, there exists an unknown number of closed head injury cases with presumably less severe injuries who cannot be taken into account when computing distribution of PTA duration. Thus questions concerning normative data on PTA duration are difficult to answer on the basis of existing literature.

In order to provide the reader with a rough idea of the distribution of PTA durations in a population of closed head cases, we have presented in Table I the data of Russell and Smith (1961, p. 9). This study involved a large sample of closed head cases and employed well-defined criteria for PTA assessment. Additionally, PTA durations is presented as a function of when the patient was assessed: either within three days of trauma (group A), within three weeks (group B), or after three weeks (groups C and D). Group D differs from group C in that it is composed of patients who displayed "... substantial neurological injuries and symptoms... (Russell and Smith, p. 5)..."

TABLE I  
PTA Duration in Four Closed Head Injury Groups  
(from Russell and Smith, 1961)

	PTA duration				
	Nil	< 1 hr.	1-24 hrs.	1-7 days	> 7 days
Group A (N = 186)	23	75	51	13	24
Group B (N = 168)	14	44	37	39	34
Group C (N = 661)	59	117	224	156	105
Group D (N = 309)	19	36	67	99	88

### *Retrograde amnesia (RA)*

In the closed head injury literature, the term retrograde amnesia refers to the post-traumatic inability to recall events experienced prior to the trauma. Two classes of RA have been distinguished in the literature: (1) A temporary RA which may initially cover up to weeks, months or years pre-trauma, and which gradually shrinks during the recovery period; (2) A permanent RA which usually does not cover more than a few seconds pre-trauma. Literature concerning both forms of RA will now be considered.

While the literature does provide quantitative assessments of the relatively permanent form of RA, there has been little quantitative study of shrinking RA (An excellent qualitative study of shrinking RA is provided by Benson and Geschwind, 1967). Thus Russell (1932) questioned head injured patients after they had regained normal consciousness, and found an RA covering "a few seconds" in 69 patients, 1-30 minutes in 24 patients, and over 30 minutes in 3 patients. In addition, good correspondence between duration of impaired consciousness and RA length was observed; RA tends to be longer with increasing duration of PTA. Unfortunately, this relation is not statistically analyzed. Russell claimed that RA was of greater length when patients were questioned during the PTA period than after it, suggesting shrinkage of RA, but he does not provide data pertaining to this statement. Russell and Nathan (1946) present data on length of permanent RA from a larger sample of closed head injury patients who had emerged from PTA. "Nil" RA was found in 133 patients, RA covering under 30 minutes in 707 patients, and RA covering over 30 minutes in 133 patients. Again, longer RA tends to be associated with longer PTA duration, but this relationship is not statistically documented.

Eden and Turner (1941) have also provided data on the distribution of RA length as assessed after the termination of PTA in closed head patients. They found no RA in 5 patients, RA of "seconds" in 45 patients, of "minutes"

in 35 patients, and of "hours" in 8 patients. Blomert and Sisler (1974) conducted several interviews with closed head patients within hours of trauma in order to determine RA duration. Interviews were continued until RA had "... reached a stable minimum as evidenced by no change in memory from the previous interview or a retrograde amnesia of less than one second (p. 187)." Using this criterion for permanent RA, they found that 14 patients had RA of "less than one second," 9 had RA of one second to one minute, and 2 had RA of over one minute. They noted that shrinkage of RA was observed in 5 patients; data pertaining to the form of this shrinkage is not presented. Blomert and Sisler also studied the relation between RA duration and length of the anterograde amnesia. They found a statistically reliable relationship between RA length and duration of anterograde amnesia, thus lending support to the non-statistical findings mentioned above.

Sisler and Penner (1975) have provided important data concerning RA shrinkage, and the question of RA permanence. In this study, the RA length of 24 closed head patients was assessed in psychiatric interview at various times post-trauma (ranging from a few days to almost two years post-trauma; each patient was interviewed several times). RA length was classified at each interview as being either less than a minute, less than an hour, less than a day, and so on, up to "more than a year." RA length was defined as "changed" for a given patient if at a particular interview it fell into a different category than RA length as assessed at the previous interview. Sisler and Penner found that five patients exhibited no change in RA length over the various interviews, eight showed shrinkage of RA, five showed increases of RA, and six showed both increase and shrinkage of RA. These findings, if replicated, will challenge conventional thinking concerning the nature of RA. First, variation of RA duration such as observed here would cast serious doubts on the notion that there is a unidirectional temporal progression in the shrinkage of RA, the older memories returning before the more recent ones (Russell and Nathan, 1946; Wicklegren, 1974). Second, these findings would challenge the notion of RA permanence. Although Sisler and Penner (1975) do not specify whether their patients were out of PTA as defined by Russell and Nathan (1946), it seems reasonable to assume that they were, since all had been discharged from the hospital. Thus the implication of their data is that fluctuations in length of RA exist beyond PTA termination. Russell and Nathan (1946) had observed continued shrinkage of RA after PTA termination in several cases, but they did not report RA fluctuations of the sort observed by Sisler and Penner.

The single greatest deficiency in the literature concerned with RA following closed head trauma is the lack of appropriate methods which permit quantitative study of the phenomenon. The development of such methods might help to resolve existing conflicts in the literature, most of which are based on qualitative rather than quantitative analyses of RA.

The strategy employed by Sisler and Penner (1975) — to repeatedly assess RA duration at various times post-trauma, and record RA length observed at each assessment — provides one means for generating data which can be quantitatively analyzed. However, serious problems exist concerning the measurement of RA length as derived from patient's accounts. The major difficulty concerns the analytical precision which is available to the investigator when trying to measure RA for durations which are often only of seconds or minutes. For instance, Blomert and Sisler (1974) include a RA category of "less than one second." Assuming that this does not refer to a lack of RA, we might ask how it is possible to accurately measure RA of "less than one second," as distinct from RA of 1 second, 3 seconds, etc. Even when the RA durations is purported to be on the order of minutes or more, the investigator is often dependent on a witness of the trauma to establish when it occurred — and the memory of "eye-witnesses" has been shown to be notoriously unreliable and susceptible to numerous sources of variation (Loftus, 1975). Finally, it should be asked how well a person with normal memory can recall the details of what he was doing at a given time in the past (Williams, 1969). The point to be stressed is that adequate methods for collecting and analyzing data pertaining to RA duration have not yet emerged.

As a possible alternative or supplement to the patient's account of his last pre-accident memory for the measurement of RA, investigators might turn to quantitative methods for assessing long-term episodic memory. Such methods have been developed by Squire and his colleagues (Squire and Slater, 1975; Squire, Chace and Slater, 1975) and by Warrington and her colleagues (Warrington and Silberstein, 1970; Warrington and Sanders, 1971). In these tests, recognition of past public events from various time periods is probed. The tests have proved useful for the elucidation of remote memory function in normal young adult subjects (Squire and Slater, 1975; Squire, Chace and Slater, 1975), elderly subjects (Squire, 1974b; Warrington and Sanders, 1971), in patients who have undergone electro-convulsive therapy (Squire, 1974a; Squire, Slater and Chace, 1975), and in global amnesics (Marslen-Wilson and Teuber, 1975; Sanders and Warrington, 1971, 1975).

It should be noted that tests of this sort might not prove particularly useful in the analysis of RA following closed head injury, since it has often been observed that most RAs cover only a few seconds or minutes; that is, recent memories seem to be more affected than remote memories (Russell, 1971; Williams and Zangwill, 1952). However, a sampling bias may have contributed to the existence of this opinion. Squire, Slater and Chace (1975) have raised this issue in a more general discussion of remote memory "... when an interview covers a period of many months or years, questions about the remote past tend to sample a greater time interval and tend to be more general than questions about the recent past (p. 77)." A similar argument has been offered by Kinsbourne and Wood (1975) in regard to the ostensibly



greater effect of RA on recent than remote memories. Thus in addition to providing a possible mode of assessing the longer RAs, application of tests such as those developed by Squire may provide a firm basis for answering the recent-remote question: it is possible that these tests will uncover previously undetected abnormalities of remote memory function following closed head injury. Also, by careful application of cuing procedures in objective remote memory tests (Marseln-Wilson and Teuber, 1975), the hypothesis that shrinking RA indicates a memory retrieval deficit, while permanent RA indicates a memory storage deficit (Benson and Geschwind, 1967) may be systematically investigated.

Another possible method for exploring RA is the semantic cuing technique of Crovitz and Schiffman (1974). In this paradigm, subjects are asked to produce a personal memory in response to each of 20 common English nouns. Subjects are then asked to date these memories with respect to the present. Wood (1974) used this technique with Korsakoff patients, and found that these patients have great difficulty in generating specific episodic memories, in striking contrast to normal subjects. We may ask if closed head patients suffering from RA have similar difficulties in generating episodic memories. If they are able to generate episodic memories, we may compare the age distribution of these memories to the known distributions for normal young adults (Crovitz and Schiffman, 1974; Crovitz and Quina-Holland, 1976). Such a comparison might provide a firm basis for determining whether recent memories are indeed more affected by RA than remote memories. The one drawback of this technique, as noted by Crovitz and Quina-Holland (1976), is that the accuracy of reported memories cannot be easily checked. Nonetheless, use of this paradigm — possibly in combination with the Squire or Warrington methods — may provide new insight into RA.

#### *PTA duration as an indicator of later memory impairment*

The duration of PTA has often been taken as a mark of the “severity” of closed head trauma and has been related to a number of indicators of recovery of function. For example, Moore and Ruesch (1944) noted that the length of “disorientation” correlates well with the severity of a variety of neurological signs; Russell and Nathan (1946) reported that the length of PTA is a good indicator of “recovery of efficiency” among soldiers with closed head injuries; Symonds and Russell (1943) reported that invalidism is more probable with increasing PTA duration; and Symonds reported that the length of PTA is a good index of time until return to work following closed head injury. An excellent review of this literature can be found in Smith (1961). In the present section, we will confine ourselves to examination of studies which have considered PTA duration as an indicator of the degree of memory impairment present after PTA termination.

Studies by Russell (1932) and Russell and Nathan (1946) had shown a positive (although statistically undocumented) relationship between PTA duration and length of permanent RA. Russell (1932) also presented data on severity of memory loss following PTA termination as a function of PTA duration. This data indicates that longer PTA duration is associated with more severe memory loss. However, Russell does not present his method for assessing late memory loss, nor does he state when patients were tested. A stronger case for a relation between PTA duration and later memory difficulty can be gained from taking the data of Russell and Smith (1961, pp. 12-13) and collapsing over their various age groups in order to relate PTA duration to the percentage of cases in each PTA duration group who later developed "memory or calculation defect." Such data is presented in Table II. Unfortunately, we cannot know from this paper how the memory diffi-

TABLE II  
Percentage of Cases Developing Memory and  
Calculation Defect as a Function of PTA Duration  
(from Russell and Smith, 1961)

	PTA duration				
	Nil	< 1 hr.	1-24 hrs.	1-7 days	> 7 days
% cases with defect	10	8	11	29	56

culty was assessed nor when it was assessed with respect to the time of the injury.

More recent studies have suggested that time since injury at test and age of patient may be important variables to consider when relating PTA duration to late memory impairment. Several studies reported by Brooks indicate a fairly clear-cut effect of age on the relation between PTA and subsequent memory impairment. Brooks (1972) tested 27 patients on a variety of memory tests about 7 months after trauma. Mean age of these patients was 32. A significantly negative correlation was found between PTA duration and scores on immediate and delayed tests of logical memory, associative learning, visual reproduction, and a continuous recognition task, for the patients *over* the age of 30 years. Only "percent forgetting" on logical memory was significantly negatively correlated with PTA duration in the patients *under* age 30. Brooks (1974a) found a significantly negative correlation between PTA duration and number of correct responses (minus false positives) on the Kimura (1963) continuous recognition test in his *older* (> 30 years) but not in his *younger* (< 30 years) subjects. A significantly *positive* correlation between PTA duration and number of false positives was

found in the older but not the younger subjects. An insignificant correlation between number of false negatives and PTA duration was observed in both age groups. Brooks (1975) did not find significant differences between three PTA duration groups (7 days or less; 8-28 days; more than 28 days) on performance of a number of short-term and long-term memory tests. Although the mean age of subjects in this study is comparable to that of the subjects in his previous studies (early to mid-thirties), Brooks (1975) did not examine the relation between PTA duration and memory performance separately for the older and younger subjects, as he did in previous studies. Thus age effects may well be embedded in the Brooks (1975) data.

The literature concerning the effect of time since injury at test on the relation between PTA duration and later memory function is equivocal. A number of studies suggest a strong effect of time since injury at test. Thus Kløve and Cleland (1972) found that duration of PTA correlated significantly with an impairment index derived from various memory and cognitive test scores if testing is done within 3 months of injury, but not after. The significant correlations reported by Brooks (1972, 1974a) in older subjects were obtained with mean time since injury at test being 6.9 months in Brooks (1972) and 12 months in Brooks (1974a). Smith (1974), who tested patients 10-20 years post-trauma, found no correlation between PTA length and performance on the Wechsler Memory Scale in 77 closed head subjects, and Norrman and Svahn (1961) found a nonsignificant correlation between PTA duration and performance on a picture memory task in 28 closed head patients tested 2 years and more since injury. These studies appear to suggest that a significant correlation between PTA duration and later memory function is more likely to emerge if memory testing is done fairly soon after injury.

However, results from other studies considerably weaken this suggestion. Dailey (1956) was able to find significant correlations between PTA duration and memory-cognitive performance in closed head injury patients tested 5 years after injury. Similarly, von Wowern (1966) tested closed head patients several years after trauma, and found more severe "dementia" to be associated with longer PTA, with dementia assessed through a variety of intellectual and memory tests. Also, Norrman and Svahn (1961) were able to correlate PTA duration with memory and concentration ability as judged from patients' self-reports and from clinical ratings in their subjects tested 2 years after injury. Finally, Fodor (1972) found that memory performance in patients who were tested only hours after closed head trauma was unrelated to "period of unconsciousness" and "period of disorientation." However, methodological shortcomings in the Fodor (1972) study (to be reviewed in the next section) limit the force of these findings.

In sum, while there is a general tendency for PTA duration to be correlated with degree of later memory difficulties, inconsistencies are plentiful in the literature. As Smith (1961) pointed out, differences in methods for

measuring PTA duration and the presence of focal damage in some closed head samples account for part of the variance encountered when correlating PTA duration with later cognitive and behavioral function. The work of Brooks indicates that the age variable may also contribute heavily to this observed variance. In addition, we suggest that the use of differing methods for assessment of late memory function may add to inconsistencies in the PTA duration-late memory function relationship. Future studies should examine the relation between PTA duration and specific features of memory as revealed by objective testing; such an approach might provide a more precise picture of the relation between PTA duration and later memory capacity.

### *Is there memory during PTA?*

A critical and as yet unanswered question about PTA concerns a person's capacity to store and retrieve new information during PTA. At first glance, the question hardly seems worth asking; after all, Russell and Nathan (1946) defined PTA as the interval in which continuous memory function is lacking. However, there is evidence that patients tested in PTA are able to process information skillfully enough to attain a "borderline" score on the verbal section of the Wechsler Adult Intelligence Scale (Mandleberg, 1975). We may ask whether the application of sensitive memory tests during PTA would reveal at least some residual capacity for storing and retrieving new information. Unfortunately, the quantitative literature is scanty and equivocal regarding this question (An interesting qualitative description of memory capacity during PTA has been reported by Schilder, 1934).

Ruesch and Moore (1943) studied the performance of 120 closed head patients on a variety of cognitive tasks within 24 hours of injury. They found that Hayman's (1942) serial subtraction test, which depends in large part on intact memory for adequate performance, was the most difficult task for these patients to perform. While many of these patients failed this test completely, many of them simply exceeded the time given to complete the test, suggesting some capacity to store and retrieve small bits of new information. Also, digit span backward and forward was reasonably close to normal. However, interpretation of the Ruesch and Moore (1943) results relative to the question of memory capacity during PTA is severely constrained by the fact that Ruesch and Moore did not state their criteria for assessing presence or absence of PTA, and, as Mandleberg (1975) has pointed out, patients in the Ruesch and Moore study who were in "... semi-coma, confused, or delirious states were not tested, and the possibility exists that it was precisely these who were in PTA, while the remainder were fully conscious (p. 1132)."

Methodological problems are also found in a study conducted by Fodor (1972), who set out to systematically investigate memory functions during PTA in 47 closed head patients tested within 24 hours of injury. No inde-

pendent criterion for PTA presence or absence was employed; thus we are not assured that all patients tested were unequivocally in the PTA period. Fodor divided her patient sample into two groups of severity, based on Ammons I.Q. Test scores: patients scoring 80 or above on Ammons I.Q. were classified as the less severe group, and patients with scores of less than 80 were classified as the more severe group. This procedure would appear to confound pre-morbid intelligence level with injury severity, which raises serious questions about the validity of Fodor's groupings. Fodor found that the "less severe" group was normal with respect to matched controls for immediate (5 second delay) and delayed (5 minute delay) recall of "unrelated" stimulus materials, but was not normal for delayed recall of "related" stimulus materials. Object naming and recognition of both "related" and "unrelated" stimuli were normal for the less severe patients with respect to the controls.

The glaring deficiency here is that stimulus materials are never specified ("items" were tested for immediate recall, and "pictures" at delayed recall and recognition), and the criteria which determine whether stimuli are "related" or "unrelated" are never mentioned. Also confusing is the fact that Fodor never says *when* recognition tests were administered (At 5 second delay? At 5 minute delay? At both?). Thus Fodor's suggestion that, since recognition is intact in these patients relative to delayed recall of related stimulus materials, "... the prime deficit is one of retrieval by recall (p. 820)," cannot be evaluated until when we know when recognition was assessed. For instance, if recognition were assessed only at 5 second delay (and is intact), it might be that recognition impairment would show up at 5 minute delay. Fodor's conclusions regarding the "more severe" patients — that they exhibited a more global memory deficit — is contaminated by the procedural shortcomings outlined above.

Aside from the Ruesch and Moore (1943) and Fodor (1972) studies — whose findings have limited application to the problem at hand due to methodological inadequacies — the literature has little quantitative to offer concerning memory capacity during PTA. Thus basic questions concerning memory processes during PTA remain unanswered: What kinds of coding processes (e.g., semantic, acoustic, visual) are available to persons in PTA? How do temporal parameters affect memory performance during PTA, for instance, presentation rate of to-be-remembered items and length of retention intervals? Does provision of retrieval cues at recall significantly improve memory performance during PTA? If so, what kinds of cues effectively access otherwise unrecallable information? Are there systematic changes in these and other properties of memory as PTA progresses?

Possible guidelines for the investigation of memory processes during PTA may be found in the existing data on memory capacity in other so-called global amnesiac states. For instance, in the Korsakoff syndrome, clinical features similar to those found in PTA are observed: disorientation, confu-

sion, retrograde amnesia, and seeming inability to store and retrieve new information (Talland, 1965). In recent years, there has been a proliferation of studies which have systematically examined memory processes in Korsakoff patients. Thus Cermak and Butters and their colleagues (Cermak and Butters, 1972; Cermak, Butters and Gerrein, 1973; Cermak, Butters and Goodglass, 1971; Cermak, Butters and Moreines, 1974) have concluded that the major memory deficit in Korsakoff patients involves faulty semantic encoding of verbal materials; Warrington and Weiskrantz (1970, 1971) suggested that Korsakoff patients and amnesics in general are excessively sensitive to the effects of proactive interference, resulting in retrieval difficulties; Wood (1974) has concluded that a deficit in retrieval from episodic memory underlies mnemonic incapacity in the Korsakoff syndrome; and Fuld (1976) has found both storage and retrieval difficulties in Korsakoff patients. While some of these studies are not without their major methodological shortcomings (see Kinsbourne and Wood, 1975, for an excellent critique of this and related literature), they have shown that Korsakoff "amnesics" are capable of storing and retrieving at least some new information. They have also provided a beginning framework for the investigation of memory processes in amnesic states. Employment of some of these paradigms in the study of PTA would serve two useful purposes: (1) Initiate systematic investigation of memory processes during PTA, and (2) Provide a basis for comparing the patterns of memory impairment found in Korsakoff and PTA patients, with the aim of elucidating the functional similarities and differences between memory processes in these two amnesic conditions.

It would also be desirable to compare memory processes during PTA to those found in transient global amnesia (TGA). TGA, as described in the classic reports of Fisher and Adams (1958, 1964), consists of the abrupt onset of disorientation, anterograde amnesia, and retrograde amnesia in middle-aged persons of stable psychiatric history. The episode typically lasts a few hours, and is characterized by shrinking retrograde amnesia and a permanent amnesia for the period of the attack. Ischemia of the posterior cerebral arteries has been implicated as a cause of TGA (Heathfield, Croft and Swash, 1973). Although most studies of TGA have been clinically oriented (the transitory nature of the phenomenon poses an obstacle for experimental investigation), the fact that both TGA and PTA are *temporary* amnesias, and that they share several clinical features suggests that comparative study of these two syndromes may be fruitful. Careful study of storage and retrieval of new information, and the temporal patterns of remote memory function during PTA and TGA may reveal the degree to which functional impairment of memory is similar in these two conditions of quite different etiology.

Additionally, an intriguing and as yet unanswered question in the analysis of PTA might be profitably pursued in comparison with TGA: To what extent (if any) is the "permanent" amnesia for the period of PTA or TGA

a product of state-dependent learning? (See Overton, 1973, for a review of state-dependent learning research.) That is, instead of conceptualizing "permanent" amnesia for the events of PTA (or TGA) as reflecting the failure to establish new memory traces during the amnesic period (Russell and Smith, 1961), it might be argued that "permanent" amnesia for the pathological period is related to the dissimilarity of the brain states underlying PTA (or TGA) and subsequent normal consciousness. One implication of this suggestion is that appropriate cuing in the normal state would aid retrieval of memories established during the amnesic state, since it has been shown that state-dependent effects in a verbal learning task are effectively eliminated when category cuing is presented at retrieval (Eich, Weingartner, Stillman and Gillin, 1975). This suggestion is highly speculative, but controlled study of this question in PTA and TGA, and comparison of results obtained with PTA and TGA patients, may prove to be worthwhile.

Finally, we suggest that the possibility of learning motor skills during PTA should be investigated. Several studies have indicated near normal motor skill memory by amnesics. The well-known amnesic H.M. is reported to have learned a mirror drawing task (Milner, 1970) and other motor skills including pursuit rotor (Corkin, 1968). Starr and Phillips (1970) reported that the amnesic M.K. was able to learn to trace mazes when blindfolded and to retain the ability two weeks after initial learning. Brooks and Baddeley (1976) found that amnesics showed only mild impairment on learning perceptual-motor Porteus mazes, jigsaw puzzle assembly, and pursuit rotor. Whether motor skill learning remains intact during PTA, as it seems to in other amnesic conditions, and if so, whether retention of motor skills persists into the period following PTA termination, represent intriguing questions for study.

#### MEMORY FUNCTION AFTER PTA TERMINATION

We have now reviewed the major quantitative studies concerning the effects of closed head injury on memory functions up to the time of the termination of PTA, and we have examined the value of PTA as a indicator of later memory impairment. Studies concerned with three aspects of the later effects of closed head trauma on memory function will now be considered: normative data, time course of memory recovery, and the nature of the later memory impairment.

##### *Normative data*

What proportion of closed head injury cases develop memory problems after PTA is over?

An early study by Russell (1932) analyzed 72 cases of closed head injury

with regard to late memory problems. Memory problems after PTA termination were reported to be "severe" in 4 cases, "slight" in 22 cases, and not present in the other 40 cases. Thus about 36% of these cases developed some sort of late memory problem. However, the methods used for assessing memory problems in their various degree are not presented. In a later and larger study, Russell and Smith (1961) report that 310 (23%) of their sample of 1324 closed head cases developed a "memory and/or calculation defect" after PTA termination. Again, the method of assessing such defects is not presented.

Lidvall, Linderöth and Norlin (1974), in a study of 83 closed head cases, depended on the patient's subjective account in order to determine the incidence of memory impairment after PTA termination. Sixteen percent of these individuals reported a subjective memory impairment, a percentage which remained fairly constant from 2 to 90 days post-trauma. This finding can be contrasted to reports of other post-concussion symptoms in the same sample. Headache was a complaint for 50% of the sample two days after trauma; this percentage dropped to about 20% after two weeks. Dizziness was reported by 40% of the sample on day 2, declined to about 20% on day 6, and then remained about constant to day 90. Klonoff and Paris (1974) reported the incidence of subjective complaints of poor memory and concentration in a sample of 200 children (aged 2-15) who suffered closed head trauma. At one and two year follow-up, 10% of the children gave subjective complaints of poor memory and concentration. It should be noted that although preliminary data concerning late memory impairment after closed head injury do exist (see Russell, 1932, p. 589), the development of more data relating to this problem would be desirable.

The few studies reviewed in this section have provided varying estimates of the percentage of the closed head injury population who develop memory problems after PTA has ended. This is not surprising, since the notion of "poor memory" or a "memory problem" is ill-defined in all of these studies.

Using the patients' subjective account of memory function does not seem to hold much promise as a method for determining the incidence of "post-PTA" memory impairment. First, the development of various neurotic and hysterical tendencies after closed head trauma is rather common (Miller, 1961a, 1961b; Thompson, 1965). It may be supposed that such tendencies interact with memory function in some unknown way to produce a subjective report of memory impairment. Second, the notion implicit in asking patients whether or not they have a memory problem — that a unitary "memory problem" results from closed head injury — obscures the possibility that various memory functions may be differentially affected by closed head injury. We believe that the development of meaningful normative data concerning the incidence of memory problems following PTA termination should be



based on objective testing, and that this testing should probe memory function with regard to modality, time, and other features of memory.

### *Time course of memory recovery*

Symonds (1962, p. 3) suggested that the effects of closed head injury, "however slight," may not be completely reversible. We will now review a set of studies which provide data relevant to the question of recovery of memory function at various times post-trauma.

Fodor (1972), in a study reviewed previously, found no improvement in the memory performance of closed head patients tested one, two, three, and four days after injury. Conkey (1938) and Ruesch and Moore (1943) studied closed head patients in the first months after injury. Conkey compared the performance of closed head and control patients on a variety of memory and other cognitive tests. The first testing was given two to three weeks post-trauma, with retesting done four times at about three month intervals. Conkey found gradual recovery of memory and cognitive functions from the first through the fourth test (which was administered 34 weeks post-trauma). No further improvement was seen on the final test, administered at 50 weeks post-injury. By the time of the fourth test, performance of the head injured group approximated that of the control group. Conkey claimed that recovery in memory performance lagged behind recovery of other functions, and this general conclusion seems reasonable when inspecting her curves. However, statistical analysis is lacking in this study, forcing us to treat her conclusions with some caution. Ruesch and Moore (1943) found that performance on Hayman's (1942) serial subtraction test did not significantly improve during the first four days after closed head injury, either with respect to the time it took to do the task, nor the number of errors made. However, both faster times and fewer errors were observed at a follow-up testing one to three months later. Interpretation of these results is clouded by the fact that we do not know whether patients were in or out of the PTA period at any of the various test times.

Brooks (1972, 1974a) tested a variety of memory functions in closed head patients who were unequivocally out of PTA. He found no significant correlation between memory performance and time since injury; closed head patients performed worse than controls regardless of time since injury. These findings led Brooks (1974a, p. 800) to suggest that "... recovery has finished by the time the patients were tested." In a later study, Brooks (1975) separate indices of short term memory and long term memory recovery were investigated. Patients were put into two groups, an early group (mean time since injury at test = 2.4 months) and a late group (mean time since injury at test = 16.6 months). The two groups did not differ on long term memory performance, but the patients in the late group were significantly better than

those in the early group on short term memory tests. Brooks (1975, p. 338) suggested that "It may be that whereas STM [short term memory] is showing a recovery effect over the time scale used in this experiment, LTM [long term memory] has either reached a stable level early in the recovery process or is recovering at a very much slower rate than STM."

Two studies carried the question of memory recovery far into the future with respect to the moment of injury. Smith (1974) argued that memory deficits remain 10 to 20 years after closed head trauma, based on comparisons of patients with differing sites of impact. Dencker (1960), using a novel methodology, studied 36 monozygotic twins who had suffered closed head injury a mean of 10 years previous to testing, and compared them to their non-injured co-twins. No significant difference was found between head injured and control twins on memory tests of digit span and prose passage recall.

These several studies indicate that memory performance following closed head injury does improve with time. However, not enough points in time post-trauma have been sampled for us to be able to draw a precise picture of the time course of memory recovery. Also, the Brooks (1975) findings suggest that different memory processes may recover at different rates, and this possibility should be more extensively examined in future work.

Symonds' assertion that the effects of closed head injury may not be completely reversible receives some support from these studies. Indeed, almost all studies of memory after PTA termination do show impairment in closed head patients relative to controls (see next section). However, the Conkey (1938) and Dencker (1960) findings that memory performance of closed head patients does not substantially differ from controls at 1 and 10 years post-trauma, indicates that more studies of memory several years post-trauma will be required before the question of reversibility of memory impairment can be satisfactorily answered.

#### *Nature of the memory impairment*

Some recent studies have explored memory function after PTA termination with the aim of specifying which aspects of memory processing are most affected by closed head injury.

#### *Storage vs. retrieval*

In the more general literature on memory impairment, much research has attempted to ascertain whether observed memory deficits arise primarily at the input (storage) or output (retrieval) stages of memory processing (see Drachman and Leavitt, 1972; Kinsbourne and Wood, 1975). This issue has been raised in the closed head injury literature with regard to shrinking and permanent retrograde amnesia (see above), and several studies

have explored the relative impairment of storage vs. retrieval mechanisms after PTA termination.

Brooks (1975) examined the number of intrusion errors made by closed head patients and controls during free recall of word lists. Intrusion errors are defined as incorrect recall of items from previous word lists on the current word list. Such errors are thought to be possible only if the item has been stored during list presentation. Warrington and Weiskrantz (1968) have shown that amnesics make more intrusion errors than controls, suggesting a retrieval deficit in these patients. In contrast, Brooks (1975) found that closed head patients tested after PTA termination make significantly *less* intrusion errors than controls. He interpreted this finding as evidence of defective storage in these patients. Although many intrusion errors from a previous list do argue strongly that the memory deficit cannot have been a lack of storage, we suggest that few intrusion errors do not argue strongly for a storage deficit; there may be other ways of demonstrating that the information has been stored, such as semantic or acoustic cuing (Gardner, Boller, Moreines and Butters, 1973; Jaffe and Katz, 1975).

Simple storage-retrieval explanations of memory deficits in closed head patients will find difficulties in the findings of Brooks (1972). Brooks examined recall of verbal and visual material at immediate and 30 minute delay in closed head patients and controls. He found that closed head patients performed significantly worse than controls at immediate recall, and further found that they retained proportionately less of what they did learn than controls at 30 minute delay. Thus faulty retention of information that has been stored may be a problem for closed head patients. A case study reported by Levin and Peters (1976) of a closed head patient tested one year after trauma provides evidence supporting Brooks' (1972) findings. Recognition memory for nouns was tested in this patient and six controls immediately following inspection of the nouns and at 30 minute delay. In the immediate condition, the patient performed perfectly and the controls were 95% correct. At 30 minute delay, performance of the patient declined to 50% correct, whereas only a 10% decrement was observed in the control subjects.

These findings suggest that it may prove useful to compare the performance of closed head patients to that of Korsakoff patients on the Brown-Peterson short term memory task. In this paradigm, presentation of a to-be-remembered item is followed by a retention interval of variable length (usually between 3 and 20 seconds) that is filled with distractor activity. Memory for the to-be-remembered memory item is then probed. Kinsbourne and Wood (1975) found that memory performance of Korsakoff patients is significantly worse than controls by a constant amount at each retention interval tested. The findings of Brooks (1972) and Levin and Peters (1976) suggest that differences between closed head injury patients and controls might be magnified with longer retention intervals; that is, we might observe diverging curves

over time for closed head patients and controls, whereas parallel curves are observed between Korsakoff patients and controls.

### *Visual vs. verbal memory*

Smith (1974), noting the prevalence of contre-coup damage in closed head injuries (Courville, 1942), studied visual vs. verbal memory functions in patients with differing sites of impact. She found that patients with right-side impact (and presumably maximal left hemisphere damage) performed more poorly than those with left side impact (and presumably maximal right hemisphere damage) on verbal memory tasks. This finding was expected given the major role of the left hemisphere in verbal processing (Dimond and Beaumont, 1974). However, patients with right-side impact also performed more poorly than those with left-side impact on tests of visual-spatial memory. Smith was puzzled by the fact that the left-impact group did not show greater visual-spatial memory impairment, given the role of the right hemisphere in mediating visual-spatial processing (Dimond and Beaumont, 1974). Smith suggested the need for more complex visual-spatial memory tasks. Although this study does provide important data concerning impairment of visual and verbal memory as a function of site of impact, we cannot know whether visual and verbal memory are differentially impaired by closed head injury, since no normal control subjects were used.

Impairment of visual memory after closed head injury relative to normal subjects is found in the case report of Levin and Peters (1976). Their patient achieved a score corresponding to less than the second percentile of a normative distribution on the facial recognition task of Benton and Van Allen (1972). Tests of verbal memory showed a mixed pattern of results. Brooks (1972) found that closed head patients performed as well as controls on a visual reproduction task, in contrast to their poor performance relative to controls on verbal memory tasks. Brooks noted that this result may be due to the relatively easy visual memory task that was used in this study. Thus one problem indicated by the Brooks (1972) and Smith (1974) work for future study of visual vs. verbal memory processes after closed head injury is to equate visual and verbal memory tasks for difficulty.

### *Long-term memory and short-term memory*

Brooks (1975) has provided the major quantitative investigation of long-term memory (LTM) vs. short-term memory (STM) in closed head patients, and we will review his study in some detail.

Brooks tested 30 closed head injury patients with a mean PTA duration of 28.8 days (who were out of PTA), and compared their memory performance with that of a matched control group. Brooks used the Glanzer and Cunitz (1966) paradigm in order to distinguish between LTM and STM. Here,

recall of word lists is tested immediately after list presentation, and at a 20 second delay. At immediate recall, there is a strong recency effect, which is attributed to STM. At 20 second delay, the recency effect disappears, which is supposed to reflect the more stable LTM component. Subjects in this experiment were presented with 20 lists containing 10 words per list at both immediate and 20 second delay. Subjects were instructed to count backwards by 3's starting from a 3-digit number in the delay condition. Digit span was also assessed.

Brooks found no significant difference between closed head and control subjects on the immediate recall trials or on digit span. At 20 second delay, closed head subjects were significantly worse than controls. Brooks interpreted these findings as indicating a defect in LTM, and normal STM in closed head subjects. However, the serious problems involved in assuming that this method of testing does indeed permit analysis of STM vs. LTM have been explicated by Watkins (1974). Thus, although Brooks' results may provide information regarding the effects of time on memory performance in closed head patients, they may not be relevant to the issue of short-term vs. long-term stores in closed head injury, due to the limitations of the method employed.

Brooks also analyzed the kinds of errors made by his subjects. It had previously been found that errors from LTM tend to be semantic confusions (Baddeley, 1966), and that errors from STM tend to be acoustic confusions (Conrad, 1964). Brooks found that closed head patients made significantly less semantic errors than controls, and about the same amount of acoustic errors. Brooks interpreted this result as supporting the hypothesis that closed head patients are impaired in LTM relative to STM. Again, the choice of method poses a problem: the validity of the semantic vs. acoustic error analysis as a technique for distinguishing LTM from STM has been questioned by Craik and Lockhart (1972), who noted recent experiments indicating that a variety of coding processes are available for STM processing — not just acoustic codes. While Brooks' error analysis may tell us something about coding and retrieval processes in closed head patients, it may not speak to the question of STM vs. LTM in these subjects.

A third method used by Brooks to investigate LTM vs. STM — the Tulving and Colotla (1970) procedure in which items are classified as either LTM or STM based on the total trials between item presentation and item retrieval — has been found to be a relatively sound method for assessing LTM vs. STM (Watkins, 1974). Using this procedure, Brooks found that closed head patients recalled significantly less words designated as LTM than did controls, and non-significantly less words designated STM. However, the difference between the LTM and STM words for closed head patients is extremely small, and does not provide strong support for hypotheses concerning LTM deficiency in closed head patients.

Finally, the finding of near normal digit span in closed head patients may not provide a basis for making STM-LTM distinctions. Normal digit span has been found in amnesic patients who perform poorly once information has been displaced from immediate awareness by distractor activity (e.g., Talland, 1965; Starr and Phillips, 1970). As Kinsbourne and Wood (1975) have noted, "... amnesics have a normal immediate memory span. That may very well be true, but it is a fact independent of the sort of short-term forgetting over a period of several seconds that is measured by the Peterson paradigm. Immediate memory span relates to material held within the focus of conscious awareness... Short-term memory deals with the re-entry into awareness of material that was previously displaced from primary memory (p. 271)." Whether digit span assesses operations similar to those assessed in standard STM tasks — which usually involve distractor activity — remains uncertain.

A critical and wide-ranging issue raised by the Brooks (1975) paper concerns the importation of models from experimental psychology for the study of memory phenomena following closed head injury. While the application of current experimental methods and models to the study of clinical phenomena is highly desirable, the investigator must be explicitly aware of the theoretical and empirical status of the approach to memory phenomena that he employs. The issue of the existence of long-term and short-term memory stores is the object of considerable debate in contemporary experimental psychology (see Craik and Lockhart, 1972; Wicklegren, 1973, 1974), and the specific methods used by Brooks have been effectively criticized, as noted earlier. If the short-term vs. long-term distinction is to be of substantial aid in the analysis of memory following closed head trauma, then Brooks should explicitly face the empirical and theoretical controversies surrounding the particular approach that he has taken. It is hoped that the increasing application of experimentally developed paradigms to the study of memory function after closed head injury will be paralleled by increasing sophistication of investigators regarding the complex and often unresolved issues which surround these paradigms.

### *Memory sensitivity vs. decision criteria*

The question of whether late memory deficits in closed head injury are due mainly to changes in memory sensitivity or decision criteria has been investigated by Brooks (1974a, 1974b).

Brooks (1974a) found that closed head patients achieved significantly fewer correct responses than control subjects on the Kimura (1963) continuous recognition task. An analysis of errors made by the two groups showed that closed head patients make significantly more false negative errors than control subjects. No significant differences in false positive errors were ob-

served. Brooks noted that the large number of false negative errors made by closed head subjects might be due to impaired memory function, or alternatively might result from the use of strict decision criteria by closed head subjects — that is, closed head patients might offer a response only if they are quite certain that it is correct.

Brooks (1974b) attempted to choose between these two possibilities by subjecting his data to analyses based on Signal Detection Theory (SDT). Brooks found that  $d'$  — the SDT measure of “pure” memory sensitivity — is significantly lower in closed head patients than controls. Low  $d'$  indicates poor memory sensitivity. The SDT measure of decision criteria ( $\beta$ ) was significantly *higher* in closed head patients than controls. High  $\beta$  indicates strict decision criteria, that is, extreme cautiousness in responding. Thus the results suggest that less efficient memory processing combined with caution in responding result in poor memory performance by closed head patients.

These results have potentially important implications for the study of memory function in closed head patients who have emerged from PTA. They raise the question of whether different memory processes are differentially affected by the use of strict decision criteria. That is, rather than contributing equally to performance impairment on all memory tasks, the use of strict decision criteria may impair performance on certain memory tasks more than performance on others. Such a possibility merits detailed investigation.

### *Concluding remarks*

We have now reviewed the major quantitative studies of memory function following closed head injury; we have discussed the critical issues raised by these studies; and we have suggested possible directions for future research in this area. We will conclude by briefly directing our attention to three issues which have received little explicit study in the literature, but which we feel are of importance for future research.

The first issue concerns the relation between memory impairment and other cognitive deficits which follow closed head injury. Intellectual deficits as measured by the Wechsler test have been found after closed head injury by Cole (1943) and Mandleberg and Brooks (1975) (however, see Norrman and Svahn, 1961). The work of Reynell (1944) and Norrman and Svahn (1961) suggests attention and concentration difficulties in closed head patients, and a study by Miller (1970) indicates that closed head patients are impaired in their decision-making capabilities. However, there are no studies which systematically examine the interaction between memory processes and these other cognitive functions in closed head patients. Studies which explore this question both during and after PTA would be desirable.

A second question that we wish to raise concerns the relation between memory processes observed *during* and *after* PTA: Is the difference in me-

mory function between these two times a *qualitative* or *quantitative* one? Mandleberg (1975) has investigated this question in regard to Wechsler I.Q. performance of patients in PTA and those who had emerged from PTA. He found some evidence for a qualitative difference between PTA and "post-PTA" performance, but noted that his findings are equivocal. Research which examines the patterns of performance on tasks which assess a variety of memory functions may be able to provide important clues regarding this problem. If there is a pattern of memory impairment that is characteristic of the PTA phase, it would be interesting to know if after PTA termination there is an overall qualitative change in the observed pattern of memory functions, or if the various indicators of memory impairment change quantitatively while maintaining a consistent relation to each other.

Finally, we suggest that the possibility of improving the memory of closed head injury patients should be explored. It is clear from the literature we have reviewed that significant memory deficits may exist in closed head patients up to years post-trauma. It is also clear that little attention has been given to the possibility of improving these deficits. Several recent studies have indicated that the use of visual image mnemonics significantly improves the memory deficits of Korsakoff amnesics (Cermak, 1975) and individuals with penetrating damage to the dominant hemisphere (Jones, 1974; Patten, 1972). The therapeutic use of visual image mnemonics for closed head injury patients suffering memory impairment merits serious investigation.

#### SUMMARY

Studies which provide quantitative analyses of memory function following closed head injury were reviewed. Specific issues covered include criteria for assessing post-traumatic amnesia (PTA), PTA duration, relation of PTA duration to later memory impairment, memory functions within PTA, and comparisons between PTA and other amnesic conditions. Issues associated with the assessment of retrograde amnesia were also reviewed. With regard to memory function after PTA has terminated, we described and discussed normative data, the time course of recovery, and issues related to the nature of the later memory impairment. Directions for future work which seem particularly useful from a practical and theoretical viewpoint were also considered.

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