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Amnesic H.M. exhibits parallel deficits and sparing in language and memory: Systems versus binding theory accounts

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This study examines sentence-level language abilities of amnesic H.M. to test competing theoretical conceptions of relations between language and memory. We present 11 new sources of experimental evidence indicating deficits in H.M's comprehension and production of non-cliché sentences. Contrary to recent claims that H.M.'s comprehension is unimpaired at grammatical levels, H.M. performed 2–6 standard deviations worse than controls matched for age, IQ and education in seven tasks: detecting grammatical errors, repairing sentences identified as containing an error, answering questions about who did what to whom in sentences, multiple-choice recognition of possible versus impossible interpretations of sentences containing ambiguities and figurative speech, discrimination between grammatical versus ungrammatical sentences, and describing the meanings of ambiguous sentences, phrases, and words. However, H.M.'s deficits were selective, e.g., sparing comprehension of familiar

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but not unfamiliar phrases. Parallels between H.M.'s selective deficits in language, memory and other aspects of cognition, e.g., reading and visual cognition are discussed. These parallels were predicted under binding theory but did not have a parsimonious explanation in systems theories that postulate non-overlapping units and processes for language versus memory.

Since his 1953 operation at age 27 (Scoville & Milner, 1957), H.M. has become one of the most studied patients in the history of neuropsychology (Ogden & Corkin, 1991). This "frankly experimental operation" largely overcame H.M.'s debilitating and otherwise untreatable epileptic condition, but had several tragic side effects. One was a selective memory deficit that greatly impaired recall of new or never-previously-encountered information, but spared memory for information that H.M. encountered frequently before his operation (see James & MacKay, 2001). Because Scoville's operation has never been repeated, H.M.'s lesion is unique, but H.M.'s condition has had profound effects on theories of memory and human cognition more generally.

Researchers initially thought that H.M.'s medial temporal lobe (MTL) lesion caused a pure memory deficit that completely spared all other cognitive processes, including the comprehension and production of sentences (see Milner, Corkin, & Teuber, 1968). This conclusion went unchallenged until 1998, and secondary sources continue to suggest that H.M. "understands complex verbal material, including jokes" (Kolb & Whishaw, 2003, p. 447) and can carry on sophisticated conversations (Carlson, 2004), with no mention of language deficits. A partial exception is Corkin (2002) who suggested that H.M. exhibits "mild" or "subtle" language deficits, with no mention of statistical or theoretical significance.

The nature, extent, and theoretical significance of H.M.'s language deficits are controversial at present. Extensive evidence gathered from 1967–1999 indicates that H.M. exhibits selective deficits in comprehending, producing, and reading aloud non-cliché sentences (Lackner, 1974; MacKay, Burke, & Stewart, 1998a; MacKay & James, 2001; MacKay, Stewart, & Burke, 1998), and in comprehending and reading aloud low frequency (LF) words (James & MacKay, 2001; MacKay & James, 2002). However, Kensinger, Ullman, and Corkin (2001) criticised some of this evidence and argued that H.M.'s language comprehension and production is unimpaired at grammatical and lexical levels. As discussed next, this ongoing controversy over H.M.'s language abilities is extremely important for two competing frameworks in widespread use within both the cognitive sciences and neurosciences: memory systems versus distributed-memory theories.

MEMORY SYSTEMS THEORY AND RELATIONS BETWEEN LANGUAGE AND MEMORY

The basic assumption of memory systems theory, or systems theory for short, is that memory is not a unitary capacity but can be divided into anatomically and functionally independent systems (Barnard & Dalgleish, 2005; Squire, 1987). For example, systems theory postulates anatomically and functionally independent units and processes for episodic memory (conscious recall of time and place for personally experienced events), implicit memory (effects of prior experience on retrieval without conscious reference to stored information), and semantic memory (recall of frequently repeated factual information).

Systems theory likewise divides language into systems with functionally and anatomically distinct units, prime examples being language comprehension versus language production. Under systems theory, language comprehension and production involve separate systems that function independently from memory systems. At the same time, however, language and memory are not *entirely* unrelated because systems theories often postulate a fixed and fundamentally unidirectional processing relation between language comprehension, memory storage, memory retrieval, and language production: Verbal inputs are first comprehended in the comprehension system, which transmits the products of comprehension to one of the memory systems for long-term storage. Retrieval mechanisms then recover the stored memory for transmission to the language production system, which enables verbal expression of the recovered memory (Gordon, 1989; for general reviews, see MacKay et al., 1998a; MacKay & James, 2002). Feedback loops between language and memory systems are possible (e.g., the phono-logical loop) but do not alter this fundamental processing sequence in systems theories.

Data from H.M. have provided a major source of support for systems theory assumptions (see MacKay et al., 1998a): If, as initially assumed, H.M. exhibits unimpaired comprehension and production together with a pure memory-encoding deficit for identical verbal materials, then H.M.'s performance strongly supports systems theories by dissociating the storage system (damaged) from the separate systems for retrieval (undamaged), comprehension (undamaged), and production (undamaged).

Spared versus impaired aspects of H.M.'s performance have also been cited as support over the past 20 years for other memory systems, and other, somewhat controversial language systems, e.g., a mental lexicon and a mental grammar. The present study examines the least controversial and most fundamental language systems in systems theory: comprehension and production. However, because several newly postulated memory systems are central to systems theory, we review these systems in relation to H.M. and the MTL next.

According to LeDoux (1996; see also Cohen & Eichenbaum, 1993), most neuroscientists agree on how the "MTL memory system" works both in general and in the case of H.M. In general, sensory systems in the neocortex process external stimulus events and create perceptual representations independently of the hippocampus and other MTL structures. Sensory areas then transfer these perceptual representations to palaeocortical regions, which process these representations further and transfer them to the hippocampus. The hippocampus then stores these perceptual representations over the short term (a few years) and/or actively maintains them via interactions with the neocortex, mediated via links to the surrounding palaeocortex. Maintaining a memory over the short term therefore requires an intact MTL system, but gradually, over many years or decades, the hippocampus "relinquishes its control over the memory to the neocortex, where the memory appears to remain as long as it is a memory, which may be a lifetime" (LeDoux, 1996, p. 193).

Turning to H.M., the general consensus is that his 1953 MTL surgery impaired a memory system specialising in explicit, declarative, or consciously retrieved memories, but spared many other memory systems, including an eyeblink conditioning system in the brain stem, an implicit memory system, and procedural memory systems for a variety of skills such as mirror tracing, language production, and practice- or procedure-linked thinking. To summarise this list of intact memories, H.M.'s lesion was thought to spare implicit or procedural systems outside the MTL that enable unconscious retrieval from memory.

Problems with systems theory

Despite this general consensus and the popularity of systems theory assumptions in the literature (Hayman, MacDonald, & Tulving, 1993; MacKay et al., 1998a; Schachter, Chio, & Ochnser, 1993; Shimamura & Squire, 1987, 1988; Tulving, Hayman, & MacDonald, 1991), systems theory currently suffers several problems, discussed next.

Other variables. A major problem for systems theory is that "other variables" can readily explain the unique aspects of different types of memory without assuming functionally and anatomically independent systems. One such other variable is the processing history of the components representing different memories (e.g., frequency of activation over a lifetime; see MacKay & James, 2002). Another is the structure of the connections that components representing different memories participate in (MacKay, 1987, pp. 14–38).

Boundary disputes. Ongoing controversies concerning the dividing lines between currently proposed systems illustrate another problem for systems theory. For example, no generally accepted dividing line has been established for where language ends and where memory for verbal materials begins, and some have argued that no dividing line is possible in principle (MacKay & Abrams, 1996). For example, consider the "tip-ofthe-tongue" (TOT) phenomenon, the temporary inability to recall the name of a familiar object, concept, or acquaintance (Burke, MacKay, Worthley, & Wade, 1991). Memory researchers are in agreement that TOTs reflect a *memory* problem, elicited when participants attempt to retrieve the name corresponding to a definition or a picture of an object or action (Au, Joung, Nicholas, Obler, Kass, & Albert, 1995). In fact, however, TOTs normally occur, and were initially discovered and described in the 1890s, as a problem in everyday *language production*. However, systems theory provides no way of resolving whether TOTs originate in a memory system or in the language production system.

Similar boundary disputes afflict distinctions between cognitive versus motor or procedural memory systems (Keele, Ivry, Mayr, Hazeltine, & Heuer, 2003), comprehension versus production systems (MacKay, 1987), and semantic versus lexical versus propositional memory systems, with some researchers restricting the term semantic memory to universal factual knowledge, and others defining semantic memory more broadly, e.g., to include proper names such as *Judy Garland* (Skoto et al., 2004; Tulving et al., 1991).

Such boundary disputes carry fundamental implications and cannot be solved by fiat. Consider the controversial dividing line between comprehension versus production systems. Theories with entirely separate components for comprehension versus production are fundamentally different from theories where some comprehension-production components are shared (MacKay, 1987), and separate system theories must be wrong if comprehension and production do not depend on entirely separate components and processes, as Lashley (1951) suggested and a great deal of data since then indicate. Equally seriously, postulating separate comprehension versus production systems fails to explain the many detailed similarities and differences between comprehension versus production (MacKay, 1987, pp. 111–125). However, problems with how systems are currently defined do not imply that there are no principles for defining systems. As we illustrate in the General Discussion, excellent theoretical and empirical criteria have been developed for postulating separate language systems for phonological versus semantic units.

Falsifiability. Questions regarding falsifiability pose other problems for systems theory (MacKay & James, 2002). Because there exist no generally accepted criteria for what constitutes a functional system let alone a functional-anatomical system, new functional systems are readily postulated post hoc to explain away data that contradict systems theory. Skoto et al. (2004) provide a recent example. Their data indicated that H.M. was able to learn and retain new semantic information, a fact embarrassing to the general consensus that H.M.'s MTL lesion damaged his semantic memory system. To save this situation, Skoto et al. simply postulated a "supplementary system" for "limited neocortical semantic learning" that stored semantic memories independently from H.M.'s damaged MTL. However, this newly postulated neocortical system created problems for the consensus assumption that H.M.'s "profound amnesia resulted entirely from (his) MTL lesion and not from cortical damage (p. 766)". Skoto et al. (2004) therefore suggested that H.M.'s "residual semantic learning" is probably localised in *undamaged* portions of H.M.'s ventral perirhinal cortex, a post hoc assumption that again preserved the systems theory consensus.

This system reassignment strategy has enjoyed widespread application. Consider, for example, H.M.'s language comprehension deficits demonstrated in MacKay, Stewart, and Burke (1998b), an embarrassment to the consensus assumption that H.M.'s lesion has disrupted only storage systems. However, Schmolck, Stefanacci, and Squire (2000) simply reassigned H.M.'s language comprehension deficits to *damaged* portions of his ventral perirhinal cortex and other non-MTL structures, thereby saving consensus assumptions concerning H.M., memory, and the MTL.

Another strategy for preserving systems theory consensus is to ignore established deficits. Consider for example H.M.'s deficits in visual cognition. Milner et al. (1968) and MacKay and James (2000) demonstrated deficits in H.M.'s detection of "hidden figures" that secondary sources have simply ignored, thereby preserving the assumption that systems for perception and visual cognition accurately represent stimulus events independently of H.M.'s MTL damage. Such strategies raise the question of whether systems theories are testable in principle and whether data of any kind can falsify the general systems theory consensus.

Functional–neuroanatomical correspondence. Another problem for systems theory concerns the assumed correspondence between functional and neuroanatomical systems: determining for particular patients what specific neurological systems and functions are damaged is extremely difficult. To illustrate the scope of these difficulties, consider amnesic E.P., who in 1995–98 reports (Hamann, Cahill, & Squire, 1997; Reed, Hamann, Stefanacci, & Squire, 1997) exhibited "foci of damage" in right medial and dorsal frontal cortices, together with behavioural evidence indicating frontal lobe dysfunction. Squire and Knowlton (1995) also reported major deficits in E.P.'s performance on frontal tests such as the Wisconsin Card Sort, and Hamann et al. (1997) and Buffalo, Reber, and Squire (1998), provided further evidence for E.P.'s "frontal dysfunction". However, contrary to these earlier claims, Squire, Schmolck, and Stefanacci (2001, p. 274) reported that "E.P.'s lesion . . . does not involve frontal cortex" (see also Stefanacci, Buffalo, Schmolck, & Squire, 2000). Neither shades of grey nor recovery of function are at play here: These contradictory reports from the same laboratory of damage (pre-2000) versus no damage (post-2000) to the same system in the same patient indicate that determining functional and neurological damage is extremely difficult.

Theoretical problems. The main unsolved problem for systems theory is a theoretical rather than descriptive or technical question: By what theoretical means does neurally encoded information (memories) transfer from one anatomically and functionally independent system to another, say, from a comprehension system located in the neocortex to a memory system located in the hippocampus? No one has proposed theoretical mechanisms (let alone provided empirical evidence) for the central assumption of systems theory: that synaptic transmission between neurons can function like an email system. However, the distributed-memory theories discussed next do not make this theoretically problematic assumption of email-like transfer either within the brain or between functional systems.

DISTRIBUTED-MEMORY THEORIES, BINDING THEORY, AND RELATIONS BETWEEN LANGUAGE AND MEMORY

A variety of distributed-memories theories have been proposed (Carpenter & Grossberg, 1993; Dell, 1986; Gluck & Myers, 2001; Grafman & Weingartner, 1996; Hasselmo & Wyble, 1997; Levy, 1989; MacKay, 1990; MacKay et al., 1998a; McClelland, 1985; McClelland, McNaughton, & O'Reilly, 1995; Metcalfe, Cottrell, & Mencl, 1992; O'Reilly & McClel-land, 1994; Rolls, 1989; Saffran, 1990; Wickelgren, 1979), and several have been applied to verbal memory phenomena in general and to H.M.'s memory deficits in particular. Several other distributed-memory theories have been applied to either language comprehension or language production. However, only one distributed-memory theory has been applied to detailed aspects of both memory and language in H.M., including both language comprehension and language production: node structure binding theory or binding theory for short (first outlined in MacKay, 1990).

The present study therefore used binding theory to perform the "primary function of a theory": to guide research, enable detailed predictions, and generate "new ideas and new discoveries" (Higgins, 2004, p. 138). Binding theory also served to explain why the experimental data reported in Kensinger et al. (2001) do not support their conclusion that H.M.'s lexical and grammatical processing are unimpaired (see Experiments 1–2). Also useful for the present research were the prior applications of binding theory to memory-normal, neurologically unimpaired older adults (age 65–85), the relevant comparison group for H.M. (age 79 in 2005). Finally, binding theory provided a parsimonious account of the present results, although other distributed-memory theories that address H.M.'s language comprehension and production in future applications may provide post hoc accounts for future test.

Like most other distributed-memory theories, binding theory requires normal cortical *and* MTL processing to accurately encode episodic memories. However, binding theory is unique in assuming that subcortical binding processes underpin normal comprehension, production, and memory for never-previously-encountered, novel, or non-cliché language units. Mirroring the main focus of Experiments 1–6, we will first describe binding theory for comprehension and memory, and then production and memory (one aspect of Experiments 1 and 6).

Under binding theory, comprehension and memory for non-cliché verbal inputs engage the same processes and can involve some of the same cortical units or content nodes. Moreover, the strength of connections between large numbers of content nodes distributed throughout a vast interactive activation network determines the success of both comprehension and memory in binding theory. For example, memory storage involving verbal materials occurs when connections between content nodes become strengthened, a process that occurs many times a day during normal language comprehension. The strength of connections between content nodes in turn determines success in retrieving verbal memories via activation processes that are identical to those underlying normal language comprehension and production (MacKay et al., 1998a).

However, processes for activating content nodes with old or already established connections differ fundamentally from binding processes for forming content nodes to represent non-cliché or never-previously-encountered information in binding theory (MacKay & Burke, 1990). Node activation suffices for many aspects of language use, e.g., comprehension of familiar words and phrases represented via content nodes with connections established during childhood and strengthened throughout a lifetime of use. However, sentences often communicate new or never-previously-encountered ideas, and representing genuinely new ideas in comprehension and memory requires the formation of new connections between content nodes located in the cortex. A supplementary input from subcortical binding nodes to the cortex normally helps to create these new cortical connections, and as a consequence, subcortical lesions such as H.M.'s can impair both comprehension and memory under binding theory.

To illustrate the structure of cortical content nodes for comprehending and retrieving familiar language units, Figure 1 represents selected bottom-up connections that enable readers familiar with the concept *working memory* to comprehend that noun phrase. Not shown in Figure 1 are the binding nodes for efficiently forming *new* connections. These binding nodes only play a role in comprehending *working memory* when someone familiar with the words *working* and *memory* encounters the conjunction *working memory* for the first time: A noun phrase binding node quickly helps form new bottom-up links from the existing lexical content nodes for *working* and *memory* to a never previously activated chunk node representing their conjunction. Other binding nodes can then quickly link this new chunk node to propositions essential for more general comprehension of the concept *working memory* (see Figure 1 for a small subset of such proposition nodes).

In summary overview, binding nodes facilitate the formation of conjunctive connections between cortical units for representing conceptual relations, an assumption that characterises several recent conjunctive and relational learning theories of hippocampal function (McClelland, 1985;

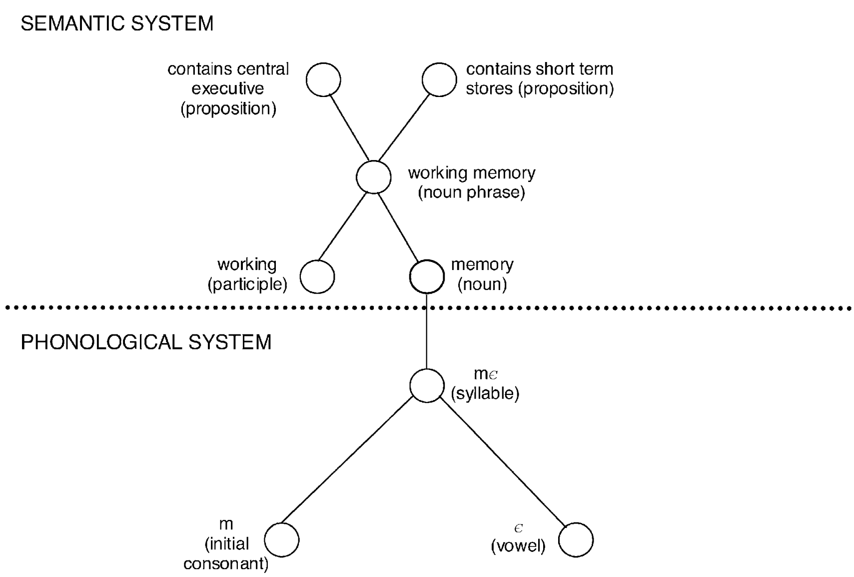

Figure 1. Selected bottom-up connections between content nodes for comprehending the noun phrase *working memory* in binding theory. Memory storage is distributed across connections between large numbers of content nodes, and occurs following engrainment (node activation) and binding processes. Binding nodes for forming new connections between content nodes are not shown.

McClelland et al., 1995; O'Reilly & Rudy, 2001). However, unlike other recent theories, binding theory provides detailed descriptions of the binding nodes that conjoin content nodes during language comprehension and production, as discussed next.

Binding nodes are subcortical activating mechanisms that specialise in conjoining different classes of cortical content nodes. For example, when a normal child initially learns to produce the phonological syllable /mЄ/ in words such as *memory* and *metal*, a specific type of phonological binding node is engaged for conjoining the phonological classes onset and vowel, so as to conjoin the initial consonant (*m-*) and the vowel (*-Є*) to form the internal representation for that syllable (see Figure 1). Similarly, when initially learning or representing the participle *working*, a specific type of morphological binding node is engaged for conjoining the classes verb and verb suffix, so as to conjoing the verb (*work*) and the verb suffix (*-ing*) to form *working*. Likewise, when initially learning or representing the noun phrase *working memory* within the sentential-semantic system (or semantic system for short), a noun phrase binding node is engaged for linking the classes participle and noun, so as to conjoin the participle (*working*) with the noun (*memory*) to form that phrase. Current evidence suggests that H.M. has damage to phonological, morphological, and semantic binding nodes that makes it difficult to learn new phrases and new words, both simple and morphologically complex. For example, consider the noun phrase *flower child*, the morphologically complex adjective *biodegradable*, and the morphologically simple noun *frisbee*, all expressions that entered English after H.M.'s 1953 surgery. H.M. currently thinks that a *flower child* is "a young person who grows flowers," that *biodegradable* means "two grades", and that *frisbee* is not an English word (see Gabrieli, Cohen, & Corkin, 1988; also James & MacKay, 2001).

HOW NEW CONNECTIONS ARE FORMED IN BINDING THEORY

Binding theory postulates two distinct but closely interrelated processes whereby new connections or representations can be formed: *engrainment processes,* which do not involve input from binding nodes and are intact in H.M., and *binding processes*, which do involve input from binding nodes and are impaired in H.M.

Engrainment processes

Engrainment occurs whenever an established cortical content node becomes activated: its connections with other established cortical nodes become slightly stronger following each activation. This connection-specific engrainment effect accumulates over the course of a lifetime and contributes to a wide variety of phenomena, e.g., repetition priming (MacKay & Abrams, 1996), frequency effects at all levels of memory and language (MacKay, 1987, pp. 12–13), and the TOT phenomenon (Burke et al., 1991).

Engrainment processes also enable a primitive means of forming new connections between established cortical content nodes. When one or more sequentially related content nodes become activated repeatedly one after the other, engrainment processes serve to burn in new connections to an unused or uncommitted chunk node without help from subcortical binding nodes. This chunk node then serves to represent the conjunction of the original units, and links between any two stimuli or concepts can be formed via this engrainment process. To illustrate, consider how engrainment alone suffices to represent the simple fact that the sequence *working memory* represents a meaningful English phrase. Following initial encounter with the never previously conjoined words *working memory*, extensive (internal or overt) repetition of the familiar words *working* and *memory* in sequence will burn in weak or fragile connections to a new chunk node representing the noun phrase *working memory.* The reason is that comprehension and production engage the same lexical content nodes (see MacKay, 1987, pp. 14–62 for a review of supporting evidence), so that repeated production (activation) of the words *working* and *memory* causes engrainment processes that burn in bottom-up connections from *working* and *memory* to a chunk node representing the conjunction *working memory.* Forming and activating this chunk node is necessary but of course insufficient for full-blown comprehension of the phrase *working memory*: The "click" that accompanies genuine comprehension follows the formation and activation of at least one conceptual proposition associated with *working memory*, e.g., *working memory is a system,* or *working memory contains slave systems.* For engrainment processes alone to form a single component (say the verb phrase *contains slave systems*) and create its propositional link to the noun phrase *working memory* would require hundreds of repetitions, proceeding bottom-up component by component up to the proposition level, in the same manner as forming the noun phrase *working memory.* However, if and when such propositional representations have been formed, activation alone will suffice for subsequent comprehension of propositions such as *working memory is a system that contains slave systems.*

Engrainment processes explain how deliberate internal or overt rehearsal influences the rate and probability of overt recall of any unit at any level in any system (see MacKay, 1981; MacKay, 1987, p. 89; MacKay & Bowman, 1969). However, engrainment processes differ in several respects from rehearsal processes as usually conceived. Engrainment processes per se are unlearned, involuntary or non-strategic, and without fixed or inherent limits in either capacity or loop time, unlike rehearsal-related concepts such as the phonological loop. Also unlike rehearsal loops, engrainment can facilitate retrieval of any repeatedly activated unit at any hierarchic level of an internal representation developed for perception, comprehension, or any aspect of cognition involving internal representations (see MacKay, 1982; MacKay & Bowman, 1969).

Engrainment processes also explain effects of repetition in implicit memory tasks. However, engrainment differs in several respects from implicit memory processes as usually conceived. Unlike implicit learning, the repeated activation that causes strong engrainment in the standard repetition priming paradigm can be conscious and deliberate as well as unconscious and unintended, and can involve units at any level, including not just words, but phonological segments (see MacKay & James, 2002), propositions, and entire paragraphs (see MacKay et al., 1998a).

Engrainment processes also explain many aspects of H.M.'s behaviour. Because content nodes with old or already established cortical connections can undergo activation (but not prolonged activation, discussed shortly) without help from subcortical binding nodes, H.M. has learned to compensate for his non-functional subcortical binding nodes by forming new connections via engrainment, i.e., repeated activation of established content nodes. Under this *deliberate engrainment hypothesis,* H.M. can in principle encode the isolated noun phrase *working memory* as a familiar unit by repeating the words *working* and *memory* a large number of times (internally or overtly). Consistent with this deliberate engrainment hypothesis, H.M. achieved normal recognition memory performance for never-previously-encountered episodic information when the time available for H.M. to rehearse was multiplied by a factor of 20 relative to memory-normal controls in Freed, Corkin, and Cohen (1987). The deliberate engrainment hypothesis may also explain why H.M. is slower than controls in a wide range of tasks, a slowness that MacKay and James (2002) demonstrated is unrelated to cerebellar damage or muscle movement processes.

Intact engrainment processes also explain H.M.'s slow but otherwise unimpaired ability to learn a wide range of new information, e.g., frequently repeated aspects of experimental procedures (Milner et al., 1968), definitions for a small number of high frequency (HF) words that entered English after his operation (Gabrieli et al., 1988), aspects of frequently encountered post-operative episodes, e.g., a connection between the name Kennedy and death (Ogden & Corkin, 1991), and post-operative semantic information that was massively repeated in Skoto et al. (2004). (See Skoto et al. for a review of studies indicating that other amnesics exhibit the same slow learning of frequently repeated postoperative semantic facts).

Intact engrainment processes also explain three additional facts that play a central role in systems theory accounts of amnesia: that H.M. and other amnesics exhibit normal perceptual, stimulus-response, and motor learning (see e.g., Spiers, Maguire, & Burgess, 2001). We contrast engrainment versus systems theory accounts of these three types of repetition-based learning next.

Perceptual learning. The fragmented figure test provided the initial demonstration that H.M. exhibits intact perceptual learning: Participants in Milner (1970) saw drawings of familiar objects such as a chair, dog, or bird, in versions that were initially so fragmented as to be unrecognisable. Then progressively less fragmented versions were presented until the object could be accurately named. Memory-normal controls performed better than H.M. on this task, but H.M. nevertheless exhibited perceptual learning because his performance slowly improved with repeated tests using the same stimuli.

Intact perceptual learning has since been demonstrated for other amnesics and other modalities in tasks that now fall under the label *repetition priming*. To illustrate the need for this more general label, when H.M. and memory-normal controls process a familiar word *perceptually*, this facilitates subsequent *production* of the word in a stem completion task, extending the phenomenon beyond perception. Subsequent research has also demonstrated that repetition priming is not *entirely* intact in H.M. and other amnesics: H.M. only exhibits normal repetition priming for familiar words, and not for words introduced into English after his 1953 operation (Gabrieli et al., 1988). For example, if H.M. processes the familiar word COMPLAINT, and later receives the word stem COM for completion with the first word that comes to mind, he will exhibit normal repetition priming, producing COMPLAINT rather than some other word that begins COM. However, if H.M. and controls are exposed to a word that entered English after H.M.'s 1953 lesion, e.g., FRISBEE, memory-normal controls will later complete the stem FRI with FRISBEE, whereas H.M. will complete the stem with an "unprimed" word such as FRIDAY.

Under binding theory, normal repetition priming results from the engrainment process that follows activation of established internal representations without input from subcortical binding nodes. Because H.M.'s engrainment processes are unimpaired, H.M. exhibits intact repetition priming for familiar words and visual forms with internal representations formed prior to his operation. However, only already-established content nodes can benefit from engrainment processes because never-previously-formed representations cannot be activated. Because of his impaired ability to form the connections for representing never-previously-encountered forms, H.M. cannot therefore exhibit normal repetition priming for non-words and other forms that he did not know before his operation.

This distributed-memory account of H.M.'s spared and impaired repetition priming contrasts with the usual systems theory interpretation (Carlson, 2004, pp. 454–459): that systems for storing relational, episodic, explicit and declarative memories are impaired in H.M. and other amnesics, whereas separate systems for storing perceptual, implicit and procedural memories are intact, an account that fails to explain why only *preoperatively familiar* words and visual forms exhibit normal repetition priming in amnesics.

Stimulus-response learning. Like other amnesics, H.M. exhibits relatively normal stimulus-response learning during classical (Woodruff-Pak, 1993) and instrumental conditioning (Sidman, Stoddard, & Mohr, 1968). Because massive repetition characterises both types of learning (e.g., 25 trials or stimulus-response repetitions in Sidman et al.), H.M.'s intact engrainment processes readily explain his intact stimulus-response learning without postulating a special memory system.

Motor learning. Milner (1965) demonstrated that H.M. exhibits intact motor learning during mirror-drawing: H.M. slowly improved with practice using a stylus to trace the outline of a figure visible only in a mirror. Acquiring this and other motor skills (Corkin, 1984) involves engrainment processes *par excellence*. For example, two rules contrary to everyday experience receive massive repetition within trials, across trials, and across days of practice in the mirror tracing task. Rule one is to move the stylus upward in order to trace downward on the figure seen in the mirror, and rule two is to move the stylus downward in order to trace upward on the figure seen in the mirror. H.M.'s unimpaired engrainment processes therefore provide a parsimonious explanation for his slow improvement over thousands of repetitions of these "motor skill rules" without postulating a special memory system for motor learning.

Binding processes in binding theory

Supplementary input from subcortical binding nodes provide the second, much more rapid and efficient way of forming new cortical connections in binding theory. This binding node input functions to accelerate normal engrainment processes, and without rehearsal, efficiently creates strong new connections between established cortical content nodes currently undergoing activation and a chunk node representing their never-previously-encountered conjunction. To illustrate in detail the close relation between binding and engrainment processes, we next discuss how binding nodes enhance normal engrainment to quickly form new connections linking established content nodes to a never-previously-activated chunk node.

We first provide a two-sentence summary of how established content nodes for familiar words become activated in binding theory (for further details, supporting evidence, and theoretical rationale, see MacKay, 1986, pp. 39–62, and MacKay 1987, pp. 169–170): An established content node becomes activated following application of an activation mechanism that selectively causes the most-primed content node in some sequential domain or category, say, the category noun, to become activated. Once activated, established content nodes normally sustain their activation only briefly because a self-inhibitory process quickly terminates activation so that some other content node in the category can become activated (for additional theoretical and empirical reasons for postulating self-inhibition, see MacKay, 1987, pp. 141–164). A side effect of self-inhibition relevant here is that normal (unrepeated) activation of established content nodes cannot engrain functional connections to chunk nodes representing never-previously-encountered conceptual conjunctions.

What binding nodes do is prevent self-inhibition in two or more categories of established content nodes, thereby causing the currently activated nodes in those categories to prolong their activation. Prolonged activation of content nodes resembles long-term potentiation (Cain, 2001), and quickly burns in new bottom-up connections to a chunk node representing their conjunction, thereby enhancing normally short-lived engrainment effects without the need for repeated activation. Nouns and adjectives represent two content node categories that a noun phrase binding node can conjoin, e.g., during initial encounter with a phrase such as *new connections* (see MacKay, 1990, 1992a, for other conjoinable content node categories). MacKay (1990, 1992a) also discusses in detail three conditions necessary for content nodes to trigger the binding node for a particular category conjunction: pertinence, simultaneous activation, and novelty. A binding node is only triggered when established content nodes in pertinent or conjoinable categories (the pertinence condition) become simultaneously activated (the simultaneous activation condition) without activating an established node in the category representing their conjunction (the novelty condition). For example, consider the very first encounter with the noun phrase *working memory* by a listener who knows the words *working* and *memory.* The established content nodes for the participle *working* and the noun *memory* are members of pertinent or conjoinable categories (participle and noun), and simultaneous activation of these content nodes triggers the activation mechanism for noun phrases (the category pertinent to conjunctions of nouns and participles, among other subcategories). However, our hypothetical listener (by hypothesis) lacks an established content node for the noun phrase *working memory* (the novelty condition), so that the noun phrase activating mechanism will fail to activate a content node in the noun phrase category, which is the activation failure that triggers the noun phrase binding node (for further details, see MacKay, 1990, 1992a).

Once activated, the noun phrase binding node inhibits the self-inhibition mechanisms of all established content nodes in categories combinable into

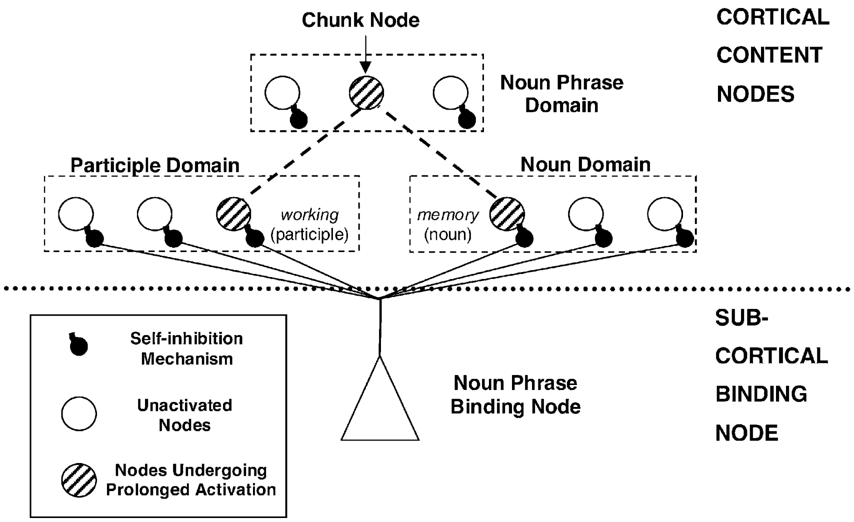

Figure 2. New bottom-up cortical connections (shown with broken lines) to a chunk node representing the conjunction of the participle *working* and the noun *memory*. The subcortical noun phrase binding node connects with the self-inhibition mechanisms of all content nodes representing participles and nouns. Chunk nodes undergo prolonged activation because they lack a self-inhibition mechanism, and binding node input prolongs activation of the remaining cross-hatched content nodes.

noun phrases, including participle and noun (see Figure 2). Because *working* and *memory* are the only currently activated content nodes in those categories, *working* and *memory* will therefore fail to self-inhibit, causing prolonged activation that rapidly boosts the strength of the extremely weak connections from *working* and *memory* to a never-previously-activated chunk node representing their conjunction (see Figure 2).

This rapid boost in connection strength enables the chunk node to accumulate sufficient priming to enable activation under the most-primed-wins principle, and because chunk nodes lack a self-inhibition mechanism, the chunk node also undergoes prolonged activation, which further strengthens the relatively weak and fragile connections to the chunk node representing *working memory.* However, this initial increase in connection strength is fragile and temporary: Unless the chunk node is activated again within a critical period, probably several days, connection strength will decay to zero, rendering the chunk node non-functional. For example, following several days of non-activation, connections to the newly formed content node representing the noun phrase *working memory* will decay to zero, so that the concept *working memory* can no longer be activated without new binding and/or engrainment processes.

On the positive side, once a chunk node becomes non-functional it can potentially represent some new combination of concepts (see MacKay, 1990). Moreover, if the newly bound chunk node *is* used repeatedly within the critical period since last activation, engrainment processes will eventually burn in a connection between the chunk node and a self-inhibitory collateral node (see Figure 2), so that the by now established *working memory* node will be activated automatically without input from binding nodes during normal comprehension and production of this phrase.

In summary, binding theory postulates a special relation between language comprehension-production and rehearsal-like processes that are unique to the study of memory in other theories. This special relation arises ready-made in binding theory because the end result of binding processes and massively repeated activation or rehearsal is identical: Both processes form the same new connections via engrainment, differing only in how rapidly the new connections are formed.

BINDING THEORY PREDICTIONS FOR H.M.'S LANGUAGE COMPREHENSION AND PRODUCTION

We first spell out binding theory predictions regarding H.M.'s sentence comprehension abilities. Under binding theory, H.M. has intact engrainment processes together with a *binding deficit*: his 1953 operation destroyed some (but perhaps not all) of the thousands of binding nodes required for efficiently representing novel or newly encountered information during normal sentence comprehension (see MacKay, 1990). Because intact binding nodes are necessary to quickly form internal representations for comprehending novel concepts, H.M.'s lesion should therefore impair his comprehension for a range of verbal concepts that are new to him. By contrast, comprehension of concepts familiar to H.M. before his operation and used frequently since then should be intact because reactivating established internal representations (i.e., content nodes with pre-formed connections) does not require supplementary input from binding nodes. For example, H.M. will comprehend without difficulty units that he used frequently before 1953, e.g., the word *morning*, the phrase *good morning*, and the proposition *I was born in 1926* (H.M.'s birth date).

This combination of impaired binding versus spared activation processes provided the basis for the "contextual-integration hypothesis" of MacKay et al. (1998b; see also MacKay & James, 2001): that H.M. can comprehend isolated HF words and familiar phrases, but cannot comprehend their relations to other words and phrases in non-cliché sentences because representing never-previously-encountered conceptual relations requires the formation of new connections. Experiments 1–5 were designed to test this contextual-integration hypothesis, and Experiment 6 tested a corollary of the contextual-integration hypothesis that applies to lexically ambiguous words. Under this corollary, H.M. can activate the two meanings of familiar lexically ambiguous words in *isolation* but has difficulty with the process of integrating the meanings of lexical ambiguities into the context of non-cliché sentences (see MacKay et al., 1998b).

To illustrate this contextual-integration corollary in detail, consider the word *bank*. Taken in isolation, *bank* has at least three meanings, corresponding roughly to "savings and loan bank", "river bank" and "the act or result of banking a billiard ball". However, within the sentence, *The boys were throwing stones toward the bank* (from Corkin, 1973), the "bank shot" interpretation must be rejected: Only the "money bank" and "river bank" meanings are coherent with the sentence context. Determining whether a lexical meaning fits its sentence context depends on successful formation of a new and distinct internal representation under the contextual-integration corollary. For example, comprehending the verb phrase *were throwing stones toward the* (river) *bank* requires an internal representation that is conceptually distinct from *were throwing stones toward the* (savings and loan) *bank* because we normally comprehend stones as thrown downward when thrown toward a river bank, but not when thrown toward a savings and loan bank. Under the contextual-integration corollary, this contextual-integration process explains why H.M. exhibits difficulties in detecting lexical ambiguities in sentences (see MacKay et al., 1998b): Due to his binding deficit, H.M. cannot readily form the new representations that integrate lexically ambiguous word-meanings with their never-previously-encountered or novel sentence-contexts.

To test this contextual-integration corollary, the present study examined H.M.'s ability to comprehend lexical ambiguities in never-previously-encountered or novel sentences (Experiment 5) versus in isolated words and phrases that he would have encountered before his operation (Experiment 6). The contextual–integration corollary predicted deficits in H.M.'s comprehension of lexical ambiguities *in sentences* because his binding deficit makes it difficult to form new representations that integrate lexical meanings with novel or never-previously-encountered sentence-contexts. However, the contextual–integration corollary predicted no deficits in H.M.'s comprehension of *isolated* lexically ambiguous words and phrases because activating familiar concepts does not require input from binding nodes. To summarise, unlike systems theories in which H.M. has a pure memory deficit, binding theory predicted selective deficits in H.M.'s sentence–level comprehension in the present experiments.

Binding theory also predicted engrainment-linked repetitions during H.M.'s attempts to comprehend lexically ambiguous and contextual words in sentences but not in familiar phrases. To illustrate, when unsuccessfully attempting to describe the lexically ambiguous word *position* in "The captain liked his new position" (MacKay et al., 1998b), H.M. repeated the critical word *position* four times and the contextual word *captain* six times, as if engrainment-linked repetition was necessary to burn in a connection between *captain* and *position*. However, because activation without new connection formation suffices for comprehending familiar phrases, binding theory predicted no similar word repetitions in H.M.'s attempts to comprehend lexical ambiguities in the familiar phrases in Experiment 6.

Finally, binding theory predicts language production deficits whenever H.M. must express propositions or phrases that are new to him (MacKay & James, 2001). In particular, binding theory predicts an interesting dissociation between H.M.'s ability to *comprehend* the familiar word and phrase stimuli in Experiment 6 versus to produce sentences that *describe* his comprehension of these stimuli: Under binding theory, H.M. will *describe* familiar words and phrases less coherently and with greater use of clichés or familiar phrases than memory-normal controls because creating sentences that are appropriate, coherent, and novel or cliché-free requires the formation of many new connections, entailing multiple iterations of binding processes resembling the ones in Figure 2. To illustrate, consider the following coherent and appropriate definition for the "lottery" meaning of the ambiguous word *lots*: "Lots can refer to objects such as pieces of straw of various lengths that are used to make a choice or determination by chance." Under the contextual-integration hypothesis, H.M.'s memory contains the familiar word *lots* with links to cliché phrases such as *pieces of straw* and *long and short*, which H.M. can produce to successfully indicate comprehension of this meaning of *lots.* However, to create the full definition incorporating these familiar words and phrases during production, H.M. must create a large number of never-previously-formed links to phrase and proposition nodes (for details, see MacKay & James, 2001). Under the contextual-integration hypothesis, H.M.'s binding deficit will therefore hinder the formation of these new connections for creating full and coherent definitions of familiar words and phrases. To summarise, unlike theories in which H.M. has a pure memory deficit, binding theory predicted selective deficits in H.M.'s sentence-level language comprehension and production in the present experiments.

GENERAL PROCEDURES AND THE STRUCTURE OF THE PRESENT PAPER

To test the predictions of binding versus systems theories for H.M.'s language comprehension and production, Experiments 1–6 followed the standard convention of describing as deficits differences between patient and controls that exceed 2 standard deviations and indicating as 6 standard deviations deficits that are infinitely large (as can occur when a control group performs a task with $SD = 0$). Experiments 1–6 also adopted the special procedures used with H.M. in Lackner (1974) and MacKay et al. (1998b): Our experimenters continuously displayed a summary of the instructions for each experiment and verbally repeated them throughout the experiment to prevent forgetting. Materials for Experiments 1–6 are provided in the Appendix.

Experiments 1–6 also addressed the Kensinger et al. (2001) criticisms of earlier research on H.M.'s sentence-level comprehension. These criticisms focused on the primary task in MacKay et al. (1998b): to detect and describe ambiguities in short visually presented sentences. Even though controls in MacKay et al. were matched with H.M. on general factors such as education, background, and IQ, Kensinger et al. suggested that "H.M.'s deficit in ambiguity detection . . . may stem from factors unrelated to H.M.'s lesion, such as his upbringing or education (p. 357)". As a second criticism, Kensinger et al. suggested that H.M.'s comprehension deficits are specific to ambiguous sentences and tasks that may require the storage and maintenance of multiple meanings in memory. Reinforcing these criticisms, Kensinger et al. showed that H.M. exhibits no reliable deficits relative to controls in 15 experiments, several of which tested sentence-level comprehension and/or metalinguistic judgements.[1]

To address these criticisms, the present study adopted two general strategies: to use tasks that did not in principle require storage or maintenance of multiple meanings; and to test for *selective* or context-specific deficits so as to rule out general or across-the-board explanations of H.M.'s deficits. For example, across-the-board factors such as upbringing, education, or epilepsy-related learning failure cannot explain inability to comprehend one and the same stimulus word in sentences but not in isolation.

An important distinction in Experiments 1–6 concerned what was familiar versus novel in our sentences given H.M.'s prior experience. To operationalise this distinction, we could have asked participants to rate their familiarity with the words, phrases, and sentences in our materials, but for H.M., these procedures introduce unsolvable problems. Experiments 1–6 therefore did the next best thing: to present sentences containing high frequency words that we know with virtual certainty that H.M. knows. What was novel for both H.M. and controls was therefore how the words

[1] Although two additional tasks in Kensinger et al. (2001) yielded language deficits, these deficits were readily explained in terms of H.M.'s cerebellar damage and/or episodic memory deficits.

combined into non-cliché sentences, the factor of theoretical interest throughout the present research.

Experiment 1 was a metalinguistic judgement task requiring yes–no discrimination between grammatical versus ungrammatical sentences. The goal was to replicate the main "syntax comprehension" results of Kensinger et al. (2001, p. 352) using improved procedures. Experiment 2 was designed to replicate the Experiment 1 results using additional control procedures. The primary goal of Experiment 3 was to test whether H.M. exhibits comprehension deficits in identifying thematic roles, i.e., who did what to whom in sentences with a wide variety of structures.

Experiments 4–6 examined more specialised but nevertheless ubiquitous aspects of everyday language comprehension, namely metaphor and ambiguity (Jay, 2003, pp. 128–134, 313–323). Experiment 4 presented metaphoric sentences containing familiar words that require unusual interpretations to fit the sentence context. The procedures tested two hypotheses. One hypothesis (based on anecdotal evidence; Hilts, 1995, pp. 115–116) was that H.M. readily comprehends never-previously-encountered metaphors such as "Henry, you're the puzzle king". The other was the contextual-integration hypothesis, that metaphors such as "puzzle king" should cause special difficulties for H.M. because comprehending the meaning "someone who dominates at solving puzzles" requires the formation of many new connections, together with an unusual and context-specific interpretation of the familiar word *king*.

Experiment 5 tested the Kensinger et al. (2001) hypothesis that memory load resulting from maintaining more than one meaning in memory contaminated previous results involving the comprehension of ambiguous sentences (Lackner, 1974; MacKay et al., 1998b; Schmolck et al, 2000). Experiment 5 participants saw never-previously-encountered ambiguous sentences, together with a single interpretation, and responded "yes" if the interpretation fit the sentence and "no" otherwise. To test the memory load hypothesis, we then compared H.M.'s performance on this task (where only a single sentence-meaning was relevant and maintaining more than one meaning in memory was unnecessary) with earlier studies where maintaining ambiguous meanings in memory may in principle have been a factor.

Experiment 6 compared H.M.'s ability to detect and describe the two meanings of lexical ambiguities in sentences vs. isolated words and familiar phrases to test two theoretical accounts of prior research: the Kensinger et al. (2001) memory load hypothesis, and the contextual-integration corollary discussed earlier. Experiment 6 also tested a task difficulty hypothesis: that H.M. exhibits across-the-board deficits on more difficult tasks (detecting and describing ambiguity in sentences) but not on easier tasks (detecting and describing ambiguity in isolated words and phrases).

To anticipate, Experiments 1–6 will show with appropriate procedures that H.M. exhibits selective sentence-level comprehension deficits that are consistent with binding theory *and* with the Kensinger et al. data: Under binding theory, H.M. *should not* exhibit deficits using the experimental procedures of Kensinger et al.

PARTICIPANTS: EXPERIMENTS 1–6

H.M. We tested H.M. in 1998 and 1999 when IQ scores on his most recent W-B I test were 107 (verbal) and 117 (performance). H.M.'s bilaterally symmetric surgery in 1953 lesioned his amygdala and part of his hippocampus and connected subcortical structures (for further details, see Corkin, Amaral, González, Johnson, & Hyman, 1997). The thin metal tubes inserted sub-orbitally for this suction surgery damaged the temporal poles only slightly and otherwise spared the entire neocortex, including all neocortex with known links to language comprehension (see Hart & Gordon, 1990). Also spared were parahippocampal cortex, temporal stem, collateral sulcus, including portions of the ventral perirhinal cortex, and the caudal 2 cm of the hippocampal body, although the functional status of this spared 2 cm (approximately 50% of the hippocampus) is currently unknown. Recent MRI data (Corkin et al. 1997) indicate a large cerebellar lesion due to H.M.'s use of dilantin for treating epilepsy since 1953, together with *possible* damage to lateral temporal neocortex that was not due to the original surgery. This possible but at most *minimal* damage may reflect either an age-linked effect or occurrence of transneuronal degeneration subsequent to H.M.'s 1953 surgical lesion.

Control participants. Controls in Experiments 1–6 were tested from 1999–2003, reported an absence of neurological problems, spoke English as children, and participated for $10/hour. Controls were matched with H.M. as closely as possible for mean verbal IQ, mean performance IQ, mean age at time of test, and highest educational degree (see Table 1). The number of controls varied from 6–8 across experiments and is shown for each experiment in Table 1.

EXPERIMENT 1: THE GRAMMATICALITY DETECTION TASK

Experiments 1 and 2 resembled the metalinguistic judgement task labelled Syntax Comprehension I (SC I) in Kensinger et al. (2001), where H.M. and controls produced yes–no judgements of grammaticality for 128 sentences

TABLE 1
Mean age, verbal IQ, performance IQ and highest educational degree for H.M. and the control participants in Experiments 1–6, with *SDs* in parentheses

Participants	*N*	*Mean age*	*Mean W-B I* verbal *IQ*	*Mean W-B I performance IQ*	*Highest educational degree*
H.M.	1	72.5	107	117	High school
Experiment 1 controls	7	73.71 (3.82)	111.14 (5.98)	119.57 (9.81)	High school
Experiment 2 controls	8	70.25 (3.99)	110.00 (7.27)	117.75 (9.60)	High school
Experiment 3 controls	8	70.19 (3.52)	109.50 (7.67)	118.88 (8.43)	High school
Experiment 4 controls	6	74.17 (3.76)	111.17 (6.94)	115.00 (10.99)	High school
Experiment 5 controls	6	69.33 (3.92)	113.83 (3.49)	114.67 (7.55)	High school
Experiment 6 controls	6	71.33 (2.80)	115.17 (3.31)	123.67 (6.83)	High school

resembling examples 1 (grammatical) and 2 (ungrammatical). Results for SC I provided the main support for the Kensinger et al. (2001) conclusion that H.M.'s language comprehension is unimpaired at grammatical levels.

1. Yesterday I tied my shoe.
2. Yesterday I try it on.

However, we saw two potential flaws in SC I. One was that participants could in principle achieve perfect performance via word-comprehension alone. For example, correct responses to sentences 1–2 can be based on comprehending the lexical meaning of the verbs and adverbs without full comprehension of the sentences, a critical factor because H.M. can comprehend familiar word-meanings without deficit under binding theory. The second potential flaw concerned massive repetition: 128 trials involving basically similar verb tense cues to the correct response, a flaw under binding theory because massive repetition enables H.M. to encode new information via repetition-based engrainment processes (see the introduction).

To eliminate these potential flaws, the grammaticality detection task in Experiment 1 ruled out repetition and word-comprehension as possible bases for correct responses. On each trial in Experiment 1 participants saw a single sentence that was either grammatical and semantically coherent, e.g., 3, or contained anomalous syntax, incoherent meaning, or both, as in 4:

3. I helped myself to the birthday cake. (grammatical)
4. I helped themselves to the birthday cake. (ungrammatical)

They responded 'yes' if they considered the sentence grammatical and error-free, and 'no' otherwise. We recognise that "agreement errors" resembling 4 are debatably ungrammatical, semantically anomalous, or both, but following Kensinger et al. (2001), we label our sentence classes grammatical versus ungrammatical to simplify exposition. In fact, Experiment 1 by design included ungrammatical sentences containing a wide variety of semantic and syntactic anomalies to prevent repetition of cues to the correct response across sentences (see also Kemper, 1997).

Also by design, our sentences varied widely in syntactic structure, and correct responses could not be derived from the meaning of individual words taken in isolation: Determining "grammaticality" required the formation of new representations involving relations between several words in the sentences. For example, to detect the anomaly in *I helped themselves to the birthday cake,* comprehension of *themselves* is insufficient: The relation between the sentence subject *I* and the reflexive pronoun *themselves* must be computed and understood as inappropriate.

Many of our sentences were identical to ones used in Kemper (1997), with minor modifications to ensure word-level comprehension by H.M. The sentences came in paired grammatical and ungrammatical versions, e.g., 5–6. Most grammatical and ungrammatical versions were identical except for a word substitution that violated number agreement between subject and verb, e.g., 6, person or number agreement between antecedent and pronoun, e.g., 4, and 9–10, selection restrictions between a word and its modifier, e.g., 7, and semantic or logical coherence between various constituents within the sentences, e.g., 6, and 11.

5. The brothers were fixing up the old car. (grammatical)
6. The brothers was fixing up the old car. (ungrammatical)
7. The boy stepped on the insect flat. (ungrammatical)
8. Tuesday was slept on by Andy. (ungrammatical)
9. John gave me the car that he couldn't drive by ourselves. (ungrammatical)
10. Our new neighbours moved in but I haven't met us yet. (ungrammatical)
11. Someone who we don't remember just walked into the room inviting. (ungrammatical)
12. So many people that there wasn't enough to eat came to the party. (ungrammatical)

The basis for ungrammaticality was usually simple but subtle to ensure against ceiling effects for controls. For example, in sentence 11, normal readers often fail to detect the logical inconsistency between seeing someone walk into the room and not remembering them. They then unwittingly "repair" this anomalous sentence and respond to the unpresented but pragmatically common, *Someone whose name we don't remember just walked* *into the room*. In deliberate exception to this simple-but-subtle rule, four ungrammatical sentences thoroughly scrambled the words in a grammatical sentence, thereby violating large numbers of syntactic selection restrictions. An example scrambled sentence is 13, the ungrammatical version of *She has decided to buy a house.*

13. Has house she decided to a buy. (scrambled sentence)

Theories in which H.M. exhibits a pure memory deficit predicted no deficits in H.M.'s ability to distinguish between grammatical versus ungrammatical sentences in Experiment 1, and binding theory predicted no deficits in H.M.'s responses to scrambled sentences involving multiple violations of highly practiced selection restrictions between adjacent words, e.g., *to buy* versus *to a buy*. However, binding theory predicted deficits for the remaining sentences because correct responses required the formation of new representations involving relations between non-adjacent words in the sentences. For example, to recognise that "John gave me the car that he couldn't drive by himself" is grammatical requires a new and coherent representation in which *John, he* and *himself* become bound to the same referent, and to recognise that "John gave me the car that he couldn't drive by ourselves" is ungrammatical requires understanding that no coherent representation is possible: If *he* binds to *John*, the sentence must end "that he couldn't drive by himself" and if *ourselves* becomes bound to the referents *John* and *me*, the sentence must end "that we couldn't drive by ourselves".

Method

Materials. The materials are shown in the Appendix, and consisted of 56 short sentences, mean length (ML) = 8.88 words. Half of the sentences were grammatical, e.g., 5, and the remainder were length-matched ungrammatical versions, e.g., 6. Fifteen grammatical versions were simple active declaratives, the remainder had more complex syntactic structures. Practice trials consisted of six additional grammatical and ungrammatical sentences.

Procedure. The instructions were presented orally and visually on a continuously displayed card: Read each sentence aloud, and say "yes" if it seems grammatical or error-free and say "no" if it contains an error or seems ungrammatical. The experimenter displayed the sentence for each trial by flipping over the 4 × 6-inch index card on which it was typed in capital letters in large font. The stimulus card then remained in view until the participant responded "yes" (grammatical) or "no" (ungrammatical).

H.M. and controls saw the 56 experimental sentences in identical pseudo-random order with 28 trials separating grammatical versus ungrammatical versions of the same sentence. One minor procedural difference for H.M. was that the experimenter (L.J.) read the sentence and interpretations aloud on each trial as H.M. read silently along. This procedure ensured correct registration of the materials because unlike controls, H.M. often misreads simple sentences in ungrammatical and meaning-changing ways (see MacKay & James, 2001). In addition, the experimenter (L.J.) sat behind a shield during stimulus display so as to prevent guesses and response revisions based on subtle facial cues (a problem noted in MacKay & James, 2001).

Results and discussion

Overall responses were 83% correct for controls (*SD* = 6.00%), versus 70% for H.M., a 2.13 *SD* deficit. As another indication of deficit, H.M. exhibited a response bias in favour of "no" (61% vs. 39%). Due to this response bias, H.M. was only 59% correct when the correct response was "yes" (grammatical), a 3.59 *SD* deficit relative to controls (*M* = 88%, *SD* = 7.93%). Signal detection analyses of these data confirmed that controls exhibited greater sensitivity than H.M. (d prime = 1.98 vs. 1.11), and a more liberal response criterion than H.M. (beta = 0.69 vs. 1.43), indicating greater willingness than H.M. to say that a sentence was grammatical.

These results indicate that H.M. exhibits deficits in a task requiring metalinguistic judgements based on comprehension of sentence syntax and semantics. These deficits contradict theories in which H.M. exhibits a pure memory deficit, but comport with binding theory predictions because correct responses required the formation of new representations and integration of lexical meanings across novel or never-previously-encountered sentence contexts, a problem for H.M. under the contextual-integration hypothesis. Experiment 1 results also indicate that contrary to Kensinger et al. (2001), H.M.'s comprehension-linked deficits are not confined to ambiguity detection or to maintaining multiple meanings in memory (see Ferreira, Bock, Cohen, & Wilson, 2005, for data indicating a similar conclusion for other amnesics).

Subsidiary results. One explanation of H.M.'s deficits in Experiment 1 is that his memory problems determined his language problems, and only structures that are difficult for memory-normal individuals to recall were problematic for him in present materials. To test for this possibility, we examined H.M.'s performance for sentences with two types of grammatical structure: simple active declaratives, the easiest syntactic structure for memory-normal English speakers to remember (Miller, 1962), versus harder-to-remember structures such as passives, and sentences with subordinate clauses (both cleft-object and cleft-subject relatives) and propositions coordinated with *and* or *but*. Examples of the easy-to-remember simple active declaratives are 5, 6, and the grammatical version of 7 (*The boy squashed the insect flat*) and 8 (*Andy slept on Tuesday*). Examples of more complex and difficult-to-remember structures are the grammatical versions of 9–13. If H.M. only exhibits deficits for difficult-to-remember structures, H.M. should exhibit no deficits for the easy-to-remember simple active declarative structures.

For grammatical sentences, H.M.'s correct response rate for simple active declaratives was 60% correct, a 3.53 *SD* deficit relative to controls, and little better than for all sentences combined ($M = 59\%$ correct, including the sentences with more complex structures), for which H.M. exhibited a 3.59 *SD* deficit relative to controls. This control result indicates that H.M.'s comprehension deficits with Experiment 1 materials were not due solely to syntactic structures that are difficult for memory-normal participants to recall. This control result also suggests that H.M.'s memory problems were not the basis for his language deficits. However, this control result does not bear on the issue of whether syntactic complexity influences language comprehension in general or in tasks such as sentence repetition (Shapiro, McNamara, Zurif, Lanzoni, & Cermak, 1992). To adequately address *that* issue would require comparison of simple versus complex sentences in a counterbalanced design with minimal pairs that are controlled for length and an unlimited number of other variables.

No differences in H.M.'s deficits emerged between grammatical or ungrammatical sentences in our materials that involved violations in person agreement, number agreement, selection restrictions, and semantic and logical coherence relations. For example, H.M.'s deficits for sentences involving anomalies in number agreement versus pronoun agreement were almost identical (16.5% vs. 17%). These results indicate that H.M. exhibits deficits in detecting grammaticality for a wide variety of sentence structures. However, neither H.M. nor controls made errors in identifying scrambled sentences as ungrammatical ($M = 100\%$ correct; $SD = 0\%$), a non-deficit with several possible interpretations, e.g., ceiling effect. This non-deficit nevertheless indicates that H.M. comprehended the present instructions and was motivated to follow them.

EXPERIMENT 2: THE WHAT'S-WRONG-WITH-THIS-SENTENCE TASK

Experiment 2 had three goals. One was to replicate the basic results of Experiment 1, which seemed important because Kensinger et al. (2001) reported conflicting results. Goal two was to test whether H.M.'s Experiment 1 response bias favouring "no" was specific to the word "no" or to the concept "ungrammatical": Sentences in Experiment 2 contained a wrong or misordered word, and on each trial participants responded "yes" if the sentence was ungrammatical or "contained a word that is wrong or in the wrong order", e.g., 14, and "no" otherwise. A bias based on the lexical meaning of "no" predicts that H.M. should exhibit a "no" bias in Experiment 2, but a bias based on experiment-specific applications of the concept "ungrammatical," predicts a "yes" bias in Experiment 2, where "yes" responses represented the concept "ungrammatical".

14. The boy make a cake. (ungrammatical)
15. The boy made a cake. (grammatical)

Goal three was to evaluate the role of guessing in Experiment 1 results. After correctly responding 'yes' to sentences containing an error, e.g., 14, Experiment 2 participants indicated what word was wrong or wrongly ordered, and produced an error-free version of the sentence, e.g., 15. We reasoned that participants who responded correctly *by guessing* would be unable to correct the sentence and unable to identify what words in the sentence were incorrect. Theories in which H.M. exhibits a pure memory deficit predicted no deficits in Experiment 2 whereas binding theory predicted deficits, especially for the tasks of identifying and correcting the incorrect words in sentences identified as ungrammatical.

Method

Materials. The materials are shown in the Appendix, and consisted of 24 short sentences ($ML = 7.33$ words, $SD = 1.07$) that did not contain subordinate clauses. As in Experiment 1, half the sentences ($N = 12$) were grammatical and half (matched for mean length) were ungrammatical. Each sentence headed a single sheet of paper in large font, followed by a single question in capitals, e.g., "Does the sentence contain an incorrect word?" Next came the capitalised response alternatives, "YES" or "NO."

Procedure. Experiment 2 participants had three tasks: to *detect* the grammatical errors in the sentences, to *identify* the words in error, and then to *correct* the error. Instructions were presented orally and visually on a continuously displayed card: Read the sentence and answer the question with "yes" if the sentence is grammatically correct, and "no" if it contains a word that is wrong or in the wrong order. When participants responded "no", the experimenter (L.J.) asked them to indicate the incorrect or misordered word and then produce a correct version of the sentence, taking care not to provide verbal cues by which H.M. (especially) could modify his original response (a problem noted in MacKay & James, 2001). H.M. and controls saw the sentences in identical pseudo-random order with 11 trials separating grammatical versus ungrammatical versions of the same sentence. As in Experiment 1, the experimenter read each sentence aloud, while H.M. read silently along.

Results and discussion

For the error detection task, controls responded correctly on 98% of the trials ($SD = 5.89\%$), versus 79% for H.M., a 3.18 *SD* deficit. A signal detection analysis was not possible for controls' data because their false alarm rate was so low (0), but H.M.'s data indicated low sensitivity (d prime = 1.63) and a conservative response criterion (beta = 1.26) indicating reduced willingness to respond "yes". H.M.'s consistent response bias in favour of "no" suggests a word-specific rather than concept-specific bias because "no" represented the concept "ungrammatical" in Experiment 1, but "grammatical" in Experiment 2. Because of this "no" bias, H.M. was only 75% correct for sentences with "yes" as the correct response, a 2.48 *SD* deficit relative to controls ($M = 97\%$; $SD = 8.84\%$).

Consistent with the hypothesis that many of H.M.'s responses were based on guessing, H.M. produced three types of errors not seen in controls when identifying the incorrect or misordered words following a "yes" response: He indicated that correct words in grammatical sentences were incorrect, he indicated that incorrect words in ungrammatical sentences were correct, and he indicated that words not even in a stimulus sentence were incorrect (see the italicised notes in Table 2 for examples). For the error correction task, controls accurately corrected 100% of the sentences that they identified as containing wrong or wrongly ordered words ($SD = 0\%$), versus 83% for H.M., a deficit in excess of 6 *SD*s. The Experiment 2 results therefore contradict theories in which H.M. exhibits a pure memory deficit, replicating and extending the Experiment 1 results. However, Experiment 2 results comport with binding theory, which predicted deficits in H.M.'s ability to discriminate grammatical from ungrammatical sentences and to correct incorrect words in ungrammatical sentences.

In summary, Experiments 1–2 demonstrated deficits in H.M.'s "syntax comprehension" when two theoretically significant aspects of SC I were eliminated: massive repetition of basically similar cues to the correct response, and the possibility of perfect performance based on word-comprehension alone. These aspects may therefore explain H.M.'s non-deficits in SC I (Kensinger et al., 2001). Moreover, Syntax Comprehension II (SC II), Kensinger et al.'s (2001) other source of evidence for H.M.'s deficit-free "syntax comprehension", exhibited these same theoretically significant features. Participants in SC II (a task adapted from van der Lely, 1996) could achieve perfect performance by comprehending the form (e.g., active versus passive) of six familiar verbs that were repeated many times across the

TABLE 2
H.M.'s responses to four stimulus sentences in Experiment 2

EXPERIMENT 2 STIMULUS SENTENCE: Kevin called Nancy for a date up.

H.M.: Well it couldn't have been Nancy that he called. Well he had to call Nancy, right, for a date in a way, if he was talking to-wanted a date with her.
Experimenter: Um-hum.
H.M.: And he wasn't being specific uh 'cause you'd-have to be opposite of Kevin's.
Experimenter: So do you think there's a word in here that's wrong?
H.M.: Yeh.
Experimenter: Which word would you say is the one that's wrong?
H.M.: Well, wouldn't call for a date up.
Experimenter: OK, but which word makes – would you guess is wrong? (pause) Is there one word in particular?
H.M.: Called. (*Note: correct word is indicated as incorrect*)

EXPERIMENT 2 STIMULUS SENTENCE: The boy the rabbit feeds carrots.

H.M.: Well was he – the boy is feeding something, but where does he get the ra – the carrot?
Experimenter: So would you say these words are in the correct order or not?
H.M.: They're not in the correct order.
Experimenter: Which words would you move around, so that it would make a good sentence?
H.M.: The carrots. Because you couldn't say definitely the rabbit was being fed by the boy. Cause the boy has to get the carrots and where is he going to get the carrots? (*Note: correct word is indicated as incorrect*)

EXPERIMENT 2 STIMULUS SENTENCE: Will be Harry blamed for the accident?

H.M.: No that – that really doesn't say that he was responsible for the action or blamed for it, so he couldn't be blamed for it.
Experimenter: OK, so do you think that sentence has all the words in the right order or not?
H.M.: No.
Experimenter: Which words would you move around?
H.M.: The blame, mostly. (*Note: word not in the sentence is indicated as incorrect*)
Experimenter: Where would you put it, what order would you put those in to make a correct sentence?
H.M.: Well, you have to find out what Harry was blamed for. And it – possibly that word b – Harry is blamed, in a way, for the accident and he could be blamed for something else. (*Note: correct word indicated as incorrect*)

EXPERIMENT 2 STIMULUS SENTENCE: Where is Ted working this summer?

H.M.: I'd say no.
Experimenter: Which words do you think are out of order?
H.M.: Where. (*Note: correct word indicated as incorrect*)
Experimenter: OK.
H.M.: I think it was wrong cause that's uh, asking a question right there.

experiment. In addition, both H.M. and controls scored over 98% correct in SC II, a ceiling effect that made deficits impossible to observe. In short, problematic procedures provided the basis for the conclusion of Kensinger et al. that H.M.'s language comprehension is unimpaired at grammatical levels.

Moreover, this same theoretically significant "massive repetition feature" characterised other Kensinger et al. (2001) tasks in which H.M. and controls produced nominalisations (e.g., *stupid-stupidity*), past-tense forms (e.g., *talk-talked*), and plural forms (e.g., *boy-boys*) that were repeated many times within each experiment. For example, a regular past-tense suffix was the correct response on 64 trials in the Kensinger et al. past-tense experiment. Under binding theory, such massive repetition readily explains why H.M.'s suffix-production was deficit-free in Kensinger et al. but not in MacKay and James (2001, 2002). H.M. produced significantly more suffix errors than controls when reading aloud sentences containing HF words with unpredictable suffixes, e.g., *they were training* misread as "they were train" (MacKay & James, 2001), and when reading aloud isolated LF words containing unpredictable suffixes, e.g., *serrated* misread as "sangrate" (MacKay & James, 2002). The conflicting suffix-production results in Kensinger et al. (2001) versus MacKay and James are therefore readily explained under binding theory as due to occurrence of massive repetition in Kensinger et al. but not in MacKay and James.

Other Kensinger et al. (2001) experiments likewise contained theoretically significant features that undermined a second Kensinger et al. conclusion: that H.M.'s language comprehension and production is unimpaired at lexical levels. These experiments involved familiar stimuli and responses such as recognising and producing names for familiar objects, spelling familiar words (most with very high frequency of use), multiple-choice identification of the semantic category of familiar objects (e.g., bird, fruit, furniture, insect), and identification of places associated with familiar landmarks or events (e.g., Alamo–Texas). Deficits for such familiar stimuli and responses would not be expected under binding theory (MacKay & James, 2001, 2002).

EXPERIMENT 3: THE WHO-DID-WHAT TASK

Experiment 3 examined what many consider the most central aspect of natural language comprehension: understanding thematic roles such as actor and patient, i.e., who-did-what to whom in a sentence (Jay, 2003, pp. 142–152). To test whether H.M. exhibits deficits in comprehending thematic roles, Experiment 3 participants read sentences, e.g., 16, and answered multiple choice questions, e.g., 17–18, concerning who-did-what in the sentence.

16. The politician released the report that the committee wanted. (example sentence)
17. WHO RELEASED THE REPORT? (question)
18a. NOBODY (incorrect response)
18b. THE POLITICIAN (correct response)
18c. THE COMMITTEE (incorrect response)

Correct responses always required integration of lexical-meaning across several words in the target sentences and could not be inferred from the meaning of any one word taken in isolation. Nor could correct responses be based on information available to H.M. before his operation. For example, understanding the relation between sentence 19 and the correct response (21b. "Nobody fed the daughter") required computation of a new representation. Moreover, prior experience would in principle impede this correct response because familiar thematic relations between the words *mother, feeding,* and *baby* in sentence 19 would prime 21c ("The mother fed the daughter"), an *incorrect* response that must be rejected. Binding theory and the contextual-integration hypothesis therefore predicted deficits on this task due to H.M.'s difficulties in forming new representations and integrating lexical meanings into novel or never-previously-encountered sentence contexts. Systems theories in which H.M. has a pure memory deficit predicted no deficits in Experiment 3.

19. The daughter that the mother adored fed her baby. (example sentence)
20. WHO FED THE DAUGHTER? (question)
21a. THE BABY (incorrect response)
21b. NOBODY (correct response)
21c. THE MOTHER (incorrect response)

Method

Materials. The materials are shown in the Appendix, and consisted of one practice sentence and 17 short sentences (mean length = 9.4 words, $SD = 0.7$) that involved plausible relations between human agents and patients. They contained either centre-embedded relative clauses ($N = 9$), as in example 19, or right-branching relative clauses ($N = 8$), as in example 16. Each sentence was typed on a separate page in (mainly) lower case, 18 point bold Courier font, followed by the "who-did-what" question and its three response alternatives in upper case. "Nobody" was always one of the (correct or incorrect) response alternatives (see examples 16–21), and the correct response alternative (a, b, or c) varied randomly across sentences.

Procedure. The instructions were read aloud and displayed on a continuously visible card: Read each sentence aloud and then choose the best answer to the question. The 18 sentences were presented in identical random order for H.M. and controls. To ensure that H.M. accurately registered the materials, H.M. read the sentence, question, and response alternatives silently while the experimenter (L.J.) read them aloud (for rationale, see MacKay & James, 2001).

Results and discussion

Controls chose the correct response on 75% of the trials ($SD = 13.36\%$) versus 41% for H.M., a 2.55 *SD* deficit relative to controls and only marginally better than chance (33%). This deficit indicates impairment in a central aspect of language comprehension: understanding fundamental conceptual relations such as actor and patient in sentences expressing novel or never-previously-encountered concepts. This deficit contradicts systems theories in which H.M. exhibits a pure memory deficit but supports binding theory and the contextual-integration hypothesis, where H.M. has a problem in representing new relations involving several words in a sentence.

H.M.'s present deficit also comports with the deficits in repetition or immediate recall of sentences by severe amnesics in Shapiro et al. (1992, p. 451). However, as Shapiro et al. note (p. 448), two interpretations of their results are possible: Deficits on their task may be specific to the act of recall or may extend as well "to the more common postures of sentence comprehension". By contrast, the present results unambiguously demonstrate amnesia-linked deficits that are specific to sentence comprehension and not dependent on sentence recall.

Subsidiary results. One explanation of H.M.'s deficits in Experiment 3 is that his memory problems determined his language problems, and only structures that are difficult for memory-normal individuals to recall were problematic for him in present materials. To test for this possibility, we examined H.M.'s performance for Experiment 3 sentences that contained right-branching relative clauses, e.g., 16, versus centre-embedded relative clauses, e.g., 19. Because centre-embedded structures are more difficult for memory-normal individuals to remember than right-branching structures (a highly robust finding; Yngve, 1961), H.M. should exhibit deficits for centre-embedded but not right-branching structures if he only exhibits comprehension deficits for sentences that are difficult to recall.

H.M.'s correct response rate was worse for the easy-to-remember right-branching relatives (25% correct) than for the difficult-to-recall centre-embedded relatives (56% correct). Although the small number of centre-embedded ($N = 9$) versus right-branching ($N = 8$) structures in

Experiment 3 qualifies this finding, this result indicates that H.M.'s comprehension deficits in Experiment 3 were not confined to sentences that memory-normal individuals find difficult to recall.

We nevertheless emphasise that present results do not indicate deficits for thematic roles that can be inferred on the basis of word-meaning or prior experience. For example, H.M. would *not* exhibit deficits under binding theory for comprehending structures with irreversible thematic roles (see e.g., Caramazza & Miceli, 1991) in sentences such as, *The mother breastfed the baby,* because he has experienced the fixed thematic relation between *mothers, breastfeeding* and *babies* many times since early childhood. Similarly, H.M. would comprehend the thematic roles in the sentence "Gold is heavier than silver" because he has experienced the standard thematic relation between the abstract concepts *noun 1, be heavier than,* and *noun 2* many times prior to his lesion.[2] Nor would H.M. exhibit deficits in comprehending the more complex thematic roles in sentences such as "Thirteen multiplied by 12 is 56", because he has experienced the standard thematic relations between the abstract concepts *number 1, multiplied by, number 2,* and *be number 3* many times prior to his lesion. Finally, H.M. would comprehend without deficit the thematic roles in a proposition such as "Tomatoes are fruits" because he has since childhood repeatedly experienced the common thematic relations linking *edible object, be,* and the familiar category *fruit.*

EXPERIMENT 4: METAPHOR COMPREHENSION

The main goal of Experiment 4 was to further test binding theory and the contextual-integration hypothesis: that H.M. can comprehend familiar word-meanings but has difficulty integrating these word-meanings into novel sentence contexts. Our materials were metaphoric sentences (modified) from the Language Competence Test (LCT; Wiig & Secord, 1988), and participants chose from a list of three alternatives the best-fit interpretation for each visually presented sentence. As in example 22, the best-fit interpretation, here, "We will be facing difficult times" required integration of word-meanings across virtually the entire target sentence and could not be inferred from the meaning of individual words taken in isolation, e.g., "sailing", "rough" and "ahead". The contextual-integration hypothesis therefore predicted fewer correct responses for H.M. than controls because

[2] With visual presentation, we assume that understanding the thematic roles in "Gold is heavier than silver" requires no new binding, e.g., between *gold* and an abstract internal node labelled noun 1 or *silver* and an abstract internal node labelled noun 2. Rather highly practiced reading rules linked to position in visually presented sentences suffice to indicate that *gold* is noun 1 and *silver* is noun 2 in this sentence.

integrating lexical-meanings across novel sentence contexts is difficult for H.M. Systems theories in which H.M. has a pure memory deficit again predicted no deficits in Experiment 4.

22. "There is rough sailing ahead for us." (example sentence)
22a. "We will be facing difficult times." (correct metaphoric interpretation)
22b. "The rough times are behind us now." (incorrect metaphoric foil)
22c. "The waves will make it easy to sail." (incorrect literal foil)

The contextual-integration hypothesis also predicted the detailed nature of H.M.'s errors in Experiment 4. The correct response always required a metaphoric interpretation, and there were two types of *incorrect* response alternatives: *metaphoric foils* or false metaphoric interpretations with meaning opposite to the correct response (e.g., 22b), and *literal foils,* or false non-metaphoric interpretations containing one or more words closely related in meaning to isolated words in the target sentence (e.g., 22c). For example, in literal foil 22c, the words *waves* and *sail* are closely related to the literal meaning of *sailing* in example 22. Under the contextual-integration hypothesis, H.M. will often comprehend *sailing* as an independent word and choose the literal foil based on overlap in lexical-level meanings of *sailing, waves,* and *sail.* However, because comparing a metaphoric target and foil requires contextual integration of lexical-meanings within both target and foil, H.M. will rarely choose the metaphoric foils under the contextual-integration hypothesis.

Method

Materials. Our materials are shown in the Appendix, and consisted of modifications of the full set of sentences and response alternatives in the Metaphor Subtest of the LCT (Wiig & Secord, 1988). Our modifications increased font size, simplified stimulus layout, and reduced response alternatives from four to three to simplify the task for H.M. To ensure that all words were familiar to H.M. prior to his lesion, we replaced words or phrases in several LCT sentences, and we dropped four LCT sentences where such rewording was not possible (reducing our materials to $N = 8$, with one practice sentence). The target metaphors were short (ML = 6.8 words) and each headed a separate page in 18 point bold Courier font, followed in random order by the three response classes: correct metaphor, metaphoric foil, and literal foil.

Procedure. The instructions were presented both orally and visually on a continuously displayed card: Read the sentence aloud, and then indicate the best interpretation from the three choices below the sentence. The sentences were presented in identical random order for H.M. and controls. The experimenter (L.J.) read each sentence aloud, while H.M. read silently.

Results and discussion

Controls correctly identified the correct metaphoric interpretation for 100% of the sentences ($SD = 0\%$), as compared with 38% for H.M., a deficit in excess of 6 *SD*s. This deficit comports with binding theory and the contextual-integration hypothesis, where integrating lexical-meanings across metaphoric sentences is problematic for H.M. Under binding theory, H.M. failed to choose the correct metaphoric interpretation for sentences such as *There is rough sailing ahead for us* because he could not fully comprehend or form a coherent representation of the correct response alternative (*We will be facing difficult times*) or its relation to the target sentence.

As an additional sign of deficit, no data indicated that H.M. understood that the target sentences required metaphoric interpretation: Only 40% of H.M.'s errors involved choosing *metaphoric* foils, whereas 60% involved choosing *literal* foils. This result was predicted under the contextual-integration hypothesis: Because H.M. comprehends familiar word-meanings without integrating them into their sentence contexts, the overlap in word-meanings between the literal foils and target sentences biased H.M.'s responses toward literal foils.

H.M.'s deficits in Experiment 4 contradict theories in which H.M. can readily comprehend never-previously-encountered metaphors. We therefore re-examined the anecdotal examples of H.M.'s metaphor comprehension in Hilts (1995, pp. 115–116). In every example, H.M. produced a contextually inappropriate and difficult to understand response that the producer of the metaphor interpreted as a sophisticated verbal quip. For example, H.M. responded to Corkin's "Henry, you're the puzzle king", with, "Yes, I'm puzzling", as if commenting on his existential condition (puzzling to himself as well as to scientists). However, H.M. may have misunderstood Corkin's "you're the puzzle king" to mean "you're (the) puzzling", an ungrammatical interpretation resembling H.M.'s ungrammatical interpretations in Experiment 1. The remaining anecdotal examples in Hilts also had simple explanations that were consistent with H.M.'s present deficits in metaphor comprehension.

EXPERIMENT 5: THE POSSIBLE INTERPRETATION TASK

Like Experiments 1–4, Experiment 5 tested predictions of binding versus systems theories. However, Experiment 5 also tested the Kensinger et al. (2001) hypothesis that H.M.'s memory deficit caused his comprehension deficits in earlier studies where participants detected and described the two meanings of unbiased ambiguities, e.g., MacKay et al. (1998b). According to Kensinger et al., H.M. forgot the first meaning of the ambiguous sentences while searching for the second, and to eliminate this possibility, Experiment 5 examined H.M.'s comprehension of sentences containing unbiased ambiguities in a task where interpretations were provided rather than retrieved from memory. Experiment 5 is therefore important for determining whether prior results reflected memory deficits rather than comprehension deficits.

On each trial in Experiment 5 participants saw a sentence, e.g., 23, together with a single interpretation, e.g., either 24a, 24b, 24c, or 24d, and responded "yes" if the interpretation was a valid or possible way to understand the sentence, and "no" if not. Unbeknownst to the participants, the target sentences were ambiguous or allowed at least two valid or grammatical interpretations. For example, 24a and 24b are valid interpretations of sentence 23, where *strike* can refer to either a "baseball strike" or a "labour strike".

23. "When a strike was called it surprised everyone." (example sentence)
24a. *Possible interpretation 1:* "The umpire unexpectedly called the pitch a strike."
24b. *Possible interpretation 2:* "The union workers unexpectedly went on a labour strike."
24c. *Somewhat-related foil:* "The union workers have not completely stopped working."
24d. *Totally unrelated foil:* "The umpire quickly called the coaches to the mound."

Four different interpretations were linked with each sentence across trials: two valid interpretations requiring a "yes" response, and two foils, i.e., invalid or "impossible" interpretations requiring a "no" response, e.g., 24c and 24d for sentence 23. Half of the foils involved impossible interpretations *somewhat-related* to a valid interpretation of the target sentence, e.g., 24c, and half involved *totally unrelated* interpretations, e.g., 24d. These totally unrelated foils served to test for guessing in the complete absence of comprehension.

If correct responses do not differ for H.M. versus controls in Experiment 5, this would support two claims in Kensinger et al. (2001): that H.M.'s comprehension of ambiguous sentences is unimpaired, and that processes linked to H.M.'s memory deficit directly caused his comprehension deficits in MacKay et al. (1998b). However, if H.M. responds incorrectly more often than controls in Experiment 5, this would indicate that H.M.'s deficits for ambiguous sentences reflect failure to comprehend single meanings rather than forgetting of multiple meanings.

Method

Materials. The materials were 28 ambiguous sentences (modified slightly from MacKay & Bever, 1967, and Lackner, 1974) with interpretations that were unbiased, i.e., the subordinate meaning was often perceived first in pilot studies with normal controls. Eight contained lexical ambiguities, e.g., sentence 23, and twenty contained structural ambiguities, e.g., "John spoke to the woman in tears". The structural ambiguities included a variety of deep structure, surface structure, and referential ambiguities (see MacKay & Bever, 1967). Seven of the surface structure ambiguities contained phrases with early versus late attachment interpretations. For example, the sentence, "John spoke to the woman in tears" has an early attachment interpretation ("John was in tears") and a late attachment interpretation ("the woman was in tears").

Each sentence was typed in large font above a single interpretation on a 4×6-inch index card. Mean length was similar for the 28 ambiguous sentences (mean length = 9.39 words), the 56 possible interpretations (mean length = 9.45 words), and the 56 impossible interpretations (mean length = 9.52 words), and the four interpretations for any given sentence never differed from the mean length by more than 1.5 words. An additional 8 sentence-interpretation pairs served as practice trials.

Procedure. The instructions were presented verbally as well as visually on a continuously displayed card: Read each sentence and interpretation aloud and respond "yes" if the interpretation is a valid or possible way to understand the sentence, and "no" if not. On each trial, the experimenter flipped over a card, displaying the sentence-interpretation pair. The card was removed after the participant responded "yes" or "no", and the next sentence-interpretation pair was displayed. Each sentence recurred four times across the 112 trials with a different interpretation each time. Sentence-interpretation pairs appeared in identical pseudo-random order for H.M. and controls with at least 10 trials separating recurrences of the same sentence. As in earlier experiments, the experimenter took care to avoid verbal cues by which H.M. or controls could modify their responses and sat behind a shield to prevent H.M. from receiving non-verbal feedback.

Results and discussion

Controls chose the correct response for 75% of the sentences ($SD = 2.71\%$), versus 56% for H.M., a deficit of more than 6 *SD*s. As a second indication of comprehension deficit, H.M.'s responses were biased in favour of "no" across all sentences (81%): When the correct response was "yes", H.M.'s raw score was 25%, 2.9 *SD*s below the mean for controls ($M = 64\%$,

TABLE 3
Responses of controls and H.M. to an example sentence-interpretation pair in Experiment 5

Sentence-Interpretation Pair "The highway patrol found the truck that was hijacked in Boston."
"The hijacked truck did not contain hostages"
Control Responses (N = 6): "no"
H.M. Response: "Well, possibly the same thing, but the hijacked truck did not contain hostages. And they'd say – they would just ... they found the truck that was hijacked in Boston.'
Experimenter: So these could mean the same thing?
H.M.: "They could mean the same thing except the truck was found, that had been hijacked in Boston, and this would did not contain hostages, so it didn't –"

$SD = 13.58\%$). As a third indication of comprehension deficit, controls responded "no" more often for totally unrelated than somewhat-related foils (92 vs. 80%), indicating recognition of the semantic overlap between target sentences and the somewhat-related interpretations. By contrast, H.M. responded "no" equally often to the somewhat-related and totally unrelated foils (89%), indicating either low motivation or guessing in the complete absence of comprehension.

However, H.M.'s deficits were not due to low motivation: Instances where H.M. refused to answer "yes" or "no" despite prompting from the experimenter indicated a strong desire to respond correctly in this task. For example, H.M. insisted that "The hijacked truck did not contain hostages" was and was not a possible interpretation of the sentence, "The highway patrol found the truck that was hijacked in Boston" (see Table 3 for H.M.'s full response). In contrast, controls never responded "yes-and-no" to any sentence-interpretation pair.

As a subsidiary result, H.M.'s comprehension deficits varied little with ambiguity type. H.M. did slightly better for structural ambiguities (59% correct and 15% worse than controls) than for lexical ambiguities (50% correct and 27% worse than controls; see MacKay et al., 1998b, for a similar result). Nevertheless, for structural ambiguities with early versus late attachment interpretations, H.M. was only 43% correct (22% worse than controls). Moreover, controls performed better for late (74% correct) than early (55% correct) attachment interpretations, a different pattern from H.M., whose performance was identical for early and late attachment interpretations (43% correct).

Present results supported binding theory, which predicted deficits for H.M. in comprehending novel aspects of never-previously-encountered sentences, including both the ambiguous sentences and the single meaning interpretations in Experiment 5. H.M.'s poor performance for lexically ambiguous sentences was also consistent with the contextual-integration corollary tested in Experiment 6; that H.M. has difficulty integrating the meanings of lexically ambiguous words with novel or never-previously-encountered sentence-contexts.

Consistent with present results, H.M. in 1967 detected two meanings in ambiguous sentences significantly less often than age-matched controls, same-cohort older adults, and a patient with bilateral frontal lobe damage equal in extent to H.M.'s MTL damage (see MacKay et al., 1998b). Also consistent with present results, Zaidel, Zaidel, Oxbury, and Oxbury (1995) reported ambiguity detection deficits in a large number of amnesic patients with unilateral left-sided surgical lesions to the anterior hippocampus.

Present results also comport in *magnitude* with H.M.'s comprehension deficits in earlier studies. For example, in MacKay et al. (1998b), H.M. scored 20% on a two-choice recognition test of lexical ambiguity in sentences, and in Experiment 5 scored 25% for valid interpretations of lexically ambiguous sentences.

Present results did not support systems theories in which H.M. exhibits a pure memory deficit with unimpaired language comprehension. Present results also failed to support the Kensinger et al. (2001) hypothesis that H.M.'s memory problems caused his comprehension deficits in earlier studies involving ambiguous sentences (e.g., MacKay et al., 1998b): H.M.'s comprehension deficits in Experiment 5 were not due to forgetting of one meaning while searching for a second because only one meaning was relevant on any trial and appeared in full view beneath the ambiguous sentence on the card, making memory retrieval unnecessary.

Many earlier findings also contradict the Kensinger et al. forgetting or memory load hypothesis. First, H.M. was often unable to repeat a single meaning that an experimenter had just explained to him in MacKay et al. (1998b), indicating a comprehension deficit for a *single meaning*. Second, H.M. required experimenter help in finding the first meaning of ambiguous sentences more often than controls in MacKay et al. (1998b), again indicating a comprehension deficit for *one meaning* in ambiguous sentences. Third, the time to begin describing the *first* meaning of the ambiguities was much longer for H.M. than controls even when H.M. never discovered the second meaning in MacKay et al. (1998b), again indicating a comprehension deficit for the first meaning that is independent of the second. Fourth, seven aspects of how H.M. *described* the sentence-meanings in MacKay et al. (1998b), indicated deficits in comprehending a *single* meaning in ambiguous sentences (see Table 4 for examples).

Impossible interpretations. H.M. often gave interpretations that were impossible or inapplicable to *either* meaning of the ambiguous sentences (see Table 4), indicating a comprehension problem that goes beyond ambiguity detection to sentence comprehension per se.

Pronoun misuse. H.M. often misused pronouns in a way that suggested impaired comprehension for pronouns and their referents in the sentences he was describing (see Table 4).

Uncorrected errors. When describing single meanings in ambiguous sentences H.M. often produced errors that resulted in ungrammatical and incoherent utterances (see Table 4), and the fact that he failed to correct these errors suggested a problem in comprehending his own output.

Free associations. H.M. often produced free associations to his own just-produced output (see Table 4), which suggested that H.M. did not understand what he himself was saying.

Failure to follow experimenter requests. H.M. often failed to follow experimenter requests, e.g., to clarify an utterance that he had just produced, as if he did not understand either the request or the need for clarification (see Table 4).

Self-miscomprehensions. After describing one interpretation for a sentence, H.M. often reiterated it immediately with only minor rewording and insisted that his first and second descriptions differed (see Table 4), as if unaware of their basic equivalence.

Misreadings. When asked to read sentences aloud, H.M. often misread them, sometimes repeatedly (see Table 4), and his misreadings indicated a problem not in perceiving orthography or phonology, but in comprehending sentence-level meaning (see MacKay et al., 1998b).

TABLE 4
Examples of H.M.'s comprehension problems involving single meanings as inferred from meaning descriptions in MacKay et al. (1998b)

Types of problems	*Example meaning descriptions*
Impossible interpretations	H.M. (in describing the sentence, *We are confident that you can make it*): "A person is sure himself that others are sure that he can do it." (a grammatically impossible interpretation)

(*Continued overleaf*)

TABLE 4—*continued*

Misuse of pronouns	H.M. (in describing *We are confident that you can make it*): "He's confident he can do it, he's sure he can do it." (substitution of "he" for "we" and "you" in "We're confident that you can do it")
Uncorrected errors	H.M. (in describing the "job" interpretation of position in *The marine captain liked his new position*.): "He liked the new position because of being, being a passenger line." (omission of "on" following "being" mistakenly conflates "job position" with "a passenger line.")
Free associations	H.M. (in describing why the captain liked his new position in *The marine captain liked his new position*): "because he was above them and of all, most of all . . ." ("most" is a free association to his immediately prior "of all")
Failure to follow experimenter requests	H.M. (in describing the meanings of *I just don't feel like pleasing salesmen*.): "Well, I think of one thing, the person doesn't like salesmen that are pleasing to him. Uh, and that personally he doesn't like them and and personally he doesn't like them and then I think of a phrase that he would say himself, he doesn't, uh, pleasing, as conglamo, of all of pleasing salesmen." Experimenter: "Uhmmm. That's one meaning." HM: "You say that's one, there's two meanings to it." Experimenter: "Why, what's the second one?" (request for clarification) HM: "Because the second one I think of is, uh, salesmen that are pleasing, they are pleasing to, he doesn't like them." (repetition without clarification)
Self-miscomprehensions	H.M. (following from the preceding excerpt): "Because the second one I think of is, uh, salesmen that are pleasing, they are pleasing to, he doesn't like them." Experimenter: "OK, that's the same meaning." HM: "No, it isn't." Experimenter: "What's the other one then?" HM: "Well, he doesn't like to see them around. Any man who is trying, they, uh, people, they say they are pleasing salesmen, well, that pleasing salesman. And uh . . ."
Misreadings	Experimenter (following from the preceding excerpt): "Read the sentence." H.M.: "I don't like pleasing salesmen." (misreading) Experimenter: "No, read it again." H.M.: "I just don't like pleasing salesmen." (misreading) Experimenter: "You're leaving out a word." H.M.: "I just don't feel like pleasing' yep." Experimenter: "Read it again, then." H.M.: "I just don't feel like pleasing salesmen." (correct)

EXPERIMENT 6: DETECTING AND DESCRIBING AMBIGUITIES IN FAMILIAR PHRASES VERSUS SENTENCES

Experiment 6 had three related goals. Goal one was to test the contextual-integration account of why H.M. exhibits deficits in detecting lexical ambiguities in sentences (MacKay et al., 1998b). As in Lackner (1974) and MacKay et al. (1998b), Experiment 6 participants performed two related tasks: detection of the two meanings in stimuli known to be ambiguous, followed by description of the two meanings. However, only lexical ambiguities were presented in Experiment 6, and the lexical ambiguities occurred in isolated words and short 2–4 word phrases, e.g., *the bank*, rather than in sentences. We then compared H.M.'s ability to detect two meanings for familiar lexically ambiguous words and phrases versus for lexically ambiguous sentences in MacKay et al. (1998b). Systems theories in which H.M. has a pure memory deficit predicted no ambiguity-detection deficit for either sentences or isolated words and phrases. The contextual-integration corollary predicted a large ambiguity-detection deficit for the sentences (where H.M. must form new representations to integrate both lexical meanings with the never-previously-experienced sentence context; see the introduction) but no ambiguity-detection deficit for the familiar words and phrases (because H.M. knew these stimuli before his operation, obviating the need for new representations to integrate lexical meaning and context). The deliberate engrainment hypothesis in combination with the contextual-integration corollary also predicted that H.M. will more often repeat words when comprehending lexical ambiguities in sentences than isolated words or phrases because repetition enables the formation of new context-based representations required for comprehension (see the introduction).

Goal two was to test the Kensinger et al. (2001) hypothesis that H.M.'s comprehension deficits reflect across-the-board factors such as upbringing or educational inadequacies. If H.M. exhibits deficits in describing but not detecting phrase meanings, or vice versa, this will indicate that H.M.'s deficits are context- or task-specific rather than general or across-the-board. Our comparison of H.M.'s detection versus description performance for phrases in Experiment 6 versus sentences in Lackner (1974) and MacKay et al. (1998b) also allowed us to test a task-difficulty account of phrase verses sentence differences; that H.M. does well across-the-board on easier tasks (detecting and describing ambiguity in isolated words and phrases) but poorly across-the-board on more difficult tasks (detecting and describing ambiguity in sentences).

Goal three was to test further the Kensinger et al. (2001) memory load hypothesis: that every word in a visually presented sentence must be stored in memory in order to detect an ambiguity, so that H.M.'s reduced memory capacity caused his ambiguity detection deficits. This memory load hypothesis predicts increased ambiguity detection deficits for H.M. as the number of stimulus words increases, and Experiment 6 tested this prediction for long versus short *phrases* (involving a minor memory load) and for long versus short *sentences* (involving a more extensive memory load) in MacKay et al. (1998b).

Method

Materials. The main materials are shown in the Appendix and consisted of 20 stimuli, e.g., *the pipe, the port, to run out of*, that each had at least two distinct lexical meanings. There were 3 additional practice stimuli, and all 23 stimuli were typed in large font on 4×6-inch index cards. All stimuli were extracted from ambiguous sentences published in MacKay and Bever (1967) and consisted of familiar phrases (mean length = 2.47 words) except for three isolated words with ambiguities that were difficult to preserve in a familiar phrase, e.g., *lots*. To test the memory load hypothesis using these materials, we defined phrases above the median length (2 words) as long, and phrases/isolated words at or below the median length as short. To test the memory load hypothesis for the lexically ambiguous sentences in MacKay et al. (1998b), we defined sentences above the median length (7 words) as long, and sentences at or below the median length as short.

Procedure. The instructions were presented verbally and visually on a continuously displayed card: Each stimulus is ambiguous or has two meanings. Read the stimulus aloud, say "yes" when you perceive two distinct meanings, and then describe the two meanings in the order perceived. The experimenter (L.J.) displayed the stimulus for each trial by flipping over the card on which it was typed. After practice but not experimental trials, the experimenter provided a succinct summary for the two meanings of the stimuli. All participants saw the stimuli in the same random order.

To determine whether H.M. exhibited production deficits in *communicating* the two meanings of the phrases, we tape recorded the sessions and created verbatim transcripts of the output of H.M. and the controls: One researcher initially transcribed each tape as accurately as possible. Later she and a second researcher read the transcript while listening to the tape and modified the transcript by consensus. We then obtained ratings of communicative ability as in MacKay et al. (1998b): Seven naive judges (mean age = 18.9, mean years of education = 13.2) rated the transcribed responses of H.M. and memory-normal controls on four global dimensions: redundancy, comprehensibility, grammaticality, and focus or coherence. Although blind to speaker identity, the judges knew the responses described the two meanings of ambiguous words and phrases. For each stimulus, the judges simultaneously compared the descriptions of all seven participants and used seven-point scales (1 = not at all; 7 = very) to rate each description on the four labelled dimensions. Instructions called on the judges to ignore factors such as the accuracy or completeness of the responses and focus exclusively on how the speakers expressed themselves.

Results and discussion

The contextual-integration corollary. Controls correctly described the two meanings for 73% ($SD = 14.4\%$) of the phrases and isolated words, versus 60% for H.M., a difference relative to controls of less than 1 *SD*, indicating that H.M. was unimpaired in detecting the dual meanings of lexical ambiguities in phrases and isolated words. This result contrasts sharply with H.M.'s large deficits in detecting many of the same lexical ambiguities when embedded within sentences. H.M. detected only 20% of the lexical ambiguities in the Lackner (1974) sentences, a deficit in excess of 17 *SD*s relative to controls (81% overall, $SD = 3.51$; see also MacKay et al., 1998b). These contrasting results for sentences versus isolated words and phrases support predictions of binding theory and the contextual-integration corollary: that H.M. has little difficulty activating multiple meanings in isolated words and familiar phrases learned before his operation, but has major difficulties integrating these meanings into novel sentences that require new context-based internal representations. However, despite the ubiquity of lexical ambiguity in everyday sentences, H.M.'s Experiment 6 deficits do not imply across-the-board comprehension failure. The ambiguity detection task requires precise discrimination between the two meanings of each ambiguity and allows no room for guessing, unlike either everyday comprehension or the comprehension of thematic roles in Experiment 3.

The deliberate engrainment hypothesis. Consistent with the deliberate engrainment hypothesis, H.M. often repeated the ambiguous words when describing lexical ambiguities in sentences regardless of whether he succeeded in discovering the ambiguity, but he rarely repeated the ambiguous words when describing lexical ambiguities in isolated phrases. Table 5 illustrates this difference for the typical case where H.M. successfully described both meanings in an isolated phrase (*the position*) but only one meaning in the corresponding sentence, *The marine captain liked his new position* (transcript from Corkin, 1973). Note that when describing the sentence, H.M. repeated the ambiguous word *position* four times and the contextual word *new* six times, but he produced *position* only once in describing *the position* as an isolated phrase (see Table 5). Table 6 illustrates this difference for the less typical trials where H.M. *successfully* described both meanings of a lexically ambiguous word (*lots*) in isolation and in a

TABLE 5
H.M.'s descriptions of the same lexical ambiguity (position) in a phrase (Experiment 6) versus in a sentence (data from Corkin, 1973)

EXPERIMENT 6 STIMULUS: the position

H.M.: The position (reading). And, it could be the place where you work, have work. And also it could be your election place. Spot. Position.

CORKIN (1973) SENTENCE: The marine captain liked his new position

H.M.: The first thing I thought of was a marine captain he liked the new position on a boat that he was in charge of, the size and kind it was and that he was just made a marine captain and that's why he liked the position too, because he was above them and of all, most of all . . .
Experimenter: So you're saying that he like (sic) his job in other words.
H.M.: He liked his job.
Experimenter: Okay. Now, there is another meaning in that sentence. Can you tell me what it is?
H.M.: I just gave you two.
Experimenter: Those are both really the same. Because they were both related to his job. There is another meaning.
H.M.: Well, cause he was on a new boat, you might say a new boat, he was made captain of a new liner or whatever it is and it's different than what he had before. He might have had a . . . a . . . a . . .
Experimenter: You mean his job was different.
H.M.: Yes, he might, he has people . . .
Experimenter: That's the same meaning that you told me. There's another meaning that's suggested by those same words, in that same order, something . . .
H.M.: Well, you see, I thought of marine captain in a new position, was one, was transporting goods, he was a marine captain of a boat there and then marine captain he liked the new position because of being, being a passenger line, I'd guess you'd call it, because of the people that would . . .
Experimenter: All right, I'm going to tell you what the other meaning is. One meaning, that one that you have, means that he likes his new job. The other meaning is that he likes his new physical position. In other words, he may have been standing up on watch for a great number of hours and then he gets to sit down and he likes that new position of being able to sit down. The position of his body.
H.M.: Oh.
Experimenter: Okay? Do you see how those are really rather different meanings?
H.M.: They're different.
Experimenter: One has to do with his job and the other is if he is sitting, standing or whatever.
H.M.: The position he's in.
Experimenter: The position of his body. OK, you see? Do you understand how the very same words can mean two different things, two different interpretations depending on how you read it? OK. (next trial).

sentence (*The salesman wanted lots of that size*; data from Corkin, 1973). Note that H.M. produced no repetitions when describing *lots* as an isolated word, but when describing *lots* in the sentence, H.M. produced five repetitions of *lots* and 10 repetitions of the contextual word *size* (one in

TABLE 6
H.M.'s descriptions of the same lexical ambiguity (lots) in an isolated word (Experiment 6) versus in a sentence (data from Corkin, 1973)

EXPERIMENT 6 STIMULUS: lots

H.M.: And that could be many or more.
Experimenter: OK – so that's – can you read it for me?
H.M.: Lots.
Experimenter: Uh huh. And so "many" is one meaning.
H.M.: And more.
Experimenter: OK, can you think of one more meaning for this too?
H.M.: And uh well, uh it'd be uh, also it'd be that the – I think it's, uh, probably, straw.
Experimenter: OK.
H.M.: Long and short ones. (a reference to "using long and short straws to draw lots")

CORKIN (1973) SENTENCE: The salesman wanted lots of that size.

H.M.: I thought of a salesman wanting meaning, wanting to buy or to collect lots of a certain size, of one size.
Experimenter: OK.
H.M.: And he wanted to sell the property he had or the lots he had in a certain size, so that he'd have, he'd get to match one size that he wanted.
Experimenter: No, I don't want you to tell me a story about it. I want you to tell me . . . (repeated instructions omitted) . . . There are two completely different interpretations of that sentence.
H.M.: Well, one would, a salesman wanted to buy different size or of that size, that particular size, one size
Experimenter: Now give me an example of what you mean.
H.M.: Well, if there were several lots, uhmm, say there's three lots and you wanted just a 50×100 and there was two of them that were 50×100 so you'd buy that those two.
Experimenter: So, you're saying that he wanted tracts of land of a particular
H.M.: Well, lots.
Experimenter: of particular dimensions.
H.M.: Dimensions.
Experimenter: Is that what you mean? OK.
H.M.: Yes, same size. Those two would
Experimenter: Now, what's the second meaning?
H.M.: The second I thought of was no particular thing but he wanted lots of them, meaning many of them, but that particular size.
Experimenter: OK. In other words, lots in this case refers to quantity.
H.M.: Yeh.
Experimenter: Rather than plots of land.
H.M. (simultaneously): plots of land.

describing *lots* as "many" and nine in describing *lots* as "plots of land"; see Table 6). Under the deliberate engrainment hypothesis, these multiple repetitions of *lots* and *size* enabled H.M. to integrate the two meanings of *lots* with the subsequent sentential context (*of that size*) to successfully describe the ambiguity.

To test the deliberate engrainment hypothesis, we compared how often participants repeated the lexically ambiguous word in sentences (Corkin, 1973) versus in isolated words and phrases (Experiment 6). When describing the ambiguities in sentences, H.M. repeated the ambiguous terms more often ($M = 7.37$ repetitions per sentence) than controls ($M = 2.78$ repetitions per sentence), a difference reliable at $p < .03$ using a sign test with sentences as unit of analysis. By contrast, when describing the ambiguities in isolated words and phrases, H.M. repeated the ambiguous terms *less* often (1.3 repetitions per stimulus; $SD = 1.2$) than controls (1.8 repetitions per stimulus; $SD = 0.8$), a marginally reliable difference ($p = .08$) using the same test as for the sentences: a sign test with the 20 stimuli as unit of analysis. This contrasting outcome is all the more remarkable because both analyses included descriptions of the second meaning of the ambiguities as well as the first, and as noted earlier, H.M. described the second meaning less often in sentences than in isolated words and phrases (both absolutely and relative to controls).

The contextual integration and deliberate engrainment hypotheses readily explain these contrasting results for isolated words and phrases versus sentences: Repetition and engrainment processes were rarely necessary for H.M. to comprehend or represent familiar words and phrases presented in isolation because no new context-based representations were required. However, repetition and engrainment processes *were* necessary for H.M. to form the new context-based representations for integrating the meanings of these familiar words and phrases with the remainder of a sentence (see also MacKay et al., 1998b).

The across-the-board hypothesis. H.M.'s selective ambiguity detection deficits in sentence but not phrase contexts indicate that his comprehension deficits are not due to general or across-the-board factors such as upbringing, education, or epilepsy-related learning failure: Failure to learn the meanings of ambiguous words cannot explain why H.M. detects an ambiguity in one context (familiar phrases) but not in another (novel sentences).

A comparison of H.M.'s performance in detecting versus describing phrases also revealed selective or context-specific effects that are difficult to explain in terms of across-the-board factors. Our judges rated H.M.'s phrase descriptions as less grammatical, less coherent, less comprehensible, and more redundant than those of controls. Mean grammaticality ratings were 4.3 for controls ($SD = 1.3$) versus 3.5 for H.M. ($SD = 0.9$), $t(6) = 3.18$, $p < .05$ (see Schmolck, Kensinger, Corkin, & Squire, 2002, for a similar result). Mean coherence ratings (averaged across the judges and the phrases) were 4.7 for controls ($SD = 1.3$) versus 4.4 for H.M. ($SD = 1.3$), $t(6) = 2.45$, $p = .05$. Mean comprehensibility ratings were 5.0 for controls ($SD = 0.9$)

versus 4.2 for H.M. ($SD = 0.8$), $t(6) = 2.87$, $p < .05$. Mean redundancy ratings were 2.5 for controls ($SD = 0.6$) versus 3.3 for H.M. ($SD = 0.5$), $t(6) = 5.36$, $p < .01$, undoubtedly due in part to the many clichés or formulaic phrases in H.M.'s descriptions, e.g., "well" and "in a way" (see Tables 2–7). This preponderance of clichés or formulaic phrases in H.M.'s descriptions comports with earlier results indicating that H.M. tends to repeat stock phrases such as "I thought of", "in a way", and "I'm having an argument with myself" reliably more often than controls (MacKay et al., 1998a).

Because H.M. achieved ratings within the middle range (3.3–4.4) rather than near the ends of our scales (1 and 7), H.M.'s deficits in describing the two meanings of isolated words and phrases might be labelled "relatively

TABLE 7
H.M.'s meaning descriptions for the stimuli board and to look in Experiment 6

STIMULUS: board

H.M.: Broad. And that could be ...
Experimenter: No, wait, read it one more time.
H.M.: Oh, board.
Experimenter: Yep.
H.M.: It could be to uh – the board you have.
Experimenter: What would that mean? Can you explain that a little?
H.M.: Well, the amount that you have to pay rent.
Experimenter: OK.
H.M.: And also, for eating there.
Experimenter: Mmhm.
H.M.: And drinking, some, board. And the other way is "broad."
Experimenter: No, using this same way, still the – just the word board, can you think of another meaning?
H.M.: Well, live in a place.
Experimenter: OK.
H.M.: I said that – I said that already.
Experimenter: You said that one. Uh huh. Can you think of another meaning for board?
H.M.: Well, wide.
Experimenter: That's what broad means. Broad is wide. Can you think of one more for board? Besides paying to live somewhere?
H.M.: Wide.
Experimenter: OK, what about um, a board, like a plank of wood, have you ever heard of that being called a board?
H.M.: A board, yes.

STIMULUS: to look

H.M.: To look. And that could be, uh, when you oversee something, and when you see something too.
Experimenter: Good, so can you explain how those two are different from each other?
H.M.: One is to, well, overlook it, in a way, and get the job – guard against it, in a way.
Experimenter: OK.
H.M.: And uh, abide by it. And the other is, to just look at it, and see how it is.

minor''. Present deficits nevertheless replicate the results of MacKay et al. (1998a) and illustrate another way in which H.M.'s language deficits are selective: Non-deficits in *comprehending* the phrases accompanied reliable deficits in *describing* the same phrases. H.M.'s production deficits also contradict stimulus- or task-difficulty explanations because H.M. did not do well across-the-board for easier tasks or stimuli: H.M. exhibited deficits when *describing* ambiguities in both simple stimuli (isolated words and phrases) and complex stimuli (sentences).

The memory load hypothesis. Contrary to the improved ambiguity detection predicted for short phrases under the memory load hypothesis, H.M.'s ambiguity detection was no better for short than long phrases. Controls detected 73% of the ambiguities in short phrases (*SD* = 14%) versus 53% for H.M, a 1.43 *SD* deficit, whereas controls detected 73% of the ambiguities in long phrases (*SD* = 30%) versus 80% for H.M, a 0.23 *SD* difference favouring H.M.

H.M.'s ambiguity detection likewise showed no improvement with reduced sentence memory load. For the short sentences in MacKay et al. (1998a), controls detected 90% of the ambiguities without help from the experimenter (*SD* = 12%) versus 38% for H.M (a 4.33 *SD* deficit), whereas for the long sentences, controls detected 67% of the ambiguities without help (*SD* = 25%) versus 37% for H.M, a difference of only 1.2 *SD*. Present results therefore contradicted the memory load hypothesis both for the relatively minor load of isolated words and phrases and for the more extensive load of sentences.

A subsidiary result. Unlike controls, H.M. produced unusual perseverative errors in the phrase description task. For example, H.M. initially misread the stimulus ''board'' as ''broad'', and corrected his error following an experimenter prompt (see Table 7). Then, after successfully describing one meaning for ''board'', H.M. repeatedly attempted to define ''broad'', despite objections from the experimenter. Another remarkable perseverative error involved the stimulus ''to bear''. H.M. first gave an appropriate meaning for ''to bear'', and then an inappropriate meaning, ''to oversee it'', which he immediately retracted: ''No – not that way.'' Nevertheless, when the experimenter requested a second meaning for ''to bear'', H.M. again produced ''to oversee'', this time without correction, and what made this perseverative error doubly remarkable was that two trials earlier, H.M. had mistakenly defined ''to look'' as ''to oversee'' (see Table 7). H.M. produced similar repetition or perseverative errors when reading lists of isolated words and pseudo-words (often with very short lags between repetitions; see MacKay & James, 2002) and in a wide range of other tasks and contexts discussed in MacKay et al. (1998a). Interestingly, however, H.M. performed normally in the early 1960s on the Wisconsin Card Sort task, a standard test of perseveration tendencies (see Milner, 1963).

GENERAL DISCUSSION

This section first summarises present results together with other evidence indicating selective impairment in H.M.'s cognitive functions. We then discuss the relation between H.M.'s selective deficits and the theoretical issues outlined in the introduction.

H.M.'s sentence-level comprehension and production deficits

The present study provided 11 new sources of evidence for deficits in H.M.'s sentence-level comprehension and production. In a task requiring yes–no discrimination between grammatical versus ungrammatical sentences with a wide variety of syntactic structures, H.M. exhibited an overall deficit of 2.13 *SD*s relative to controls, and a 3.59 *SD* deficit in recognising that grammatical sentences were grammatical.

In a task requiring detection of incorrect or misordered words in sentences, H.M. exhibited an overall deficit of 3.18 *SD*s relative to controls, a 2.48 *SD* deficit in recognising that error-free sentences were error-free, and a more than 6 *SD* deficit in repairing sentences that he correctly identified as containing an error. Moreover, H.M.'s errors in identifying wrong or misordered words indicated that many of his original comprehension responses in this task were based on guessing.

In a task requiring comprehension of the thematic role of words in sentences (i.e., who-did-what-to-whom), H.M. exhibited a 2.55 *SD* deficit relative to controls. In a task requiring yes–no recognition of the appropriate interpretation for sentences containing metaphors, H.M. exhibited a deficit in excess of 6 *SD*s, and his errors indicated no awareness that the sentences required metaphoric interpretation. In a task requiring yes–no recognition of possible interpretations for ambiguous sentences, H.M. exhibited an overall deficit in excess of 6 *SD*s relative to controls, and unlike controls, he sometimes failed to follow experimenter requests to give "yes or no" answers. Moreover, subsidiary results indicated that H.M.'s comprehension deficits for ambiguous sentences were not due to memory overload or to forgetting associated with storing or retrieving multiple meanings, findings that reinforce 1998 results indicating that H.M.'s memory deficits were not the cause of his ambiguity detection deficits (see MacKay et al., 1998b).

Subsidiary results also ruled out low motivation and failure to understand or follow the instructions as explanations for H.M.'s comprehension deficits.

Nor were H.M.'s comprehension deficits due to inability to understand individual words: Our materials only included HF words that presented in isolation are comprehended without deficit by H.M. (see James & MacKay, 2001). Finally, H.M.'s comprehension deficits were not attributable solely to syntactic structures that memory-normal participants find difficult to recall: H.M. exhibited deficits for both easy- and difficult-to-recall structures in our materials.

The selective nature of H.M.'s sentence-level comprehension and production deficits

Just as H.M.'s memory deficits spare memories based on perceptual, stimulus-response, and motor learning (Spiers et al., 2001), H.M.'s comprehension deficits in the present data were *selective* rather than across-the-board. H.M. exhibited no deficit in detecting the multiple meanings of familiar words and phrases in Experiment 6, despite his large deficits in detecting many of these same meanings when embedded within sentences in Lackner (1974) and MacKay et al. (1998b). Similarly, H.M. exhibited no deficit in identifying scrambled sentences as ungrammatical in Experiment 1, despite his large deficits in identifying other types of "grammatical error".

As further evidence for selectivity, H.M.'s response biases in the present experiments suggested unimpaired comprehension of the word "no" but only as an isolated word: H.M.'s "no" bias reflected the word-specific meaning of "no" rather than experiment-specific uses of "no" because "no" meant "ungrammatical" in Experiment 1 but "grammatical" in Experiment 2. Experiment 6 data indicated further that H.M. understands without deficit the multiple meanings of familiar lexically ambiguous words and phrases *in isolation* but not in *sentences*. This dissociation between H.M.'s ambiguity detection deficits in sentences versus isolated words and phrases was not due to stimulus difficulty or complexity per se because no analogous dissociation emerged when H.M. *described* the ambiguities in words and phrases versus in sentences.

Further illustrating the selective nature of H.M.'s language deficits, H.M. exhibited significant production deficits when describing the meanings of ambiguous phrases that he comprehended without deficit: Experiment 6 judges rated H.M.'s meaning-descriptions as more redundant, less coherent, less grammatical, and less comprehensible than those of controls. However, like his comprehension deficits, H.M.'s production deficits were selective: H.M. had no problems producing familiar phrases, clichés, and HF words as phonological units in Experiment 6. Indeed, H.M. produced an *excess* of clichés in Experiment 6, just as in MacKay et al. (1998a), where he repeated formulaic phrases such as "I thought of", "in a way", and "I'm having an argument with myself" reliably more often than controls.

Theoretical implications

H.M.'s selective sentence-level comprehension deficits carry theoretical significance because they closely parallel his selective deficits for novel but not for preoperatively familiar forms in many other domains, e.g., sentence-reading, spoken language production, and visual cognition. When reading sentences aloud (see MacKay & James, 2001), H.M. produces unusual prosodic pauses within unfamiliar but not familiar phrases in novel sentences, and at major syntactic boundaries unmarked by commas. However, H.M. pauses normally at major syntactic boundaries marked by commas, a signal for prosodic pausing that children learn during grade school. These selective sentence-reading deficits indicate that H.M. only has difficulty with the process of syntax construction when comprehending and producing novel aspects of sentences, just as he only exhibits deficits in spoken production of novel aspects of sentences (see Experiment 6; also MacKay et al., 1998a; MacKay & James, 2001). Similarly for visual cognition, H.M. exhibits selective deficits in detecting unfamiliar but not familiar visual figures hidden in concealing arrays (MacKay & James, 2000). In short, H.M.'s pattern of deficits and sparing spans sentence-level comprehension, reading aloud, spoken language production, and visual cognition.

Moreover, H.M.'s memory exhibits the same pattern of deficits and sparing. As noted in the introduction, H.M. exhibits memory deficits for novel information tested in explicit, episodic, declarative, conscious retrieval tasks, and implicit memory tasks involving preoperatively unfamiliar words (Gabrieli et al., 1988). However, H.M. exhibits sparing for familiar or frequently repeated information in repetition priming tasks, eyeblink conditioning tasks, motor skills tasks, implicit memory tasks involving preoperatively familiar words, and tasks involving massively repeated semantic information (Gabrieli et al., 1988; Keane, Gabrieli, & Corkin, 1987; Keane, Gabrieli, Mapstone, Johnson, & Corkin, 1995; Skoto et al., 2004; Spiers et al., 2001). Under binding theory, this pattern of memory deficits parallels H.M.'s language and visual cognition deficits: spared activation of familiar or already formed representations but impaired binding or connection formation processes for creating never-previously-encountered representations. For example, H.M. exhibits implicit memory deficits not for preoperatively familiar words but for unfamiliar words that lack preformed internal representations. However, H.M. always exhibits episodic memory deficits because episodic encoding always requires the formation of new connections to represent the context (e.g., place or time) of occurrence of unique events or episodes, e.g., the fact that a particular word occurred in a particular experimental list.

H.M.'s selective deficits under systems theory

Under systems theory, the parallels between H.M.'s sparing and impairment in language, memory, and visual cognition are accidental. H.M.'s lesion has by chance impaired three separate memory systems, one system for episodic, declarative, explicit or consciously retrieved memories, a second system for novel semantic information, and a third system for novel memories tested implicitly. Likewise by chance, H.M.'s lesion has spared four separate memory systems: for eyeblink conditioning; for motor skills; for massively repeated semantic information; and for familiar memories tested implicitly.

Also by chance under systems theory, H.M.'s lesion has impaired one visual cognition system for detecting unfamiliar hidden figures, but has spared another visual cognition system for detecting familiar hidden figures. Likewise by chance, H.M.'s lesion has impaired three separate language systems: for generating prosody when reading unfamiliar phrases and novel sentences without commas; for spoken production of novel phrases and sentences; and for comprehending metaphors, lexically ambiguous words, thematic roles, and "errors" or anomalies in sentences. However, again by chance, H.M.'s lesion has spared three separate language systems; for generating prosody when reading familiar phrases and novel sentences with commas; for spoken production of familiar sentences, words, and cliché phrases; and for comprehending isolated HF words. In short, to "explain" our main results under systems theory, H.M.'s MTL lesion has accidentally spared or damaged over a dozen separate systems, many with no independently motivated *raison d'etre*.

Moreover, this highly unparsimonious proliferation of systems ignores the detailed nature of our results. Why was H.M. but not controls biased toward responding "no" in both Experiment 1 and 2 when "no" represented the concept "ungrammatical" in Experiment 1 but "grammatical" or error-free in Experiment 2? Why did H.M. usually choose literal rather than metaphoric foils when miscomprehending metaphors in Experiment 4? Why did H.M. but not controls often repeat the critical ambiguous words when describing sentence meanings in Experiment 6? Why did H.M. repeat lexically ambiguous words in sentences but not in familiar phrases in Experiment 6? Systems theory provides no answer to these questions.

To summarise, present results do not contradict the concept of functional or neural systems per se: Systems theory can "explain" our results post hoc, but only at great cost in parsimony, and only by ignoring significant details.[3] On the other hand, present results indicate a clear need for principled theoretical and empirical bases whereby systems theory can define and establish memory systems and the dividing lines between them (see also Barnard & Dalgleish, 2005). To illustrate the type of criteria that seem needed, we outline the empirical and theoretical bases for postulating the systems shown in Figure 1: the phonological versus semantic systems.

Unlike the global systems for comprehension versus production originally postulated by Wernicke (1874), the semantic and phonological systems are *language-memory* systems, with content, activation and binding nodes for comprehending, producing and retrieving words, phrases and propositions housed in the semantic system, and content, activation and binding nodes for perceiving, producing and retrieving syllables, phonological compounds and segments housed in the phonological system. Three criteria discussed next were used to delineate these language-memory systems, and similar criteria may serve to delineate non-linguistic cognitive systems (see MacKay, 1987, pp. 1–61).

The independent activation criterion. Under binding theory, the distinction between priming versus activation is central to distinguishing between systems. Although activated nodes automatically transmit priming to connected nodes in any system, priming doesn't necessarily lead to activation: Application of a *system-specific* activating mechanism is necessary to trigger activation. For example, when a speaker familiar with the noun *computer* sees a computer, the node representing the noun *computer* becomes primed or readied for activation in the sentential-semantic system. However, the speaker doesn't necessarily activate and produce the word *computer* after seeing a computer: We don't go through life naming everything we see. To name an observed object such as a computer, an activating mechanism specific to the semantic system must activate the most primed lexical node in the noun domain.

Because functionally independent activating mechanisms activate the content nodes in different systems, content nodes in one system can be activated independently from content nodes in another system, and independently activatable content nodes are part of different systems under the independent activation criterion. Phonological and muscle movement nodes for producing speech clearly satisfy this independent activation criterion because we can produce internal speech without the occurrence of full articulation (MacKay, 1992b): Internal speech occurs

[3] Similar parsimony issues apply to the hypothesis that disruption of hypothetical couplings between memory systems and language systems represents the basis for HM's language deficits.

when we activate phonological nodes without activating muscle movement nodes, indicating that phonological and muscle movement nodes occupy separate systems under the independent activation criterion. Similarly, we can produce sequentially organised thought without either overt muscle movement or awareness of inner speech sounds, indicating independent activation of nodes in three separate systems under the independent activation criterion: a semantic system, a phonological system, and a muscle movement system. Of course, only phonological system nodes are activated when experimentally constructed nonsense syllables are produced internally whereas nodes in all three systems are activated in concert during full-blown sentence articulation (see MacKay, 1992b).

The connectivity criterion. Content nodes for perceiving and producing sentences are organised hierarchically within and between systems, and differing patterns of connectivity for nodes at the highest versus lowest levels in a system indicate where one system ends and another begins under the connectivity criterion. In general, the highest level nodes in a system only receive bottom-up connections from within the system, whereas the lowest level nodes receive both lateral and bottom-up connections from outside the system. For example, syllable nodes only receive bottom-up connections from within the phonological system, whereas lexical nodes receive both bottom-up and lateral connections from nodes in many other systems, so that speakers can produce the word *apple* based, for example, on the sight, smell, or taste of an apple, as well as on hearing or seeing the word *apple* (see MacKay, 1987, pp. 14–38). The dividing line between phonological versus semantic systems therefore falls between syllable and lexical nodes under the connectivity criterion, with syllable nodes as the highest level in the phonological system, and lexical nodes as the lowest level in the sentential system.

The error frequency criterion. In theory, errors are relatively more common for low-level than high-level units (for reasons related to speed-accuracy trade-off; see MacKay, 1987, p. 61), so that error frequencies can help distinguish where one system ends and another begins. For example, syllable errors are rare relative to word errors, a quantum jump in error frequency that helps locate the dividing line between the phonological and sentential systems.[4]

[4] See also MacKay (1987, pp. 44–45), where error frequencies provided the grounds for postulating hundreds of sub-systems known as sequential domains, the functionally distinct sets of content nodes that provide the organisational basis for activating nodes under the most-primed-wins principle.

H.M.'s selective deficits under binding theory

Unlike systems theory, binding theory provides a simple account of H.M.'s parallel deficits and sparing in language, memory, and visual cognition. Under binding theory, H.M.'s 1953 lesion has damaged the binding nodes essential for rapidly representing new information during comprehension, learning, and planning or production in all three of these areas. However, H.M.'s activation and engrainment processes are intact, so that H.M. is able to comprehend and learn new information via massive repetition of units at any level in any system. H.M.'s binding deficit in combination with his spared engrainment processes therefore explain why H.M. exhibits deficits for new information but not for old (pre-operatively encountered), familiar or massively repeated information in language, visual cognition and memory, including perceptual, stimulus-response, and motor learning (see the introduction).

Equally important, binding theory accounts for *detailed* aspects of the present results. For example, under binding theory, H.M. usually chose literal foils to represent his comprehension of metaphoric sentences in Experiment 4 because he understands the literal meaning of familiar words, but has difficulty integrating those meanings into novel sentence contexts, as required for metaphoric interpretations. H.M. therefore based his responses on lexical-level meaning similarities between words in the metaphoric and target sentences. However, H.M. rarely chose the metaphoric foils as might occur if he had integrated the lexical meaning of words in the target sentence to comprehend that a metaphoric interpretation was required.

Binding theory also readily explains H.M.'s response bias in favour of "no" in Experiments 1–2. Under binding theory H.M. understood the meaning of "no" as an isolated word but had difficulty forming internal representations of the novel context-specific applications of "no" in Experiment 1 versus 2.

Binding theory also readily explains H.M.'s deficits in comprehending lexical ambiguities in Experiment 5 because this task required the integration of lexical meanings into novel sentence contexts. However, H.M. had no comprehension deficits in Experiment 6 where many of the same lexical ambiguities occurred in isolated phrases that he knew before his operation. Nevertheless, H.M. did have difficulty *describing* the meanings of those same isolated phrases: H.M.'s descriptions were more redundant, less coherent, less grammatical, and less comprehensible than descriptions of memory-normal controls under binding theory because he could not readily form the new connections required to form comprehensible, coherent, grammatical, and never-previously-encountered sentence plans for describing his comprehension.

Binding theory also explains the detailed nature of H.M.'s errors in describing his comprehension in Experiment 6. Unlike controls, H.M. often repeated the ambiguous words in sentences because new connections were necessary to integrate the multiple meanings of the ambiguous words into novel sentential contexts. Because he could only form new connections via repetition and engrainment processes, H.M. therefore repeated the ambiguous words when describing the sentences, unlike controls who formed the same connections via binding processes without the need for repetition. Binding theory also explains why H.M. more so than controls used clichés and familiar phrases in his descriptions: Producing familiar words, phrases and clichés does not require the formation of new connections and is unproblematic for H.M. under binding theory.

Finally, binding theory readily explains H.M.'s comprehension deficits in other tasks. An example reported in Corkin (1984) concerns H.M.'s deficits on the Token Test of Language Comprehension. To indicate comprehension in this standardised test, participants see displays containing forms of varying shapes, colours, and sizes, and carry out simple commands such as "Touch all the circles except the green one". Under binding theory, H.M. exhibits deficits in executing such commands because this task requires the formation of new connections to represent non-cliché concepts such as "Do not touch non-circles" and "Do not touch the green circle".

Subsidiary theoretical implications

The present results also carry implications for several subsidiary hypotheses discussed next.

Across-the-board hypotheses. H.M.'s comprehension deficits are not readily explained in terms of the general or across-the-board factors suggested in Kensinger et al. (2001) e.g., deficient early upbringing or education: Failure to learn lexically ambiguous meanings during childhood cannot explain why H.M. currently has problems with lexical ambiguities in one context (comprehending novel sentences) but not in other contexts (comprehending familiar phrases).

The phonological loop: An alternate hypothesis?. H.M.'s tendency to repeat familiar words and phrases might be viewed as a malfunction of the phonological loop, a theoretical structure that reiterates phonological information in order to refresh working memory and transform short-term memory into more permanent form. Such a malfunction may perhaps explain H.M.'s tendency to repeat phonological units when reading LF words (MacKay & James, 2002) and to repeat nearly verbatim the last 3–6 words in a speaker's utterance (independent of syntax; see MacKay et al., 1998a). However, phonological loop malfunctions fail to explain why H.M. *selectively* repeats words, e.g., in sentences but not isolated phrases. Nor do phonological loop malfunctions explain how or why H.M. repeats units longer than the approximately 2 s postulated for phonological loop time, e.g., entire self-produced propositions and stories virtually concept-for-concept (see MacKay et al. 1998a). Phonological loop malfunctions also fail to explain the *conceptual* nature of H.M.'s repetitions. For example, instead of repeating the stock phrase "I thought of" as a verbatim unit, H.M. often repeated the same concept using syntactic variants such as "I think of", "I would think of", "I also think of", "I was thinking of", and "I'm thinking" (see MacKay et al. 1998a). Looping of a fixed phonological form cannot explain these syntactic variants.

Comprehension as activated long-term memory units: An alternate hypothesis? It is often assumed that ongoing comprehension and short-term memory corresponds to the activation of existing units in long-term memory (Kintsch, 1998, pp. 130–144). However, H.M.'s ability to activate/ detect identical lexical ambiguities in isolated words and phrases but not in sentences presents a challenge for this assumption. What seems necessary for explaining this dissociation is the binding theory distinction between two theoretically distinct types of activation. One type, simply labelled activation in binding theory, reflects a brief, self-terminating process necessary for using familiar or already formed internal representations such as the meaning or phonology of a familiar word. The other type of activation, known as prolonged activation in binding theory, reflects an extended rather than self-terminating process that is necessary for binding or forming novel internal representations, e.g., links between word meaning and context in novel sentences. This and other empirical dissociations also present a challenge for connectionist theories in which comprehension and production reflect the probabilistic "settling" of a unitary activation process: To explain present results, these theories require some means whereby appropriate activation settling occurs when H.M. encounters familiar words and phrases in isolation but not in novel phrase and sentence contexts.

Comprehension as short-term binding: An alternate hypothesis? It is sometimes assumed that distinct mechanisms exist for short-term versus long-term binding, such that understanding a never-previously-encountered phrase such as "purple cow" involves short-term binding mechanisms (reflecting, say, synchronisation of activation for neural representations of the "cow" and "purple" concepts), whereas *storing* the "purple cow" concept requires long-term binding mechanisms presumably located in the hippocampal MTL system. H.M.'s selective memory and language deficits therefore reflect two distinct impairments under this hypothesis: damage to long-term binding mechanisms for e.g., episodic memory, and damage to short-term binding mechanisms for comprehension but not for episodic memory (because H.M. is relatively unimpaired on short-term memory tasks). However, like systems theory, this comprehension as short-term binding hypothesis fails to explain why H.M.'s comprehension and memory deficits exhibit so many parallels. In addition, as Wickelgren (1979) noted, the short-term/long-term distinction in this hypothesis is both unnecessary and unparsimonious: the same mechanism can accomplish both immediate binding of novel combinations and long-term use of those bindings.

Comprehension-production interactions. A final subsidiary hypothesis is that H.M.'s comprehension deficits may contribute to his *production* deficits. H.M. produces large numbers of grammatical errors that he fails to correct, e.g., "he was above them and of all, most of all" (see Tables 5–7; see also MacKay et al., 1998a; MacKay & James, 2001; Schmolck et al., 2002), perhaps because he fails to comprehend that his own ungrammatical outputs are ungrammatical, consistent with the present results and the overlap of high level comprehension and production units assumed in binding theory.

Neuroanatomical perspectives on H.M.'s binding deficit

Present results directly contradict systems theories in which H.M. has a pure memory encoding deficit that completely spares systems for language comprehension and production, regardless of what brain loci are postulated for these hypothetical systems. However, present results do not bear on functional localisation per se, e.g., the hypothesis that the hippocampus represents the neuroanatomical basis for H.M.'s profound amnesia for episodic events (Schmolck et al., 2000). Present results nevertheless point to the controversial nature of this and other, more recently proposed neuroanatomical hypotheses. Although H.M. provided the original basis for the hippocampus-memory hypothesis (Milner et al., 1968), H.M. is missing more than just the hippocampus, and amnesia increases in severity for patients like H.M. with damage involving *both* hippocampal and adjacent structures (Zola, 2000). Furthermore, the hippocampus is clearly involved in more than just memory as traditionally defined (Bland & Oddie, 2001; O'Keefe & Nadel, 1978; Redish, 2001), and "is heavily implicated in both simple and complex language" (Brockway et al., 1998, p. 1; see also Ferreira et al., 2005; Milner, 1975; Zaidel et al., 1995).

Other recent studies have likewise failed to unambiguously localise H.M.'s language encoding deficits *outside* the hippocampus, contrary claims notwithstanding. Consider the comparisons in Schmolck et al. (2000) and Schmolck et al. (2002) between H.M. and two amnesic patients clamed to have damage like H.M.'s but "limited to the hippocampus". Unlike H.M., neither Schmolck et al. patient had surgically induced damage, and anoxia due to cardiac arrest for some unspecified period of time caused the damage in one patient (A.B.). The Schmolck et al. claim that A.B. and H.M. had *equivalent* hippocampal damage is therefore questionable because anoxia often has non-uniform effects, unlike surgical ablation (see MacKay, 2001). Moreover, diffuse damage due to anoxia is difficult to detect, raising questions about whether A.B.'s damage extends beyond the hippocampus. The second "pure-hippocampal" patient (L.J.) in Schmolck et al. (2002) had a bilateral "hippocampal region" reduced in area by 46% relative to her temporal lobe area, which fell somewhere within the range of values for three age- and sex-matched controls. Again, however, reduced size differs fundamentally from absent. Moreover, even if we could prove that the 46% size reduction indicates 46% fewer hippocampal neurons relative to before L.J.'s amnesia, it is unknown whether L.J.'s damaged 46% and H.M.'s damaged 50% represent comparable neurons within the hippocampus. And even if we could prove this, it is unlikely that H.M. and L.J. had *functionally* equivalent damage to a hippocampal memory system because L.J. had much higher scores on IQ subtests for General memory and Working memory than H.M. (see Schmolck et al., 2002).[5]

Comparing performance across amnesic patients with different types of hippocampal damage such as H.M., L.J., and A.B. calls for caution because different loci within the hippocampus encode different types of information. For example, amnesic patients with well-defined surgical lesions to left (but not right) anterior hippocampus exhibit deficits resembling H.M. in detecting sentence-level ambiguities (see Zaidel et al., 1995), consistent with the hypothesis of Milner (1975), O'Keefe and Nadel (1978), and MacKay et al. (1998b) that the left hippocampus in humans specialises in language-linked encoding, whereas right hippocampus specialises in visuospatial encoding. Such functional specificity suggests that patients with hippocampal damage different from H.M.'s cannot falsify the hypothesis that H.M.'s hippocampal damage contributes to his language encoding deficits.

Similar problems undermine the claim of Schmolck et al. (2000, 2002) that H.M. is similar in language performance and neuroanatomical damage to patients such as E.P., who has encephalitis-induced lesions that extend into the neocortex from lateral temporal lobes to the fusiform gyrus and perhaps

[5] The points being made here apply with even greater force to patient P.H. in Schmolck et al. (2002), where a 22% reduction in bilateral size of the hippocampal region was assumed to indicate hippocampal damage similar to H.M.'s. Also noteworthy is the sizeable margin of error for area measures. Based on the same 1998 MRI data from the same patient (L.J.), Schmolck et al. (2000) reported a 34% bilateral reduction in the hippocampal formation whereas Schmolck et al. (2002) reported a 46% reduction.

also to the frontal cortex,[6] as well as lesions involving the hippocampal formation and entorhinal-perirhinal cortex. H.M. *may* have (at most) *minimal* damage to lateral temporal lobe (of non-surgical origin, see Corkin et al., 1997), that may *perhaps* resemble the selective and irregular damage typical of encephalitis. However, E.P. *definitely* has neocortical damage that is much more extensive than H.M.'s (see MacKay, 2001), E.P. has major language deficits that H.M. does not, e.g., anomia (see Hamann et al., 1997), and E.P. gives no indication of *selective* impairment and sparing in language comprehension, unlike H.M. In short, H.M. and E.P. exhibit differing language deficits that *probably* reflect differing neural damage: Current evidence does *not* unambiguously support the Schmolck et al. claim that H.M.'s language deficits reflect his extra-hippocampal damage.

Further research into the neuroanatomical basis for the language and memory deficits of H.M. and other amnesics (see Ferreira et al., 2005) is therefore needed, and binding theory provides a framework for guiding such future research. Under binding theory, damage to a binding node will have parallel effects, regardless of whether the binding node specialises in "language", "memory", or visual cognition, and regardless of whether the hippocampus, cerebellum, or entorhinal cortex houses the binding node (possible loci given H.M.'s current damage).

H.M.'s lesion has of course destroyed thousands of binding nodes: binding nodes for representing visual form, binding nodes for representing phonological, morphological, and semantic units, and binding nodes for representing the time and place of episodic events. Future research on patients whose lesions overlap with but are less extensive than H.M.'s should therefore attempt to dissociate damage to these different types of binding nodes, e.g., damage that selectively destroys phonological but not semantic binding nodes, so that new connections can be formed to represent novel propositions, but not to represent novel phonological forms, e.g., words in a foreign language (see Vallar & Baddeley, 1984, for a case that fits this description); damage that selectively destroys morphological but not phonological binding nodes, so that new connections can be formed to combine consonants into consonant clusters and to combine syllables into novel words, but not to combine morphological stems and affixes into novel words; and finally, extremely localised damage that impairs a single binding node in a single system, say, the semantic system binding node for representing thematic role for sentence comprehension and production, without damaging other semantic, morphological, or phonological binding nodes (see Caramazza & Miceli, 1991, for a case that fits this description).

[6] Several reasons for believing that E.P. has frontal damage are noted in the introduction.

Binding theory also provides a framework for guiding future research into neural systems underlying language and memory tasks. Under binding theory, neural systems await discovery that are both different from and more specific than systems currently postulated in systems theory. For example, phonological content nodes and their activation and binding mechanisms can be expected to function as a distinct neural system from semantic content nodes and their activation and binding mechanisms. Similarly, binding nodes for conjoining phonological versus semantic units can be expected to function as parts of distinct neural systems. Similarly, *activation mechanisms* that implement the most-primed-wins principle for, say, phonological content nodes can be expected to function as a neural system distinct from other neural systems under binding theory.

CONCLUSIONS

Present results indicated that H.M. exhibits deficits relative to controls in comprehending and producing novel or never-previously-encountered phrases and sentences with a wide variety of structures. These sentence level comprehension and production deficits contradict the claim that H.M. has a pure memory deficit.

Like his episodic memory deficits, H.M.'s sentence-level comprehension and production deficits were selective rather than across-the-board, involving new information but not information encountered before his lesion and used extensively since then. Parallels between H.M.'s selective deficits in language, memory, and other aspects of cognition, e.g., reading and visual cognition, were predicted under binding theory but lacked a parsimonious explanation in theories that postulate non-overlapping systems for language, memory, and visual cognition.

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APPENDIX

Practice and experimental materials for Experiments 1–6 (originals capitalised)

Experiment 1: The Grammaticality Detection Task (the sentences are taken [with permission] from or created following Kemper, 1997

1). The brothers were fixing up the old car.
2). The brothers was fixing up the old car.
3). Sally and I am happy that you could make it.
4). Sally and I are happy that you could make it.
5). Our group weren't planning to leave so early.
6). Our group wasn't planning to leave so early.
7). Kelly likes to play the guitar.
8). Kelly like to play the guitar.
9). I helped myself to the birthday cake.
10). I helped themselves to the birthday cake.
11). Our new neighbours moved in but I haven't met them yet.
12). Our new neighbours moved in but I haven't met us yet.
13). Cindy is the type to always do their best.
14). Cindy is the type to always do her best.
15). John gave me the car that he couldn't drive by ourselves.
16). John gave me the car that he couldn't drive by himself.
17). saw wood odour the from filled burning a the room.
18). A burning odour from the wood saw filled the room.
19). Tony movie Lola at theatre the and went a to.
20). Tony and Lola went to a movie at the theatre.
21). Vampires and werewolves are repelled by garlic.
22). garlic and are by werewolves repelled vampires.

23). She has decided to buy a house.
24). has house she decided to a buy.
25). Mike filled the wagon with hay.
26). Mike filled hay into the wagon.
27). Diane donated the book to the library.
28). Diane donated the library a book.
29). Alice borrowed ten dollars from Sam.
30). Alice borrowed Sam ten dollars.
31). Andy slept on Tuesday.
32). Tuesday was slept on by Andy.
33). Lisa liked the chicken dish.
34). The chicken dish was liked by Lisa.
35). Nearly everybody doubts the rumour.
36). The rumour is doubted by nearly everybody.
37). The boy squashed the insect flat.
38). The boy stepped on the insect flat.
39). The cake was baked by the boy.
40). The boy made the cake bake.
41). The fact that John gave Bill all his old books is irrelevant.
42). The fact that John gave Bill is irrelevant all his old books.
43). It was surprising that Mary did not want to continue her work on the novel.
44). That Mary did not want to continue was surprising her work on the novel.
45). The idea that the interior could be decorated to resemble a boat was revolutionary.
46). The idea that the interior could be decorated was revolutionary to resemble a boat.
47). There doesn't exist a mystery that cannot be solved by the famous French detective.
48). A mystery that cannot be solved doesn't exist by the famous French detective.
49). So many people came into the room that there wasn't enough to eat.
50). So many people that there wasn't enough to eat came into the room.
51). The airplane was so overloaded with medical supplies it couldn't take off.
52). The airplane was so overloaded it couldn't take off with medical supplies.
53). The sheriff started the rumour about the murderer's release.
54). The sheriff started the murderer's rumour about release.
55). My dreams are all about the Paris of my youth.
56). My dreams are all about my youth's Paris.
57). David lost the book which the author had signed.
58). under Tim tree was apple asleep the found.
59). Joan poured the bowl with water.
60). The dropping of the stone was sudden from the roof.
61). Plots have been hatched by many conspirators who work for the government.
62). Someone who we don't remember just walked into the room inviting.

Experiment 2: The What's-Wrong-With-This-Sentence Task

1). Yesterday the man make a chocolate cake.
Yesterday the man made a chocolate cake.
2). The farmer bought two pig at the market.
The farmer bought two pigs at the market.
3). Every Friday our neighbour washes her car.
Every Friday our neighbour wash her car.

4). The little boy is speak to a policeman.
The little boy is speaking to a policeman.
5). Larry went home after the party.
Larry went the home after the party.
6). The girl cut himself on a piece of glass.
The girl cut herself on a piece of glass.
7). Kevin called Nancy for a date up.
Kevin called Nancy up for a date.
8). Chris should have written a letter to his mother.
Chris should has written a letter to his mother.
9). Where is Ted working this summer?
Where Ted is working this summer?
10). Will Harry be blamed for the accident?
Will be Harry blamed for the accident?
11). The boy put the book.
The boy put the book in the kitchen.
12). The boy feeds the rabbit carrots.
The boy the rabbit feeds carrots.

Experiment 3: The Who-Did-What Task

1). The poem that the boy read angered the minister. WHO READ THE POEM?
A. THE BOY
B. THE MINISTER
C. NOBODY
2). The lightning that the people saw scared the children. WHO SAW THE LIGHTNING?
A. THE CHILDREN
B. NOBODY
C. THE PEOPLE
3). The accident that the teacher caused alarmed the parents. WHO CAUSED THE ACCIDENT?
A. NOBODY
B. THE PARENTS
C. THE TEACHER
4). The water that the mother spilled surprised the young child. WHO SPILLED THE WATER?
A. THE YOUNG CHILD
B. THE MOTHER
C. NOBODY
5). The player that the coach benched made a huge salary. WHO MADE A HUGE SALARY?
A. NOBODY
B. THE COACH
C. THE PLAYER
6). The child gave the present that the father loved. WHO GAVE THE PRESENT?
A. THE CHILD
B. THE FATHER
C. NOBODY
7). The clerk sold the umbrella that the woman used. WHO USED THE UMBRELLA?
A. THE CLERK
B. NOBODY
C. THE WOMAN

8). The politician released the report that the committee wanted. WHO RELEASED THE REPORT?
A. NOBODY
B. THE POLITICIAN
C. THE COMMITTEE

9). The woman waited for the bus that the large man drove. WHO DROVE THE BUS?
A. THE WOMAN
B. NOBODY
C. THE LARGE MAN

10). The daughter that the mother adored fed her baby. WHO FED THE DAUGHTER?
A. THE BABY
B. NOBODY
C. THE MOTHER

11). The brother that the boy admired scared his parents. WHO ADMIRED THE BOY?
A. THE BROTHER
B. THE PARENTS
C. NOBODY

12). The girl who the teacher liked helped her relatives. WHO HELPED THE TEACHER?
A. NOBODY
B. THE GIRL
C. THE RELATIVES

13). The daughter that the mother adored fed her baby. WHO FED THE DAUGHTER?
A. THE BABY
B. NOBODY
C. THE MOTHER

14). The son that his father remembered phoned his uncle. WHO REMEMBERED HIS FATHER?
A. THE UNCLE
B. NOBODY
C. THE SON

15). The farmer recalled the nephew that his uncle disowned. WHO DISOWNED HIS UNCLE?
A. THE FARMER
B. THE NEPHEW
C. NOBODY

16). The woman called the grandmother who her aunt liked. WHO LIKED THE WOMAN?
A. NOBODY
B. THE AUNT
C. THE GRANDMOTHER

17). The young man visited the grandfather who his lawyer sent for. WHO SENT FOR THE YOUNG MAN?
A. NOBODY
B. THE LAWYER
C. THE GRANDFATHER

18). The woman met the nurse who her sister wrote to. WHO WROTE TO THE WOMAN?
A. THE NURSE
B. THE SISTER
C. NOBODY

Experiment 4: Metaphor Comprehension

1). "There is rough sailing ahead for us."
 a) The waves will make it easy to sail.
 b) The rough times are behind us now.
 c) We will be facing difficult times.
2). "She seems to be holding all the aces."
 a) The odds favour her.
 b) She is a card shark.
 c) She has four cards in her hand.
3). "It's hard to zero in on his ideas."
 a) He is getting his ideas across.
 b) It is difficult to number his ideas.
 c) His ideas do not come through clearly.
4). "He is high man on the totem pole."
 a) He is at a low level.
 b) He is hanging from a pole.
 c) He is at the highest level.
5). "Maybe we should stew over his suggestion."
 a) Maybe we should put more meat in the stew.
 b) Let's make sure to cook the stew long enough.
 c) Let's think about it some more.
6). "I just can't swallow that."
 a) That doesn't seem true.
 b) That is not fun to eat.
 c) That is easy to believe.
7). "The plan is still up in the air."
 a) The plan has not landed yet.
 b) The plan has already been made.
 c) The plan has not been made yet.
8). "She is easily crushed."
 a) She can handle anything.
 b) She gets mad easily.
 c) Her feelings are easily hurt.
9). "It is all behind us now."
 a) We are done with it.
 b) We always look behind us.
 c) We are just beginning.

Experiment 5: The Possible Interpretation Task (sentences followed by four interpretations)

1). THE BOY LOOKED AFTER HIS BROTHER.
 THE BOY LOOKED AT HIS BROTHER AS HE WALKED AWAY.
 THE BOY TOOK CARE OF HIS BROTHER.
 THE BOY NEVER IGNORED HIS BROTHER.
 THE BOY AND HIS BROTHER DID NOT ENJOY SWIMMING.

2). WHEN THE BEAVER ENCOUNTERED THE RACCOON IT BECAME FRIGHTENED.
THE BEAVER BECAME FRIGHTENED AFTER SEEING THE RACCOON.
THE RACCOON BECAME FRIGHTENED AFTER SEEING THE BEAVER.
THE RACCOON ATTACKED THE BEAVER WHEN THEY SAW EACH OTHER.
THE BEAVER AND RACCOON ARE OFTEN HUNTED FOR THEIR FUR.
3). THE CORRUPT POLICE CAN'T STOP DRINKING.
THE CORRUPT POLICE CAN'T STOP THE PUBLIC FROM DRINKING.
THE CORRUPT POLICE CAN'T STOP THEMSELVES FROM DRINKING.
THE CORRUPT POLICE ARE IN TROUBLE BECAUSE THEY STOP DRINKING.
THE CORRUPT POLICE NEED TO STOP ALL TYPES OF LAWLESSNESS.
4). THE CHEF WASN'T HAPPY WITH HIS COOKING.
THE CHEF WASN'T HAPPY WITH HIS OWN COOKING.
THE CHEF WASN'T HAPPY WITH THE COOKING OF ANOTHER MAN.
THE CHEF WAS ONLY HAPPY WITH HIS BAKING.
THE CHEF WAS HAPPY TO USE BEEF OR PORK IN HIS STEWS.
5). VISITING RELATIVES CAN BE A BORE.
GOING TO VISIT RELATIVES CAN BE BORING.
HAVING RELATIVES VISIT YOU CAN BE BORING.
HAVING RELATIVES VISIT IS NEVER FUN.
PEOPLE OFTEN VISIT RELATIVES ON HOLIDAYS.
6). JUDY ASKED HER SISTER IF SHE HAD BEEN INVITED TO THE PICNIC.
JUDY WANTED TO KNOW IF SHE HERSELF WAS INVITED TO THE PICNIC.
JUDY WANTED TO KNOW IF HER SISTER WAS INVITED TO THE PICNIC.
JUDY WANTED TO KNOW THE DATE OF HER SISTER'S BIG PICNIC.
JUDY WANTED TO KNOW IF SHE SHOULD BRING HER PICNIC BASKET.
7). BILL ALWAYS LOOKS BACKWARD IN A CROWD.
BILL FACES A DIFFERENT DIRECTION THAN EVERYONE ELSE.
BILL LOOKS AWKWARD OR STUPID AMONGST OTHERS.
BILL THINKS SOMEONE HAS A GUN POINTED AT HIM.
BILL LIKES TO WALK BUT DOES NOT LIKE HIKING.
8). THE DETECTIVE IN CHARGE OF THE CASE LOOKED HARD.
THE DETECTIVE IN CHARGE OF THE CASE SEARCHED CAREFULLY FOR CLUES.
THE DETECTIVE IN CHARGE OF THE CASE APPEARED TOUGH AND MEAN.
THE DETECTIVE IN CHARGE OF THE CASE DID NOT FIND MUCH EVIDENCE.
THE DETECTIVE IN CHARGE OF THE CASE WAS PROMOTED JUST LAST WEEK.
9). THE KILLING OF THE HUNTERS MAKES ME SICK.
THE FACT THAT THE HUNTERS ARE BEING KILLED BY OTHERS MAKES ME SICK.
THE FACT THAT THE HUNTERS KILLED ANIMALS MAKES ME SICK.
THE FACT THAT THE HUNTERS USE METAL TRAPS MAKES ME SICK.
THE FACT THAT THE HUNTERS WEAR CAMOUFLAGE CLOTHING MAKES ME SICK.
10). HE TALKED TO A BOY WITH A BIG SNEER ON HIS FACE.
HE HAD A SNEER ON HIS FACE WHEN HE TALKED TO THE BOY.
THE BOY HAD A SNEER ON HIS FACE WHEN THE MAN TALKED TO HIM.
THE BOY HAD A DIRT SMUDGE ON HIS FACE WHEN THE MAN TALKED TO HIM.
HE HOPED TO LEAVE THE PARTY BEFORE THE NEWS CAME ON.

11). THE POLICE RECOVERED THE CAR THAT SHE HAD STOLEN ON FRIDAY.
THIEVES STOLE THE WOMAN'S CAR ON FRIDAY AND THE POLICE HAVE NOW FOUND THE CAR.
THE WOMAN STOLE THE CAR FROM SOMEONE ON FRIDAY AND THE POLICE HAVE NOW FOUND THE CAR.
THE POLICE WERE INCOMPETENT AND THEREFORE DID NOT FIND THE CAR THAT WAS STOLEN.
THE WOMAN CLAIMED THAT SHE WAS TRYING TO HELP THE POLICE, WHO NEED MORE PUBLIC FUNDING.

12). THE MEN WITH THE WOMEN WHO WERE COMPLAINING WERE TOLD TO MOVE ALONG.
THE MEN WERE COMPLAINING AND THEY WERE TOLD TO MOVE ALONG.
THE WOMEN WERE COMPLAINING AND THE MEN WERE TOLD TO MOVE ALONG.
THE WOMEN WERE COMPLAINING BECAUSE THEY WERE NOT TOLD TO MOVE ALONG.
THE MEN WERE LOOKING AT THE WOMEN BUT WERE TOLD TO MOVE ALONG.

13). THE HIGHWAY PATROL FOUND THE TRUCK THAT WAS HIJACKED IN BOSTON.
THE HIJACKED TRUCK WAS RECOVERED IN BOSTON.
THE TRUCK HAD BEEN HIJACKED IN BOSTON AND WAS FOUND ELSEWHERE.
THE HIJACKED TRUCK DID NOT CONTAIN HOSTAGES.
THE TRUCK WAS CAREFULLY EXAMINED FOR CLUES BY THE HIGHWAY PATROL.

14). HORTENSE DEFENDED THE MAN SHE LOVED WITH ALL HER HEART.
HORTENSE DEFENDED HIM WITH ALL HER HEART.
HORTENSE LOVED HIM WITH ALL HER HEART.
HORTENSE WANTED TO PROVE HER LOVE TO HIM.
HORTENSE ALWAYS WANTED TO BE A LAWYER.

15). HE BURIED THE BODY HE FOUND IN THE CELLAR.
THE BODY WAS BURIED IN THE CELLAR.
THE BODY WAS FOUND IN THE CELLAR.
THE BODY WAS DECOMPOSING IN THE CELLAR.
THE BODY WAS FOUND BY THE POLICE.

16). PEOPLE WHO VISIT VENICE FREQUENTLY LIKE IT VERY MUCH.
PEOPLE WHO TRAVEL REPEATEDLY TO VENICE LIKE IT.
OF PEOPLE WHO HAVE BEEN TO VENICE, MANY LIKE IT.
PEOPLE WHO LIVE IN VENICE FREQUENTLY DO NOT LIKE IT.
TRAVEL TO VENICE CAN BE QUITE EXPENSIVE.

17). JOHN SPOKE TO THE WOMAN IN TEARS.
JOHN WAS CRYING AS HE SPOKE TO THE WOMAN.
THE WOMAN WAS CRYING AS JOHN SPOKE TO HER.
JOHN WAS VERY ANGRY WITH WHAT THE WOMAN SAID.
THE WOMAN AND JOHN WERE WALKING ALONG TOGETHER.

18). SHE INSISTS UPON WEARING LIGHT CLOTHES IN SUMMER.
SHE WEARS ONLY LIGHT WEIGHT CLOTHES IN SUMMER.
SHE WEARS ONLY LIGHT COLOURED CLOTHES IN SUMMER.
SHE WEARS ONLY DARK COLOURED CLOTHES IN WINTER.
SHE WEARS LARGE STRAW HATS TIED WITH RIBBONS.

19). WHEN A STRIKE WAS CALLED IT SURPRISED EVERYONE.
THE UMPIRE UNEXPECTEDLY CALLED THE PITCH A STRIKE.
THE UNION WORKERS UNEXPECTEDLY WENT ON A LABOUR STRIKE.
THE UNION WORKERS HAVE NOT COMPLETELY STOPPED WORKING.
THE UMPIRE QUICKLY CALLED THE COACHES TO THE MOUND.

20). THE FIGURE THAT I SAW THAT NIGHT HAS ALREADY ESCAPED MY MEMORY.
I HAVE ALREADY FORGOTTEN THE NUMBER I SAW THAT NIGHT.
I HAVE ALREADY FORGOTTEN THE SHAPE OR FORM I SAW THAT NIGHT.
THE FIGURE HAD ALREADY ESCAPED FROM THE BUILDING THAT NIGHT.
THE FIGURE HAD ALREADY FRIGHTENED THE OTHER PEOPLE THAT NIGHT.

21). HE WAS NOT ABLE TO HANDLE THE CASE BY HIMSELF.
THE SUITCASE WAS TOO BIG FOR HIM TO PICK UP ALONE.
THE LAW CASE WAS TOO DIFFICULT FOR HIM TO DEFEND ALONE.
THE SUITCASE WAS VERY SMALL SO HE CARRIED IT ALONE.
THE LAW CASE INVOLVED MORE THAN THREE VIOLENT CRIMINALS.

22). HIS STUDY IS ONE OF THE VERY FINEST THAT I HAVE SEEN.
HE HAS A VERY HIGH QUALITY OFFICE-TYPE ROOM.
HE DID A VERY HIGH QUALITY RESEARCH EXPERIMENT.
HE HAS AN IMPRESSIVE WAY OF PREPARING FOR A TEST.
HE HAS TO KEEP HIS LARGE BUSINESS RUNNING SMOOTHLY.

23). THE SAILORS LIKED THE PORT IN THE EVENING.
THE SAILORS LIKED THAT PARTICULAR TYPE OF WINE.
THE SAILORS LIKED THE PLACE WHERE THE SHIPS DOCK.
THE SAILORS HATED THAT PLACE IN THE MORNING.
THE SAILORS LIVE ON SHIPS FOR MONTHS AT A TIME.

24). I MAKE IT A POLICY TO REFUSE ALL HANDOUTS.
I REFUSE TO ACCEPT ANY FLYERS OR PAMPHLETS.
I REFUSE TO ACCEPT ANY DONATIONS.
IT IS ILLEGAL TO ACCEPT DONATIONS.
I REFUSE TO GO OUT ALONE AT NIGHT.

25). IF THE MACHINIST DOESN'T MAKE IT ON TIME HE WILL BE FIRED.
THE MACHINIST MUST SHOW UP TO WORK ON TIME OR HE WILL BE FIRED.
THE MACHINIST MUST CREATE THE PRODUCT ON TIME OR HE WILL BE FIRED.
THE MACHINIST MUST MAKE THE PRODUCT PERFECTLY OR HE WILL BE FIRED.
THE MACHINIST MUST BE TRAINED FOR HIS LICENSE OR HE WILL BE FIRED.

26). THE SPY PUT OUT A TORCH WHICH WAS OUR SIGNAL TO ATTACK.
THE SPY SET THE TORCH OUTSIDE TO SIGNAL THE ATTACK.
THE SPY DOUSED THE TORCH TO SIGNAL THE ATTACK.
THE SPY WAS CAPTURED BY THE ENEMY DURING THE ATTACK.

27). JANE GOT DOWN THE LONG PIPE WITHOUT ANY HELP.
JANE GOT DOWN A SMOKING PIPE ALONE.
JANE DID NOT GET DOWN THE PIPE ALONE.
JANE PUT THE PIPE ON THE TABLE ALONE.

28). HER ONLY CHOICE WAS TO THROW IT UP IMMEDIATELY OR DIE.
SHE HAD TO VOMIT OR DIE.
SHE HAD TO TOSS SOMETHING SKYWARD OR DIE.
SHE HAD TO CHOOSE TO DIE.
SHE HAD PLENTY OF TIME TO DECIDE BEFORE DYING.
29). HE SURPRISED US BY TAKING OVER THE LARGE TENT.
HE UNEXPECTEDLY PICKED THE TENT UP AND CARRIED IT AWAY.
30). CHARGING TIGERS SHOULD BE AVOIDED.
YOU SHOULD APPROACH ANY ANIMAL WHICH COMES NEAR YOU.
31). IT DID NOT TAKE HIM LONG TO UNCOVER THE DIFFICULTIES WITH HER.
HE QUICKLY FOUND OUT WHAT HER PROBLEMS WERE.
32). HE WAS SURPRISED WHEN HE FOUND OUT HOW GOOD MEAT TASTES.
HE OFFERED TO EAT A VEGETARIAN MEAL AT THE BRUNCH.
33). I THINK THAT YOU ARE TAKING THE WRONG TACK.
I THINK YOU ARE USING THE WRONG APPROACH TO THE PROBLEM.
34). DIANE PUT THE FILE ON THE TABLE WHERE EVERYONE COULD SEE IT.
DIANE PUT THE FILE UNDERNEATH THE PAPERS ON THE TABLE.
35). THE LITTLE BOY LOOKED AS IF HE HAD LOST HIS MARBLES.
THE LITTLE BOY LOOKED SAD FROM LOSING HIS TOYS.
36). TO EVERYONE'S SURPRISE BILL FELL OVER THE GIRL.
PEOPLE EXPECTED BILL TO ENJOY THE GIRL'S COMPANY.

Experiment 6: Detecting and describing ambiguities in familiar phrases versus sentences. Familiar words and phrases

Story of the year	Board	The tank	Chair
To make money	The pipe	To bear	On top of everything
Lots	The port	The plane	The office
To take	To look	To take a turn	To make if
Solid	The position	Run out of	Light

Lexically Ambiguous Sentences:
Modified slightly from corresponding sentences published in MacKay & Bever (1967, Appendix).