Losing Their Configural Mind: Amnesic Patients Fail on Transverse Patterning

Timothy C. Rickard
University of California, San Diego

Jordan Grafman
National Institutes of Health

Abstract

A configural theory of human amnesia is proposed. The theory predicts that amnesic patients will exhibit selective deficits on tasks that normal subjects perform by learning new configurations of stimulus elements. This prediction is supported by results for four amnesic patients who learned a nonconfigural control task but failed to learn the configural transverse patterning task even after extensive practice. Matched normal subjects easily learned both tasks. The theory provides unique and viable accounts of the central results in the human amnesia literature. Relations between the configural approach and other theories are discussed.

INTRODUCTION

The identification and characterization of the human amnesic syndrome represents one of the clear success stories in cognitive neuroscience over the last few decades. Pioneering studies of Scoville and Milner (1957) and Milner (1972) demonstrated that damage to the medial temporal lobe can cause severe impairment in recall and recognition memory, while leaving a number of other kinds of memory, as well as general intellectual function, relatively intact. Included among the putatively intact memory and learning capacities of amnesic patients are priming, perceptual-motor skill learning, and habit learning (for a review, see Squire, 1992).

A number of dichotomies have been proposed in an effort to characterize more precisely the critical difference between impaired and preserved types of learning and memory in amnesic patients (for a review and critique, see Grafman & Weingartner, 1996). The declarative versus procedural (Cohen & Squire, 1980; Squire, 1992) and closely related explicit versus implicit (Reber, 1967; Roediger & McDermott, 1993; Schacter, Chiu, & Ochsner, 1993) distinctions are two widely known examples. The medial temporal system is believed to support declarative (or explicit) memory; that is, it supports recollective memory such as retrieval of episodes (Tulving, 1972; Wheeler, Stuss, & Tulving, 1997) and recall or recognition of new factual information. The procedural (also termed implicit or nondeclarative) memory system, on the other hand, is hypothesized to influence performance without conscious awareness or recollection. This type of memory appears to be relatively preserved in amnesics and thus appears to be supported by neo- and subcortical structures outside of the medial temporal region.

An alternative approach to characterizing these two memory systems has focused on their computational properties (Gluck & Myers, 1993; Kroll, Knight, Metcalfe, Wolf, & Tulving, 1996; McClelland, McNaughton, & O'Reilly, 1995; Metcalfe, Cattrell, & Mencl, 1992; Metcalfe, Mencl, & Cottrell, 1994; Schmajuk & DiCarlo, 1992; Sutherland & Rudy, 1989; Wickelgren, 1979). The common thread in this work is that the hippocampus, or more generally, the medial temporal system (see Squire, 1992) is critical for binding features into new representations. From this perspective, amnesics are selectively impaired on tasks that require feature binding. A number of researchers have recently suggested possibilities for synthesizing the computational and procedural-declarative approaches. Cohen and Eigenbaum (1992) and Squire (1992), for example, have proposed that declarative memory relies fundamentally on the binding role of the medial temporal region. Along a similar vein, Metcalfe et al. (1992) demonstrated that at least some explicit tasks are better modeled by computational systems that can bind features or elements in some way, whereas implicit memory tasks appear to be better accounted for by systems that treat each exposure to an item as a separate memory trace.

Despite the substantial progress reflected in this recent work, current theories of amnesia still cannot make clear predictions for some classes of tasks. For example, a critical problem with the explicit-implicit memory framework is that it is often difficult to establish conclusively whether implicit memory, explicit memory, or both, are exerting an influence on performance (Dunn & Kirsner, 1989). Thus, if amnesics fail on a particular task, it can be interpreted as requiring explicit (or declarative) memory. If they do well, the task can be interpreted as tapping implicit (or procedural) memory (but see Schacter, Bowers, & Booker, 1989, for a proposed solution to this problem). The computational approach is also open to post hoc interpretation unless the elements upon which new learning operates can be identified. This point was made for the configural theory (Sutherland & Rudy, 1989) by Squire (1992), who noted that it is unclear whether an animal categorizes two stimuli (as defined by the experimenter) as two distinct objects or rather perceives them as a single unit, or element.

Our goals in this paper are fourfold. First, we elaborate on the basic ideas introduced by Sutherland and Rudy (1989; see also Alvarado & Rudy, 1995a, 1995b; Rudy, 1994; Rudy & Sutherland, 1992) to develop a human version of the configural theory that defines an "element" sufficiently to allow unambiguous predictions for at least some class of tasks. Second, we report an empirical test of this theory using a task adapted from Alvarado and Rudy (1992). Third, we provide an overview of how the configural approach can in principle account for many of the central empirical findings in the human amnesia literature. Finally, we compare the configural approach with other theories and suggest possible directions toward synthesis.

A CONFIGURAL THEORY OF HUMAN AMNESIA

We start with the fairly standard assumption in cognitive psychology that at any given moment the human brain has stored a set of functionally coherent representational *elements* at both perceptual and conceptual levels. At birth these may be limited primarily to perceptual and motor primitives. In the adult human they also include perceptually specific object representations, as well as conceptual and thematic representations. Next, building directly on the work of Sutherland and Rudy (1989) in the animal literature, we assume that all learning systems in the human brain can be placed uniquely into one of two categories based on their computational roles. First, there is a set of one or more *elemental* learning systems that can operate independently of the medial temporal lobe. These systems are capable of altering the strength of self-associations for existing elements (or, equivalently for current purposes, altering baseline or threshold activation levels) and of strengthening associative connections between elements. Second, there is a single *configural* learning system that requires intact temporal medial structures, including the hippocampus and adjacent cortex, to operate. This system forms new elements that are novel configurations of two or more existing elements (i.e., nonlinear learning). Each new configural representation, once established by the medial temporal system, is assumed to be subsequently consolidated (Squire, Cohen, & Nadel, 1984) in the cortex (probably by a time-dependent mechanism; for a candidate computational account of consolidation, see McClelland et al., 1995) and ultimately becomes a new element in neocortex. Thus, the set of elements is continually being extended by the configural system in a hierarchical fashion. As an example, letters are configurations of features, and words are configurations of letters. The theory does not make specific claims about the representational substrate of configural learning in any given situation. However, two viable representational formats for configuration are binding of visual objects into novel configurations by way of spatial relations (O'Keefe & Nadel, 1978) and coding of conditional linguistic rules, such as "If A and B, then C."

We assume that humans automatically categorize the environment into familiar objects and concepts that correspond to existing elements. We further assume that for both normals and amnesic patients, attention can be voluntarily directed to the level of representation that is most appropriate for the current goals. Thus, for example, attention can be directed to elements corresponding to a feature, a letter, an entire word, or a word's meaning, as necessary. The configural learning system is assumed to operate only on the elements at the level of the hierarchy that are in the focus of attention. Elements on which configural learning operates therefore do not typically correspond to the absolute primitives involved in perception itself (i.e., simple visual features). Rather, they reflect both the previous knowledge of the subject and factors such as goals and salience of objects that determine what elements are activated at any given time.

This approach directly couples the automatic categorization of objects in the environment with the operation of the medial temporal system. This coupling allows elements involved in learning to be identified ahead of time for many types of tasks, provided that the experimental materials and design allow obvious insight into the elements that are perceived and processed by the subject during study. The theory can then make two very general predictions about amnesic performance. First, if a task logically requires that one or more new configurations of elements must be formed to be learned completely (*configural tasks*), densely amnesic patients will never completely learn the task, regardless of the amount of practice given and regardless of whether the test phase is performed under implicit or explicit memory instructions. Further, the maximum accuracy for amnesic patients on such tasks will never exceed the theoretical maximum level obtainable by the elemental system. For many tasks this theoretical value can be quantified as an exact proportion. We will elaborate on this fact in the "Results" section. Second, the theory predicts that amnesics will typically exhibit some learning on tasks that can in principle be solved completely by the elemental system alone (*elemental tasks*). However, the extent to which this learning will be observed will depend on specific factors—such as the intrinsic amount of interference involved in the task—which in turn determine how important the configural system is to the performance of normal subjects on that task. These factors will be considered in the "Discussion" section.

As an initial test of the configural approach, we explored a human adaptation of the transverse patterning (TP) task (see Alvarado & Rudy, 1992; Spence, 1952). This task was presented in three phases as shown in Figure 1. In phase 1, a pair of elements (stimuli *a* and *b*) was presented side by side visually, and the correct response was stimulus *a*, regardless of whether *a* appeared on the left or right. Items in this phase as well as all subsequent phases were presented repeatedly until a preset accuracy criterion was reached. The stimuli used correspond to the shaded squares in the Figure 1, but to facilitate

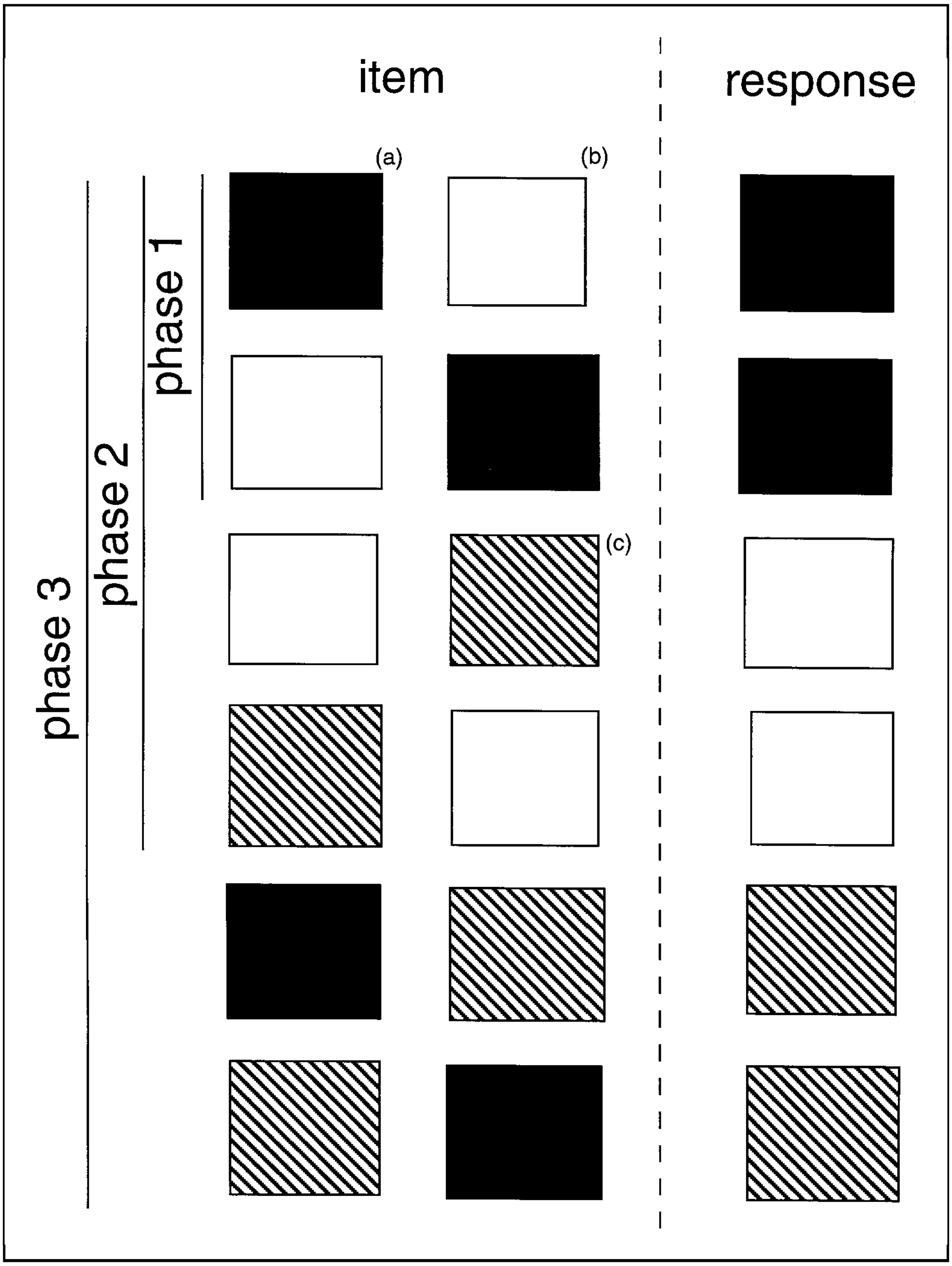

Figure 1. Stimuli used for the transverse patterning task. Letters in parentheses are included to facilitate exposition but were not a part of the presented stimuli.

exposition we will refer to them using the accompanying letters in parentheses. In phase 2, the subject again saw *a* and *b* (and the reverse) on some trials and also a new pairing, *b* and *c* (and the reverse), on other trials. The correct response for the *b*, *c* pair was always B. In phase 3, yet another pairing (A, C) was added to the mix of trials so that the subject saw *a* and *b*, *b* and *c*, and *c* and *a*, and their reverses, equally often across trials. The correct response for the *a*, *c* pair was always *c*. In phase 3 the TP task is the near equivalent of the childhood game of rock (stimulus *a*), paper (stimulus *c*), and scissors (stimulus *b*).

Phases 1, 2, and 3 of this problem entail different degrees of reinforcement for each element. In phase 1, element A is always reinforced (i.e., is correct), and element *b* is never reinforced. In phase 2, element A is always reinforced, element *b* is reinforced half of the time, and element *c* is never reinforced. Because of this differential reinforcement of the elements, phases 1 and 2 are solvable by a simple reinforcement-based elemental learning system. However, this elemental model cannot solve phase 3 of the TP problem, because in phase 3 there is no combination of relative reinforcement strengths among the elements that produces the correct answer for all pairings. Phase 3 can, however, be solved by a nonlinear learning system that can re-represent each pair of elements as a new configuration (see Rudy, 1994; Rudy & Sutherland, 1992, for further discussion of configural learning).

Now consider phases 1, 2, and 3 of the elemental control task depicted in Figure 2. In this task each pair is composed of one element that is always reinforced and a second element that is never reinforced. Thus, a simple elemental learning system can solve this task not only in phases 1 and 2 but also in phase 3. The configural theory therefore predicts that normals will learn all three phases of both tasks. Amnesic patients, however, should exhibit a selective deficit only on phase 3 of the TP task.

RESULTS

The number of trials required to reach criterion for each phase of each task is shown for each patient and control in Figures 3 through 6. Phase 3 results for both tasks in these figures reflect the number of trials required to reach the first criterion but with the additional condition that this learning was subsequently confirmed by obtaining 14 of 15 consecutive correct responses in the second delayed criterion test. The results provide striking support for the configural theory. The matched controls easily learned all three phases of both tasks quickly.[1] The amnesic patients also quickly learned all three phases of the control task, as well as the first two phases of the TP task. However, none of the amnesic patients ever reached the second criterion for the TP task, despite extensive practice. Note that subjects B.E. and S.R. did reach the first criterion three and two times, respectively, over 492 and 1008 trials of practice.[2] However, in all cases, both subjects failed to confirm that they had learned the task on the second 1-min delayed criterion test, indicating that their memory for the items was unstable even over very brief intervals (also, note that nonreplicated runs of 14 out of 15 correct trials may have occurred by chance on occasion over very long sequences of trials).

Performance of the amnesic patients on phase 3 of the configural task was examined in more detail by plotting proportion correct across consecutive intervals of 24 trials as shown in Figures 7 through 10. The solid line through the data in each graph is the least squares linear regression fit. The lower dotted line in each figure represents chance performance. The upper dotted line represents a highest theoretically obtainable performance level (0.67) for a simple reinforcement-based elemental model. This later value is based on the following reasoning: Consider the case in which the greatest response strength is for the black square, intermediate response strength is for the white square, and least response strength is for striped square. Assume that greatest strength always dictates the response. Then, given a reinforcement-based elemental learning model, we would expect perfect performance on the black-white and white-striped combinations. However, we would expect zero accuracy on the striped-black combination because the black square, the incorrect response, would have higher response strength than would the striped square, the correct response for that combination. Thus, the proportion correct in the absence of a configural learning capacity might approach, but would not be expected to consistently exceed, 0.67. This value is the maximum theoretical accuracy level for a reinforcement-based elemental system over all possible ordering of strengths for the three elements of this task.

The results for three of the four amnesic patients (J.P., S.R., and D.W.) were consistent with this supplementary prediction of the theory. Accuracy for two of these patients never consistently exceeded the maximum value expected for a pure elemental solution. A third patient, S. R., just slightly exceeded maximum nonconfigural performance on average across 1008 trials of practice (mean = 0.706). This value was statistically greater than 0.67, $t(1, 43) = 2.39$, $p = 0.02$. However, S.R. showed absolutely no improvement in performance with practice as indicated by the flat regression line fit to her data. If her performance truly reflects partially intact configural processing, it would be reasonable to expect gradual improvement with practice (as was observed for patient B.E.; see discussion below). These factors suggest an account of this patient's data based on residual short-term memory for previously seen items. This account, although speculative, is uniquely consistent with the fact that S.R.'s performance was only marginally better than the theoretical maximum elemental performance and with the fact that her performance did not improve with

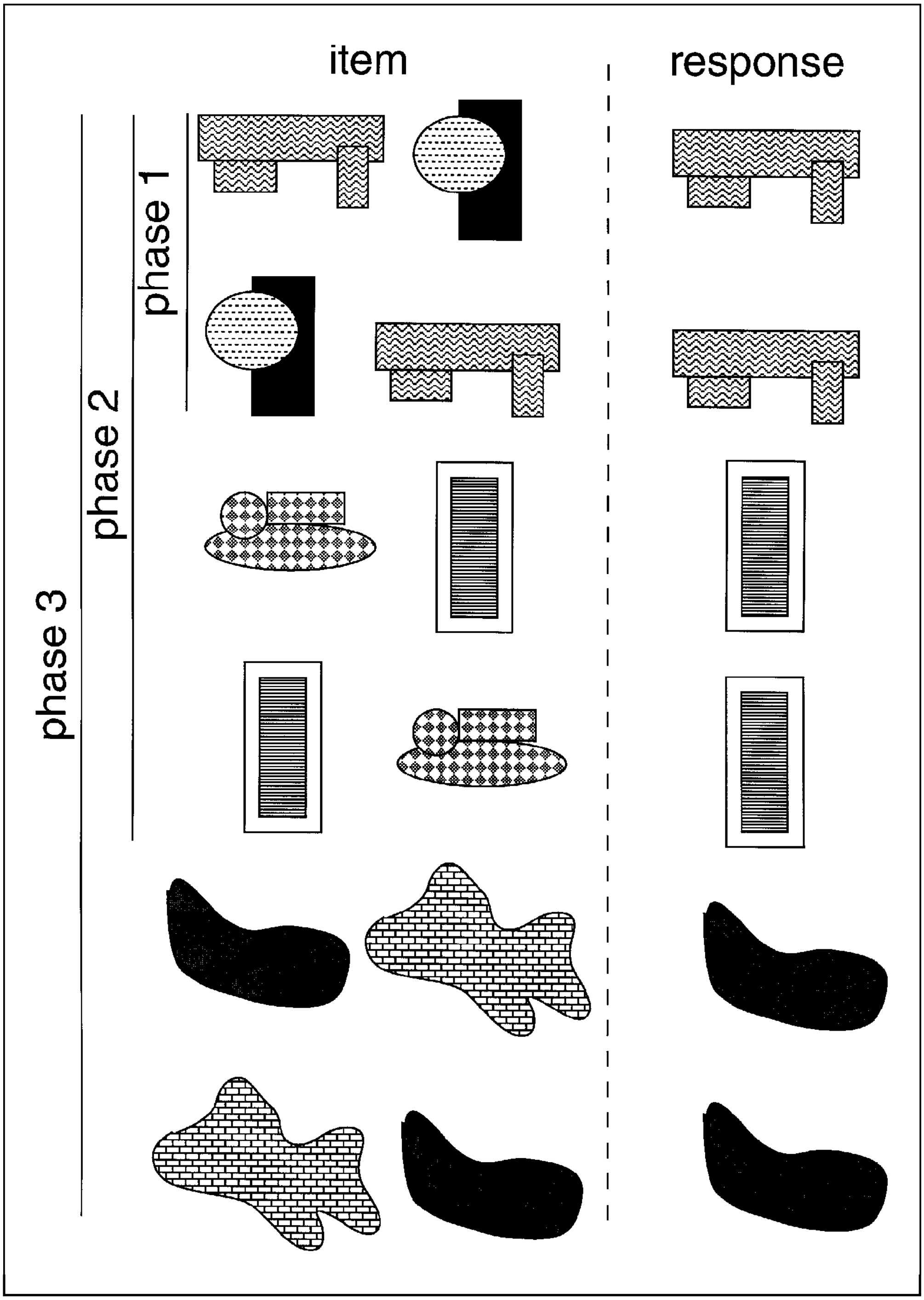

Figure 2. Stimuli used for the elemental control task.

practice (the influence on performance of residual information in short-term memory would not be expected to change with practice).

Only patient B.E. exhibited significant improvement with practice, $F(1,21) = 18.65, p < 0.001$. By the end of practice her performance was well above the maximum elemental performance level, $t(1, 21) = 4.957, p < 0.001$. This result is consistent with the finding that this subject occasionally was able to reach the first criterion for solving phase 3 of the configural problem. Apparently, B.E. does have some preserved ability for configural learning. This conclusion is supported by her neuropsychological testing, which revealed, uniquely among the group of patients, almost normal nondelayed Wechsler Memory Scale—Revised performance. Thus, a reasonable interpretation is that this patient has partially intact medial temporal processing.

DISCUSSION

The results are clearly consistent with the configural model. Normals and amnesic patients easily learned the

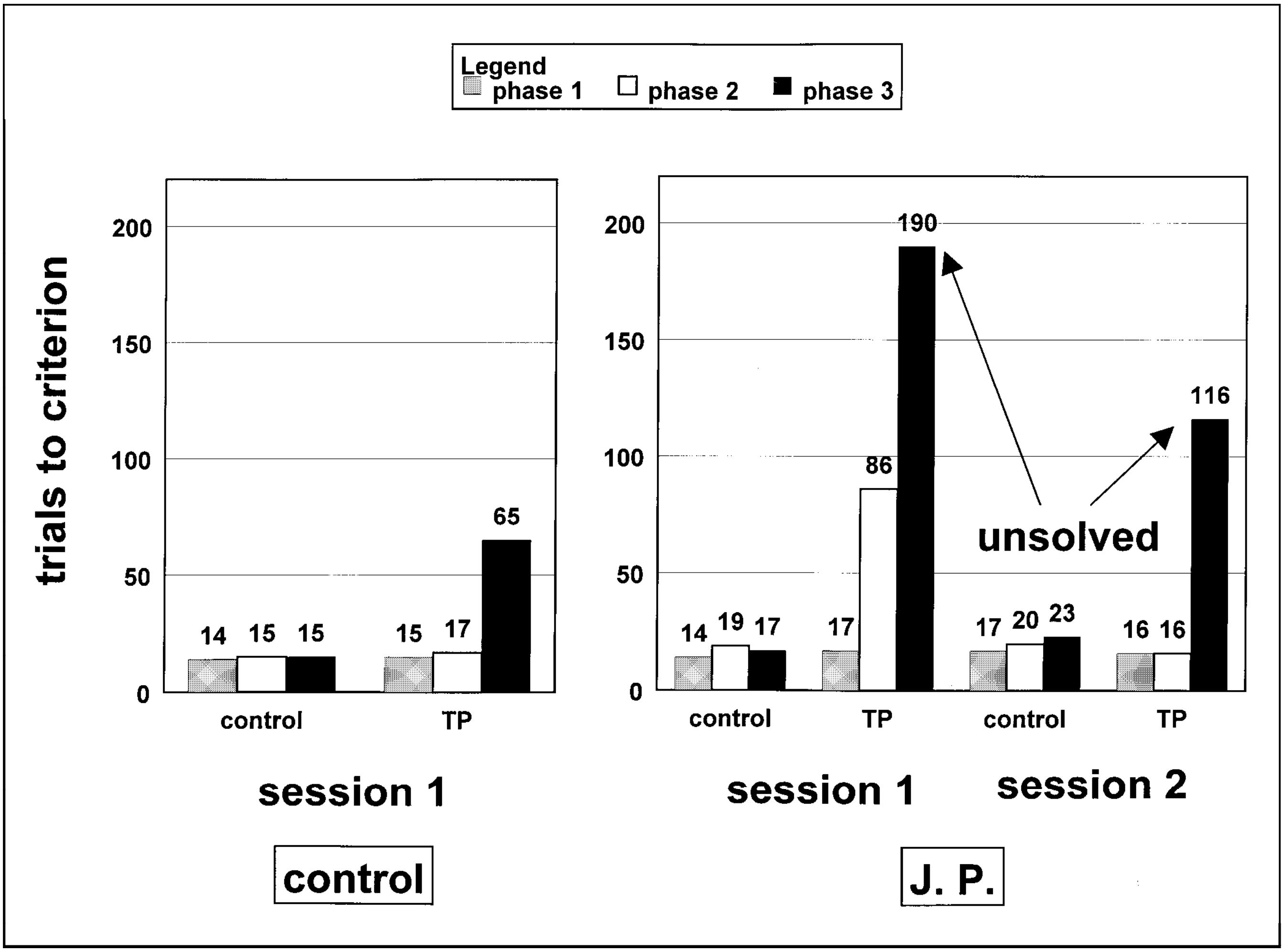

Figure 3. Trials to criterion for patient J.P. and his matched control for phases 1, 2, and 3 of the elemental control and transverse patterning task.

elemental control problem, as well as the first two phases of the TP problem. The normal controls also learned phase 3 of the TP task without difficulty. However, none of the four amnesic patients was ever able to completely solve phase 3 of the TP problem, even after extensive practice.[3]

One reasonable criticism of the data is that amnesics may generally have more difficulty with all learning problems than do normals. This account suggests that both normals and amnesics find phase 3 of the TP task much more difficult than the other phases of the two tasks. The difficulty level for normals may not have been sufficient to cause any observable performance deficit, even on phase 3 of the TP task. For amnesics, on the other hand, the shift in difficulty caused by their brain damage may have been sufficient to yield very a severe performance deficit on phase 3 of the TP task but not sufficient to cause any substantial deficits on the other tasks.

We acknowledge that a generic difficulty account cannot be conclusively rejected. However, several factors speak against it. First, the performance deficit for the amnesics on phase 3 of the TP task was not just one of modest, statistically significant degree. Rather, the patients simply never learned the task to the preset criterion even after extensive practice. Such a strong dichotomous performance deficit is not predicted a priori by any conceivable difficulty account (outside of a computational account such as that provided here). Second, the difficulty argument only applies directly to the trials to criterion data shown in Figures 3 through 6. Given the clear findings that (1) normals learned all problems, and (2) amnesics never completely learned phase 3 of the TP task, the theory makes the additional prediction that amnesic performance on phase 3 of the TP task will never exceed 0.67. Confirmation of this prediction for our three densely amnesic subjects (Figures 7, 8, and 10) constitutes empirical support for the theory, which is independent of the scaling issues present for Figures 3 through 6. Third, a generic difficulty account of the results is weakened by the fact that phase 3 of the TP task presents problems not only for human amnesics but also, after hippocampal lesions, for rats (Alvarado & Rudy, 1995a) and monkeys (Alvarado, Wright, & Bachevalier, 1995; Alvarado, 1997). There is no

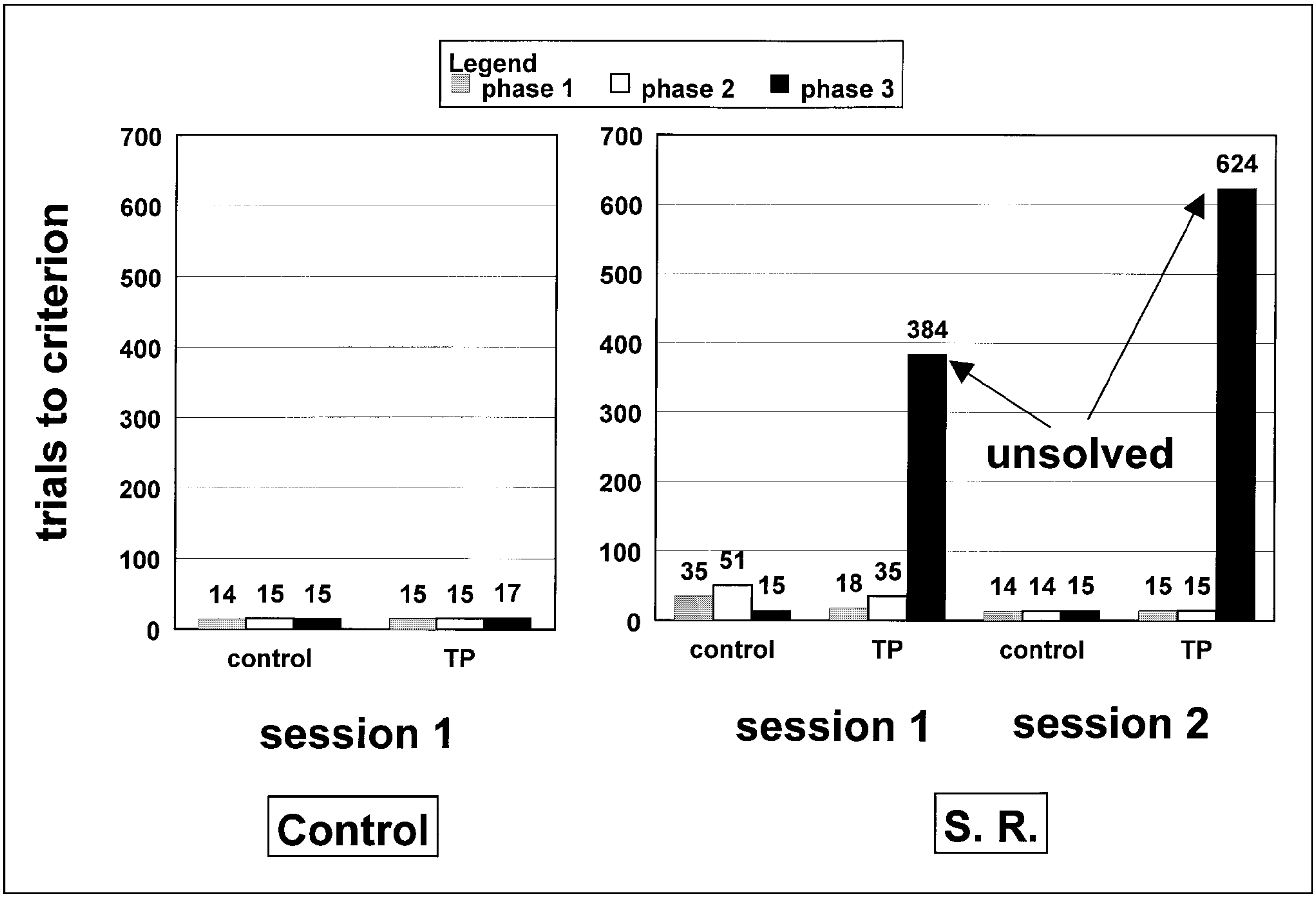

Figure 4. Trials to criterion for patient S.R. and her matched control for phases 1, 2, and 3 of the elemental control and transverse patterning task.

reason to expect that difficulty will reach the critical point precisely on phase 3 of the TP task for all of these species, unless a specific common factor such as a deficit as configural learning is involved.

Reinforcement versus Cross-Associative Elemental Models

Following Avarado and Rudy (1995a, 1995b), we have assumed thus far that a particular sort of elemental model, which we will term the *element reinforcement* model, underlies amnesic performance on discrimination tasks such those used in the current experiment. The reinforcement model can be understood as a special case elemental model in which only associations from an element back to itself can form. The strength of this self-association is directly related to the reinforcement value for the element. The higher the reinforcement value, the stronger the self-association. This appears to be the subtype of elemental model that Alvarado and Rudy have in mind for the TP task, because it fails selectively to solve phase 3 of that problem. However, it is important to note that a more general class of *cross-associative* elemental systems, in which any arbitrary association can form between the different elements, can solve all phases of the transverse patterning problem without the presence of configural units (for a general discussion of elemental, or linear, learning models, see McClelland & Rumelhart, 1986). These models can succeed in solving the TP problem by forming unidirectional associations from the incorrect element to the correct element for each pairing.

Thus, contrary to the claims of Alvarado and Rudy (1995a, 1995b), the TP task is not strictly a configural one. However, it is nevertheless reasonable to assume that elemental learning is constrained only to reinforcement learning for discrimination problems such as those studied here. Both normal and amnesic subjects may initially adopt a strategy of simply ignoring the incorrect item after obtaining feedback and of focusing only on coding the correct item into memory. Once they have learned the task, subsequent performance may simply reflect choosing and strengthening the correct element of each pair. Because the incorrect item is ignored in this account, cross-associative learning may be effectively precluded. Subjects may then jump directly to a configural strategy once they notice that this simpler strategy is insufficient in phase 3 of the TP problem. However, only

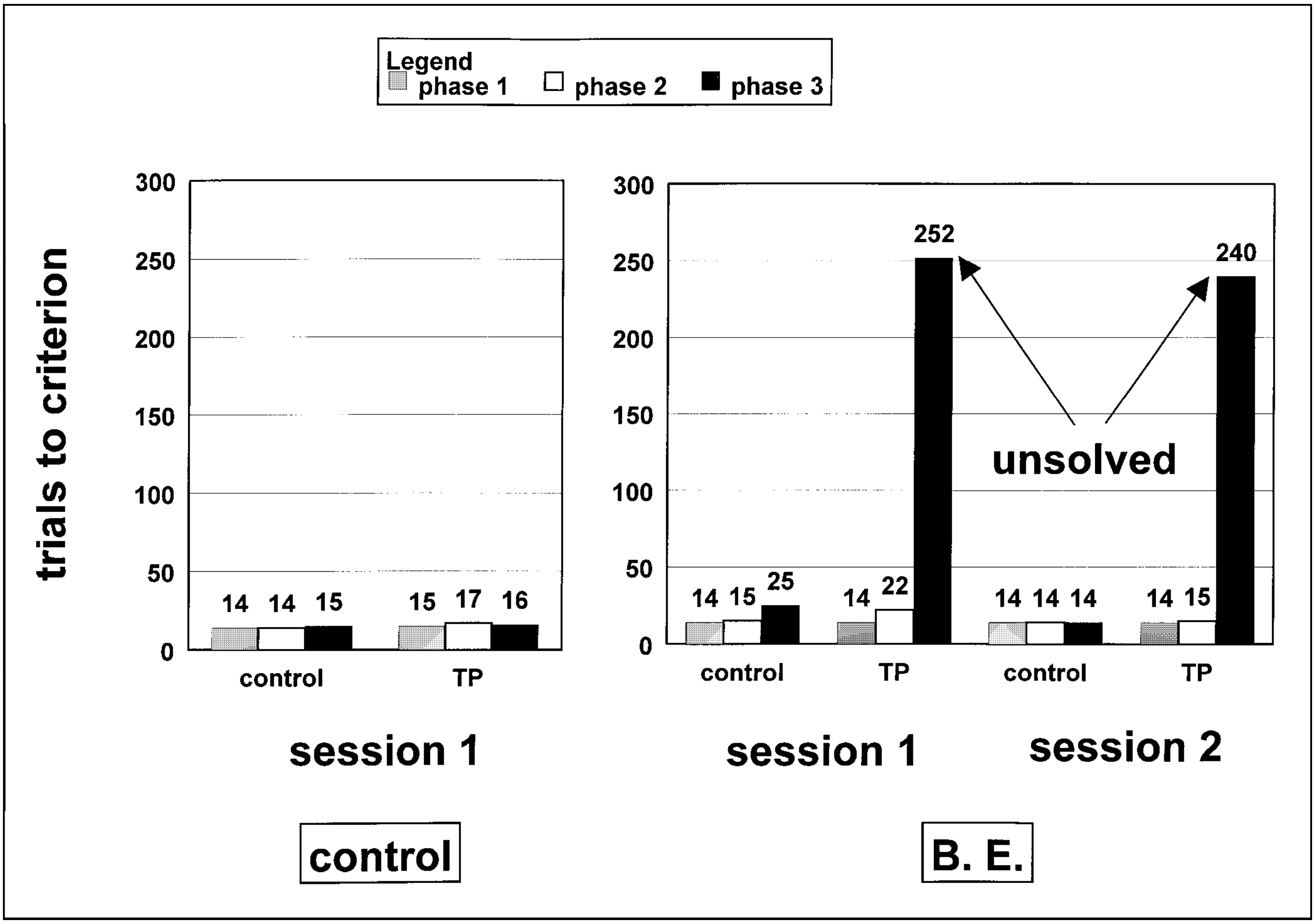

Figure 5. Trials to criterion for patient B.E. and her matched control for phases 1, 2, and 3 of the elemental control and transverse patterning task.

normal subjects would successfully store and remember configural solutions.

There is nevertheless substantial evidence that cross-element associations can be acquired by amnesic patients in other tasks domains (for a recent review see Gabrieli, Keane, Zarella, & Poldrack, 1997). Therefore, we will proceed with the discussion below on the assumption that, although elemental learning on discrimination tasks may be limited to simple element reinforcement, as a general rule cross-associative elemental learning can occur independently of the medial temporal lobe in other tasks.

A Configural Account of Other Empirical Findings in the Literature

The configural theory provides a viable and in some cases unique account of a number of other core findings in the human amnesia literature. First consider episodic memory (Tulving, 1972). We make the reasonable and generally accepted assumption that an episode could not be stored in a stable form in long-term memory without formation of a unique configuration of elements that incorporates spatial relations among objects, conceptual thoughts, emotion, time, and place of the episode. Thus, the configural theory is consistent with the profoundly impaired episodic memory observed in amnesic patients.

A more provocative implication of the theory is that amnesic patients should be impaired on all configural tasks, even if the task is believed to reflect only implicit influences of memory. A new study using the serial reaction time (SRT) task (Curren, 1997) provides direct support for this claim. Curren showed that second-order conditional learning (i.e., facilitation of a keypress response based on the combined information from the two preceding keypresses), which is most naturally treated as a form of configural learning, is impaired in amnesics but that frequency learning and first-order conditional learning (i.e., elemental learning) is not.

The prediction that amnesics cannot acquire new implicit configural memories may nevertheless appear implausible in light of a number of implicit memory phenomena exhibited by amnesic patients on seemingly complex tasks, including priming in face identification (Paller et al., 1992), artificial grammar learning (Knowl-

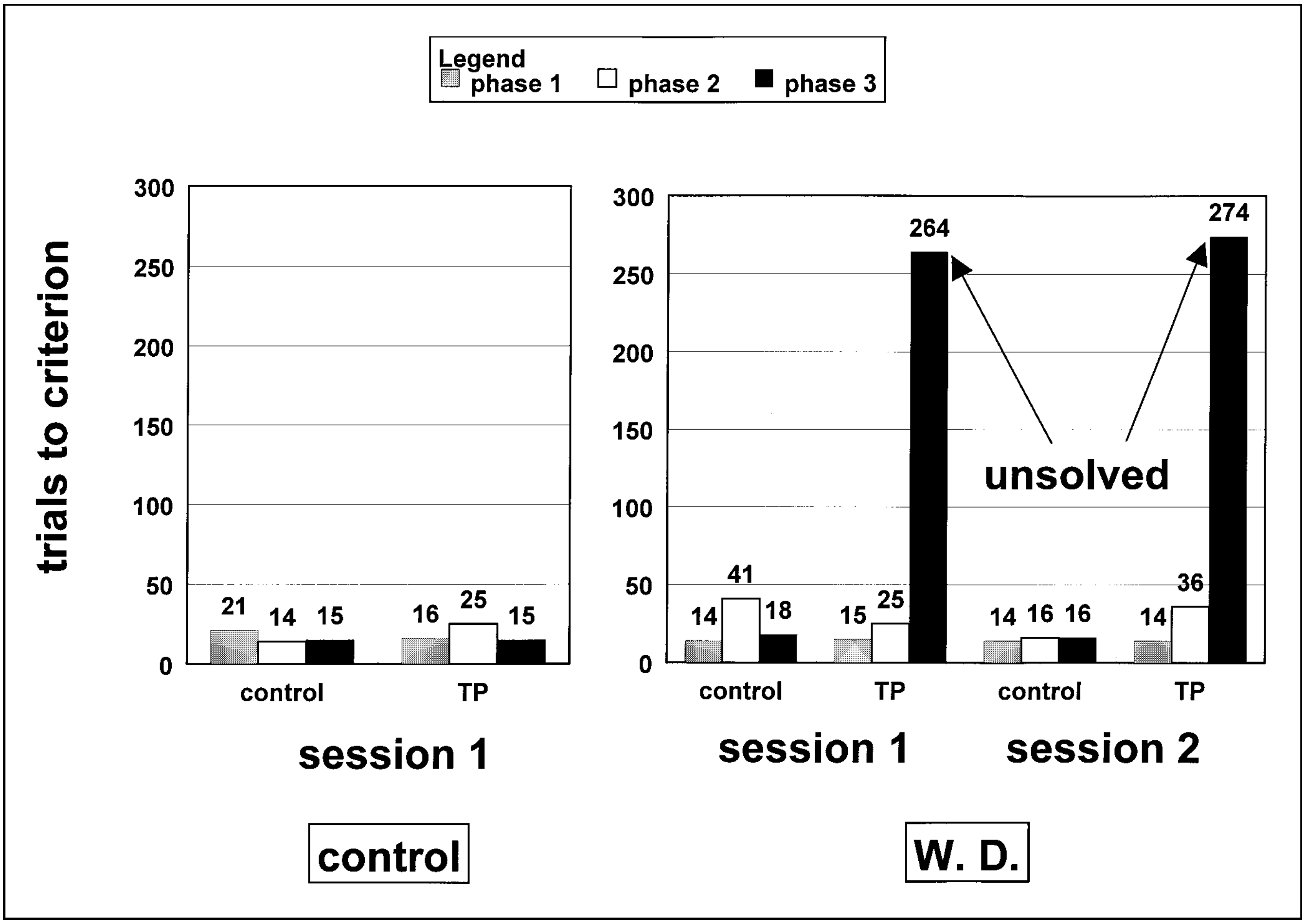

Figure 6. Trials to criterion for patient W.D. and his matched control for phases 1, 2, and 3 of the elemental control and transverse patterning task.

ton, Ramus, & Squire, 1992; Knowlton & Squire, 1996), and priming for specific depth orientations (Srinivas, Verfaellie, Schwoebel, & Nugent, 1997). However, the often modest implicit memory effects for amnesics as measured by accuracy on such tasks do not in and of themselves provide strong evidence that configural learning has occurred. A strong demonstration of configural learning requires a clear demonstration that the obtained accuracy level exceeds the theoretical limit of the appropriate elemental model of the task. Determining the "appropriate elemental model" in turn requires determining the elements upon which new learning is operating. We acknowledge that there are some tasks, such as those described above, for which this may prove difficult. Importantly, however, there are other tasks for which elements can be clearly identified and through which the configural account can be directly tested.

A number of the tasks on which amnesic patients have been shown to be profoundly impaired are solvable in principle by one or more members of the broad class of cross-associative elemental learning models. One prominent example is paired associate learning tasks, in which the formation of a new association from an element corresponding to the cue word to an element corresponding to the response word is sufficient to support learning. It may therefore appear on the surface that amnesics should learn this task easily. However, the configural theory in fact predicts that normals should exhibit much better performance on this task than amnesics, because they can form a configuration between the cue word and the context, which is in turn uniquely associated with the response word. If we make the reasonable assumption that, during retrieval, configurations of cue and context take precedence over other (probably much stronger) associations with the cue, the configuration provides a unique and interference-free pathway to the response word. In contrast, amnesics would only be able to form simple associations from individual input elements, such as the cue word, to the response word. It may be nearly impossible for a simple cue-response association between previously unrelated words to supercede other preexisting associations from the cue to other responses (other words, in this case) after one or even many learning trials. Thus, although the configural theory does not logically preclude paired as-

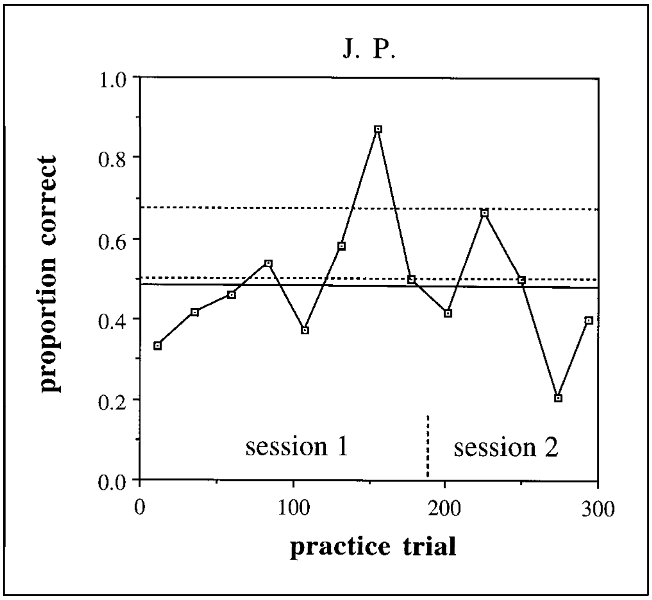

Figure 7. Accuracy averaged over consecutive 24-trial practice intervals for J.P. on phase 3 of the transverse patterning task.

sociate learning by amnesics, it does imply that such learning would be extremely difficult, and perhaps effectively impossible, in most realistic learning contexts. By the same reasoning, the configural theory can provide an account of why paired associate learning nevertheless is observed in amnesics when semantically related words are paired (e.g., table-chair; Shimamura & Squire, 1984). Specifically, if preexisting semantic associations from the cue to the response word are already strong enough to compete reasonably well with other associations to the cue word, a single exposure during study might be sufficient for the target word to be retrieved at a greater than chance rate on a subsequent test.

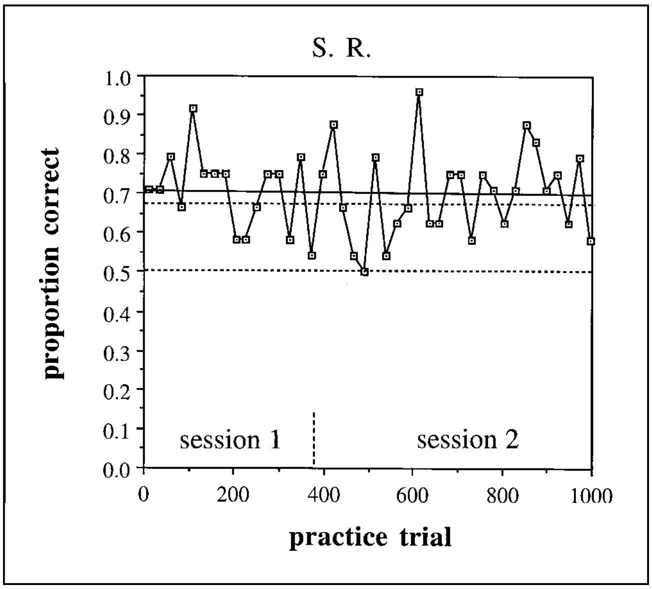

Figure 8. Accuracy averaged over consecutive 24-trial practice intervals for S.R. on phase 3 of the transverse patterning task.

Tasks such as paired associate learning, word pair fragment completion, free recall, and recollection-based recognition memory (Mandler, 1980) can all be heuristically termed *open memory search* tasks. By this term, we refer to any task for which a cue or a set of cues must be used to search long-term memory for some specific additional piece of information that constitutes the response. Generally speaking, the configural theory predicts that amnesic patients will exhibit profound impairment on open memory search tasks even when those tasks are in principle solvable by elemental learning systems, because they will not be able to overcome interference from strong preexisting associations.

In contrast, a second class of elemental tasks, which we will term *closed memory access* tasks, involves little or no search of memory for information (elements) that are not already represented by the stimulus item itself. Because no open memory search is required, interference due to preexisting associations is substantially reduced and the elemental system may generally be more able to support reasonable task performance. Priming tasks are obvious examples of closed memory access tasks (e.g., Hamann, Squire, & Schacter, 1995; Hamann and Squire, 1997). If, for example, a word is presented with instructions to identify it as quickly as possible, no memory search for information beyond the verbal label for the stimulus itself is necessary. Amnesic patients appear to exhibit largely preserved priming on a variety of tasks (but see Ostergaard & Jernigan, 1996, for an alternative perspective). The configural theory, as well as many other theories, can account for these priming effects as reflecting an increase in baseline activation of an element due to study (equivalently for current purposes, priming could be interpreted as strengthening of a self-association for the element).

Another interesting recent example of a closed memory access task is the word pair identification experiment of Gabrieli et al. (1997). In their design, word pairs were presented briefly for study, and at test these same word pairs were presented again for identification, along with recombined word pairs from the same study words and new word pairs formed from words not seen during study. The identification task at test was to read the word pairs, which were presented very briefly at the threshold of detectability. No specific information beyond that which directly corresponds to the stimuli themselves needs to be retrieved from long-term memory to perform the task. Gabrieli et al. found that normals and amnesics were statistically equivalent in their ability to identify old pairs more frequently than either recombined or new pairs. One tentative account of this finding, which is consistent with the configural theory, is that the study phase incremented the associative strength between elements corresponding to the presented word pairs. At test, this strengthened association allowed the words of old word pairs to mutually enhance their activation levels, thus effectively lowering the detection threshold for old pairs and allowing them to be detected slightly more frequently than recombined or new word pairs.

Finally, consider the evidence of priming for novel information in amnesia (e.g., Haist, Musen, & Squire, 1991; see Squire 1992 for a review). Haist et al. found that amnesics and normals exhibit statistically equivalent priming for visually presented words and nonwords, although the magnitude of the priming in both groups was greater for words. An important implicit claim of the configural theory is that the term *novel* is meaningful only relative to a particular level of representation. A pronounceable nonword is by definition novel at the level of words. However, it is not novel at the level of letters, letter combinations, and phonemes. According to the theory, both normal and amnesic learning will operate on *preexisting* elements in memory, which in the case of nonwords are the visual letters, letter combinations, and corresponding phonemes. The theory predicts that priming, and possibly strengthening of associations among these elements, will occur as a result of study. Priming is thus possible even for novel information such as nonwords. Further, it is reasonable to expect the magnitude of priming to be greater for words than for nonwords (also observed by Haist et al.), because unique elements of multiple types (i.e., visual word codes, verbal word codes, semantic representations) are accessible for each word.

Relations to Other Theories of Amnesia

It may be possible to synthesize simple computational approaches (such as the configural theory) with aspects of alternative approaches such as the implicit (procedural) versus explicit (declarative) memory framework. However, it is important to begin by emphasizing that these alternative approaches are unable make unambiguous predictions for the experiment reported in this paper for two reasons. First, the methodology of the experiment does not involve any experimental manipulation of the degree to which the subjects access explicit memory for previous trials. Instructional manipulation is the hallmark of tests of implicit versus explicit memory (Schacter et al., 1989). Second, these theories cannot make predictions regarding amnesic performance based on computational properties of the task because they (1) do not specify the elements on which new learning operates and (2) do not specify the computational properties of the two learning mechanisms in sufficient detail. Consider two extreme hypothetical outcomes of the experiment, neither of which violates the basic tenants of the explicit-implicit memory framework. First, amnesics might, with difficulty, learn all three phases of both the control and the TP task. The interpretation would then presumably be that the procedural (or implicit) system has the computational capacity to eventually learn both tasks, albeit in a brittle way that is not declaratively accessible. Indeed, Cohen and Eigenbaum (1992) suggested that a back-propagation-type algorithm, which can learn all phases of the TP task, may underlie procedural learning (their focus, however, was on the slow and incremental nature of learning in that algorithm rather than on its nonlinear learning capacity per se). At the other extreme, the amnesics may not learn phase 3, or even phase 2, of *either* task, even after many practice trials. In this case, these theories might be able to ac-

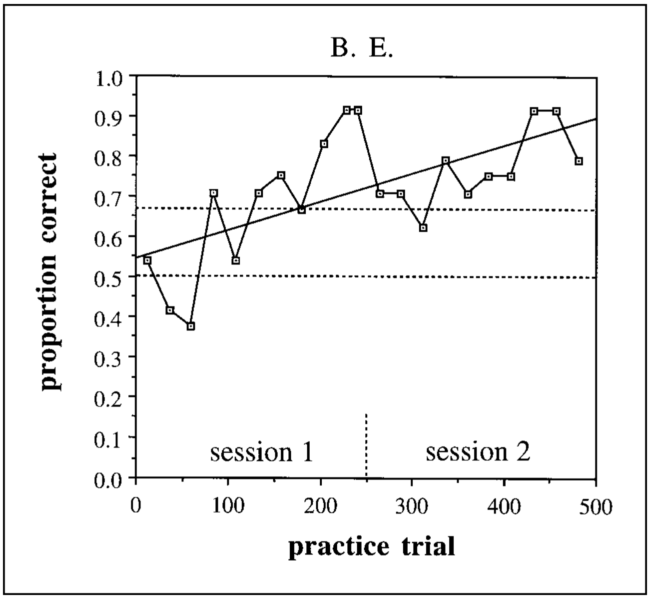

Figure 9. Accuracy averaged over consecutive 24-trial practice intervals for B.E. on phase 3 of the transverse patterning task.

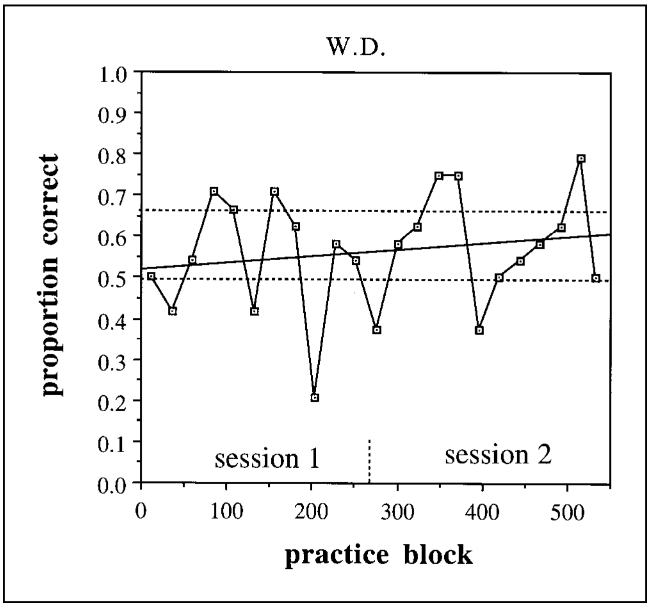

Figure 10. Accuracy averaged over consecutive 24-trial practice intervals for W.D. on phase 3 of the transverse patterning task.

count for the results in terms of the incapacity of the procedural system to learn these inherently declarative tasks. Importantly, however, the interpretations provided by the explicit-implicit memory approach would be post hoc in both of these outcome scenarios.

From the perspective of configural theory, the implicit versus explicit memory distinction and the configural versus elemental learning distinction represent two independent dichotomies. All four cells produced by crossing these two dichotomies should be observable. For example, there is nothing about the configural theory that would preclude a newly formed configuration from exerting an implicit influence on retrieval for normal subjects. In fact, this prediction receives support from recent SRT experiments (e.g., Curren, 1997) in which normals exhibited second-order conditional learning. Also, elemental learning can influence performance on operationally explicit tasks, as in the elemental control task of the experiment described in this study. Our perspective suggests that the implicit versus explicit status of retrieval has little to do in a mechanistic sense with the amnesic syndrome. Learning can be either elemental or configural. Memory retrieval can occur in either an implicit or an explicit mode. Amnesics have selective difficulty with configural learning. They have no impairment per se for either implicit or explicit modes of memory performance.

Nevertheless, there very likely is a positive relation in normals between operationally explicit tasks and access to new configurations on one hand and between operationally implicit tasks and access to elemental information on the other. In particular, it is plausible that for some tasks retrieval of a recently acquired configuration, which is not yet consolidated, is effortful and time consuming. This possibility seems reasonable if a particular configuration has been encountered only once (contrast this with the SRT task mentioned above). If this speculation is correct, under implicit instructional conditions, normals may not make the effort to retrieve new configural information from a study phase of (for example) a priming experiment simply because such retrieval would require more effort and would not obviously be relevant to the task at hand. As such, normals may by default be relying exclusively on the neocortical elemental system to perform many implicit memory tasks.

There are also interesting relations between the configural theory and recent computational theories. For example, the McClelland et al. (1995) model of retrograde amnesia suggests that neocortical learning is slow and incremental but nevertheless nonlinear (perhaps supported by an algorithm similar to back-propagation). This general approach would predict that given enough practice, true configural learning of any type is ultimately possible even without an intact medial temporal region. In contrast, our approach takes the extreme stance that densely amnesic subjects will never learn nonlinear (or configural) tasks. These are fundamentally different assumptions about properties of learning in the neocortex that can in principle be evaluated by selecting profoundly amnesic patients and giving them massive practice on a configural task such as phase 3 of the TP task. The configural approach would be entirely consistent with a finding that accuracy reaches an asymptote no higher than 0.67 (provided that residual working memory influences and partially preserved medial temporal function can be reasonably ruled out). In contrast, an incremental nonlinear learning model of the neocortex would appear to predict a gradual improvement in accuracy that would eventually reach 1.0.

The configural theory developed in the animal literature (Rudy, 1994; Sutherland & Rudy, 1989) was a direct inspiration for the human configural theory presented here. However, recent evidence suggests that hippocampal lesioned rats can in fact learn some subtypes of configural tasks, including feature neutral and biconditional discrimination problems (for a discussion see Rudy & Sutherland, 1995). However, the TP task used in the current experiment is not a member of this subset. There are at least two ways in which the human and animal findings may be reconciled. First, it is possible that our patients and other human amnesics with presumed hippocampal damage would also show preserved learning on other configural tasks such as biconditional discrimination. Testing of human amnesic patients on these tasks constitutes an important direction for future research. An alternative approach to reconciling the human configural theory with the recent results in the animal literature is to note that the animal work usually focuses on the hippocampus per se, whereas our version of the theory associates configural learning more generally with medial temporal function. It may be that, for both rats and humans, the medial temporal region is more generally responsible for configural learning but that the hippocampus proper is involved only in some aspects of it (see Rudy & Sutherland, 1995). Most human cases of amnesia involve damage that is not limited to the hippocampus but may also include other adjacent structures such as the parahippocampal and entorhinal cortices (Zola, 1996). Thus, the typical amnesic human subject would not be expected to exhibit the more exotic deficits exhibited in some animal experiments, but rather simply a global deficit in configural learning.

CONCLUSIONS

Our goal in this paper has been to describe and evaluate a viable extension of the Sutherland and Rudy (1989) configural learning theory that is applicable to human amnesia. The model is consistent with most of the data in both the human and animal literatures, including the results of the experiment presented in this paper. Such a relatively simple account will probably not prove to be correct in all respects. However, our overriding goal has been to set forth a testable theory that suggests a number of interesting new avenues for follow-up research. Considered broadly, the theory predicts that (1) amnesic patients should generally exhibit preserved (albeit not necessarily normal) memory on tasks that can be solved by simple reinforcement-based elemental models, (2) they should also exhibit some preserved memory on the more general class of tasks that are solvable by cross-associative elemental models, provided that the task minimizes interference from pre-existing associations, (3) they should never completely learn genuinely configural, or nonlinear, problems, and (4) the preceding three predictions should hold for both perceptual and conceptual tasks. At present, all of these predictions appear to be viable. It seems likely that the understanding of human learning and amnesia will be advanced considerably by testing them further.

METHODS

Subjects

The amnesic patients in this experiment regularly participate in studies in our laboratory. A set of control subjects was matched to the patients on age and years of education. Table 1 presents basic information about patients and controls and the results of neuropsychological tests. All of our patients contracted their amnesia after an episode of severe brain oxygen deprivation. Oxygen deprivation due to ischemia is known to cause damage to the CA1 field of the hippocampus along with pronounced memory impairment in humans (Zola-Morgan, Squire, & Amaral, 1986), monkeys (Zola-Morgan & Squire, 1990), and rats (Auer, Jensen, & Whishaw, 1989; Davis & Volpe, 1990).

Patient J.P. exhibited a post-ischemic amnesia syndrome in 1991 after suffering several small strokes during heart bypass grafting surgery. Patient B.E. suffered a massive insulin overdose in 1990 and was subsequently in a coma for 5 days. Afterward, she was diagnosed with severe hypoglycemic encephalopathy. Initially she exhibited generalized cognitive impairment, but much of the impairment of higher cognitive function resolved over the ensuing 2 years, leaving her with a fairly selective memory impairment. Patient S.R. suffered hypoxic encephalopathy after carbon monoxide poisoning in 1990. Patient W.D. suffered post-anoxic encephalopathy in 1989 that was associated with sustained high body temperature and malignant hyperthermia. All the patients' amnesic syndromes have remained stable over a period of at least 2 years in which they have been tested in our laboratory.

The full-scale IQs for the patients were in some cases lower than their matched controls. However, two of the patients had IQs as high or higher than two of two controls. This fact indicates that IQ is not a critical factor. Supporting evidence for this inference is provided by results in our laboratory for two patients with focal frontal lobe lesions whom we have recently tested on these tasks. Both of these patients learned both the control and the TP task easily, within the range of trials required for our matched controls. Their WAIS-R full scale IQs were 100 and 101.

Materials and Procedures

The stimuli for the TP and control tasks are shown in Figures 1 and 2, respectively. Each stimulus item had vertical and horizontal dimensions of approximately 1½ by 1½ in. and in each pair the stimuli were presented side by side, about 1 in. apart, centered on a computer monitor. The stimuli were not counterbalanced across subjects. Rather, we employed a design in which the stimuli for each pair were, if anything, easier to map onto a preexisting element for the TP task than for the control task (from the perspective of the configural theory). The stimuli used for the TP task clearly map onto "black," "white," and "striped." The stimuli for the

Table 1. Etiology and Neuropsychological Testing Results for Patients and Controls

				WAIS-R		*WMS-R*				
Patient	*Condition*	*Age*	*Education*	*FSIQ*	*VIQ*	*Verbal*	*Visual*	*General*	*Attention*	*Delayed*
J. P.	Ischemia	65	16	87	95	65	51	<50	96	<50
B. E.	Hypoglycemic	34	20	105	105	99	99	99	94	69
S. R.	Anoxic enceph.	39	16	115	110	72	78	70	110	50
W. D.	Anoxic enceph.	41	16	91	87	77	70	69	105	<50
J. P. control		65	16	124	122	98	111	104	123	129
B. E. control		34	20	106	116	123	109	125	105	116
S. R. control		39	16	133	125	113	121	120	127	122
W. D. control		40	16	102	110	96	114	99	105	80

Notes: WAIS-R = Weschler Adult Intelligence Scale—Revised. WMS-R = Weschler Memory Scale—Revised. FSIQ = full scale intelligence quotient. VIQ = verbal intelligence quotient. Anoxic enceph. = anoxic encephalitis.

control task are not as easy to map onto existing labels. If anything, this factor would be expected to make the control task more difficult than the TP task.

Prior to the first phase of each task, the following instructions were presented on the computer screen and the experimenter read them aloud as the subject read along: "The object of the game is to remember which of two pictures contains a 5-cent piece. When you choose the correct picture, a bell will sound and a 5-cent piece will appear. It will look and sound like this." At this point the bell sounded and a small picture of a 5-cent piece appeared on the screen, replacing the instructions. Next this screen was erased and a pair of example items appeared on the screen. The subject was instructed to move an arrow icon using the mouse to one of the pictures and click once as practice performing the task.

After the above preparation, the experimenter read aloud the following supplemental instructions at the beginning of the appropriate phase for both the elemental control and the TP tasks:

Phase 1: "You will have to guess at first, but this is a learning experiment so you will see the same item pairs repeatedly. Your job is try to remember the correct answer to each pair based on the earlier exposures to that pair. The answer will always be the same for each pair of pictures."

Phase 2: "In this phase you will see the same items as you saw in phase 1. The answers for these items are the same as they were in phase 1. You will also see two new pairs of items on some trials. You will have to guess at first on these new items. You will see each item pair repeatedly and your job is to learn the correct answer for each pair. The answer will always be the same for each pair of pictures."

Phase 3: "In this phase you will see the same items as you saw in phase 2. The answers for these items are the same as they were in phases 1 and 2. You will also see two new pairs of items on some trials. You will have to guess at first on these new items. You will see each item pair repeatedly and your job is to learn the correct answer for each pair. The answer will always be the same for each pair of pictures." Note that all of the instructions above were identical for the elemental control and the TP tasks. Phases 1, 2, and 3 of the elemental control task were always given first, followed by phases 1, 2, and 3 of the TP task.

Pairs of stimuli were presented one at a time, and previously presented items were erased from the screen prior to the beginning of each new trial. As each pair of items was presented on the screen, the subject used the mouse to place the arrow icon over one member of each pair and then clicked the mouse once to select that item. If the response was correct, the computer then gave the feedback described above. No explicit feedback was given before proceeding to the next trial if the response was incorrect. The intertrial interval was 1.5 seconds. During each phase of each task, all stimuli were always cycled through once and exhaustively in a pseudorandom pattern before moving on to repeated presentations of the stimuli. In phase 3 randomization was subject to the constraints that a given stimuli and its reverse did not occur sequentially and that stimuli presented at the end of one cycle and at the beginning of the next cycle were not the same. These constraints were included to minimize influences of short-term memory on performance. The program terminated when 14 of 15 consecutive trials were correct, and it then presented the notice, "Congratulations, you have solved the problem." If the subject did not reach criterion after 90 trials, the program terminated, and the message "Congratulations, you have solved the problem," was still displayed to reinforce the subject. The program was presented repeatedly until the problem was solved or the session was terminated due to time constraints. After the first criterion was reached for phase 3 of both the elemental control and the TP task, there was a delay of 1 min, during which time the experimenter held a conversation with the subject on a random topic not related to the task. Phase 3 of the same task was then given again, until 14 of 15 items were responded to correctly. This second criterion test was performed both to verify that phase 3 of each task was learned and to test for the effects of brief delay on task performance. Phase 3 was continued until the subject reached both the first and second criteria (14 of 15 correct) twice consecutively (with a 1-min delay in between). Amnesic subjects were tested on all tasks in each of two sessions, which were separated by at least 48 hours. The control subjects were tested on all tasks once in a single session.

Acknowledgments

We are grateful to Jerry Rudy for helpful discussion of the configural theory and for access to his computer programs.

Reprint requests should be sent to Timothy C. Rickard, Department of Psychology, University of California, San Diego, 9500 Gilman Drive, La Jolla, CA 92093-0901, or to Jordan Grafman, Cognitive Neuroscience Section, National Institute of Neurological Disorders and Stroke, National Institutes of Health, Building 10, Room 5S209, 10 Center Drive MSC 1440, Bethesda, MD 20892–1440.

Notes

1. Control subject J. P. did have some difficulty with phase 3 of the TP task, requiring 65 trials to reach the first criterion (he reached the replication criterion immediately as did other subjects). Informal questioning suggested that this subject was testing complex and incorrect sequential dependency hypotheses in that phase even though the instructions indicated that this strategy was inappropriate (i.e., he was hypothesizing that the answer on a given trial depended in some fashion on the answer to the preceding trial). This strategy may account for his delayed trials to criterion on that phase.
2. The first criterion was reached on trials 228, 404, and 454 for patient B. E and on trials 96 and 864 for patient S.R.

3. A fifth amnesic patient was also tested. Her trials to criterion on phases 1, 2, and 3 of the control task were 17, 19, and 17, respectively. On the TP task these values were 17, 15, and 134. However, due to a procedural oversight in the training of the technician, the second delayed criterion run was not performed for this subject. Thus, it is unclear whether or not she acquired a stable solution for phase 3 of the TP problem. However, considering that two of the other patients reached the first criterion on one or more occasions, her data appear to be generally consistent with the results for the other four patients.

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