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Review article

Creativity, Comprehension, Conversation and the Hippocampal Region: New Data and Theory

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Abstract: This article examines conceptual frameworks for explaining relations between creativity and the hippocampal region (HR) and reports two new experimental studies. In both studies, seventeen people participated in extensive face-to-face interviews: sixteen normal individuals and H.M., an amnesic with cerebellar and HR damage but virtually no neocortical damage. The results indicated that HR damage impairs aspects of everyday language comprehension and production that require creativity—defined as the ability to form new internal representations that satisfy relevant constraints for being useful or valuable in the real world. Study 1 demonstrated deficits in H.M.'s comprehension of *creative* but not *routine* aspects of the interviews—extending to the real world twelve prior demonstrations that H.M. understands routine but not novel aspects of experimentally constructed sentences, deficits that reflected his HR damage, but not his cerebellar damage, his explicit or declarative memory problems, inability to comprehend or recall the instructions, forgetting, poor visual acuity, motoric slowing, time pressure, deficits in visual scanning or attentional allocation, lack of motivation, and excessive memory load in the tasks. Study 2 demonstrated similar deficits in H.M.'s ability to *produce* creative but not routine aspects of conversational discourse, extending findings in five prior sentence production experiments to real-world creativity. Both types of deficits impaired communication in the interviews, results that support some theories of creativity and the HR but not others.

Keywords: theories of real-world creativity; sentence comprehension and production; everyday conversation; imagination; planning; insight problem solving; amnesic H.M.; hippocampal region of the medial temporal lobe; anterograde and retrograde amnesia

1. Introduction

The importance of the hippocampal brain region (HR) for learning and memory has been well established, e.g., [1]. But does the HR also play a role in creativity? The present article addresses this deceptively straight-forward question in a readily understood conversational style that illustrates our content focus: face-to-face discourse. However, understanding the relevance of this focus to creativity and the brain is not straight-forward. It requires a close look at the ongoing debates surrounding the definition of creativity.

1.1. The call for a broader definition of creativity

The current literature contains many (implicit or explicit) definitions of creativity. Some are clearly over-inclusive. One is the definition *Flexible behavior is per se creative*, e.g., [2], which encompasses actions that are routine, habitual and unoriginal, e.g., applying context-appropriate past tense rules acquired as a child [3]. *Atypical behaviors are creative*, e.g., [2] is another over-inclusive definition—which embraces activities that are counterproductive to society and the individual, e.g., routinely driving one's car at twice the speed limit. Other definitions are under-inclusive, e.g., the idea that *Concepts are only creative if nobody has ever formulated them before* (see the discussion of Big C creativity in [4]). This novel-in-the-world criterion calls for historical analyses of creative ideas that are notoriously controversial (Did Leibnitz and Newton simultaneously and independently invent calculus, or not?), unstable over time (see [5]) and irrelevant from a psychological perspective.

However, one definition enjoys almost universal acceptance: *Creativity involves the formation of ideas, concepts or images that are new (for the producer at that particular time) and satisfy relevant constraints for being useful or valuable to the producer and perhaps also to some larger social group*; e.g., [6]-[14]. By way of illustrating this the new-and-useful definition of creativity, Shakespeare was being creative when he had Romeo utter "Juliet is the sun" because this proposition was new to him (before writing *Romeo and Juliet*, Shakespeare had never previously generated or encountered Juliet Capulet described that way), and valuable (it relayed important information in a succinct and memorable manner, allowing Shakespeare's audiences to quickly grasp that Juliet was warm, life-giving, and the center of Romeo's universe—like the sun).

In its favor, the new-and-useful definition encompasses everyday activities such as the creative use of language, a process not confined to geniuses such as Shakespeare. However, the emphasis on *products* and the *producer* in the new-and-useful definition seems to exclude the clearly creative processes involved in constructing personal knowledge and understanding [15]-[17], and the present authors join the many recent calls for broadening and refining the creativity concept [9], [15], [18].

In particular, we believe that detailed understanding of creative processes in the brain requires the concept *internal representation*. Internal representations are instantiations of ideas, concepts or images that the brain stores for some period of time, however brief or long. The instantiations can be

simple, e.g., [19], or complex, e.g., [20], but the brain must form them via some biophysical or biochemical means, in however sparse or extensive a population of neurons.

Brain research aside, however, *any* generally applicable definition of creative processes requires the concept of internal representation. The reason is that images, concepts or ideas formed *without an internal representation* would not qualify as creative for most creativity researchers. By way of counterfactual illustration, imagine that Shakespeare had used a random process to select words from a dictionary in the ordered categories [PROPER NOUN], e.g., *Sam, Shirley, Adolph, Juliet, ...* + [COPULAR VERB], e.g., *is, am, are, ...*] + [ARTICLE], e.g., *a, an, the, ...*] + [COMMON NOUN], e.g., *farm, forest, physics, sun, ...*], and thereby generated the sentence "Juliet is the sun" —along with many other novel outputs such as "Shirley is the physics." Most experts would call this random, non-representational process *non-creative*, even if one of its products, namely *Juliet is the sun,* became useful in the real world.

Besides being necessary in definitions of creativity, the concept of internal representation also speaks to the domain-general versus domain-specific nature of creativity [21], provides a conceptual scaffolding for investigating relations between learning and creative expressions at any age [18], [22]-[23], and integrates under one umbrella concepts such as proactive versus reactive creativity [24], eminent versus everyday creativity [4], and the "mini c" creativity involved in developing personal understanding [15]-[17]—which all presuppose the ability to form new internal representations. Also to its credit, the concept of internal representation suggests new directions for future research on creativity and related processes such as planning and imagining (see the General Discussion).

1.2. The present creativity research

For all of these reasons, the present article defined creativity as *the process of forming internal representations that are new and useful in the real world*. Does this definition encompass *comprehension*? To address this question, let's consider the internal representation that audiences formed when they comprehended *Juliet is the sun*, and to facilitate exposition, let's indicate the information in this and other internal representations via enclosed braces. So Shakespeare's audiences formed this internal representation: {Romeo thinks Juliet is warm, life-giving, and the center of his universe}—which, being useful in understanding Shakespeare's play, counts as creative under our definition for listeners or readers who had never previously encoded the internal representation {someone is the sun}. And generalizing from this example to all internal representations of new and useful information, our definition of creativity indeed encompasses comprehension.

But wait, wrote a colleague, isn't your creative comprehension concept too general? Doesn't it encompass all grammatically possible interpretations of novel sentences? No. For example, here are three novel and grammatical, but *non-creative* ways to comprehend Shakespeare's "Juliet is the sun": {*Juliet is the sun's proper name}*; {*Juliet is millions of miles from earth}*; and {*Shakespeare's*

sentence is an oxymoron because Juliet is a human being and the sun is an astronomical body}. By failing to satisfy contextual constraints that could render them useful in the real world, including the constraint that Shakespeare wrote *Juliet is the sun*, these internal interpretations lack a *sine qua non* aspect of creativity.

Comprehending everyday discourse is similar: Some conversations engage creative comprehension processes under our definition, while others don't. For example, consider this face-to-face conversation. "Good morning." *Response*: "Good morning;" "How are you?" *Response*: "Fine." Here comprehension is routine or *non-creative* by definition because only familiar, preformed internal representations are involved. However, Conversational Excerpt 1 (from [25]), illustrates *creative* comprehension as defined here. The excerpt begins with Jean Chrétien's response to a reporter's request that the Canadian Prime Minister investigate, and perhaps do something about, the 1997 increase in drugs crossing from Canada into the U.S.

> **Conversational Excerpt 1**: Creative Everyday Comprehension Illustrated.
>
> ***Prime Minister Chrétien*:** It's more trade.
>
> ***News Reporter:*** More drugs coming in from Canada to the United States?
>
> ***U.S. President Bill Clinton:*** More **drugs**, she said. (spoken emphasis in bold)
>
> ***Prime Minister Chrétien:*** More drugs—I heard "trucks." [*Laughter*] I'm sorry.
>
> ***President Clinton:*** I'm glad we clarified that, or otherwise he'd have to delay calling the [1997] election. [*Laughter*]

Never having previously encoded Chrétien's "It's more trade," Clinton clearly formed two novel internal representations when he responded "More **drugs**, she said:" {because of increased trade, more drugs now cross from Canada into the U.S.}; and {because a Canadian prime minister supporting increased drug traffic into the U.S. is unthinkable, Chrétien may have misheard the question}.

After Chrétien confirmed that he did indeed mishear, Clinton then expressed a third internal representation that was both novel and useful: {Without this clarification, Chrétien would have to repair the political fallout from his statement and postpone his plan to call an immediate Canadian election}. What made this internal representation *useful* and therefore *creative* under our definition? The laughter it triggered was diplomatically and politically helpful, and Canadians soon re-elected Chrétien without political fallout.

With a definition and clear examples of creative comprehension and production in hand, the present research examined whether HR damage impairs creative aspects of comprehension (Study 1) and production (Study 2) during face-to-face interviews resembling Excerpt 1. The participants were sixteen normal individuals and Henry M.—an amnesic with HR damage.

2. Study 1: The Creative Comprehension of Discourse

We had good reasons for suspecting that Henry would experience comprehension deficits relative to the normal controls in Study 1: Eight experimental studies conducted between 1974 and 2007 reported major deficits in Henry's ability to comprehend *novel* but not *routine* or familiar aspects of isolated sentences. Appendix A summarizes these studies and what makes them important: All of the participants responded to the same experimentally controlled stimuli, and the memory-normal controls were matched with Henry on relevant dimensions such as age, education, verbal and performance IQ, native language, background, skills, and extraneous (e.g., cerebellar) brain damage.

However, experimental control comes at a cost: By manipulating one or two factors and holding many others constant, experiments are inherently unlike the real world, where a universe of factors is free to vary, e.g., [26]. Laboratory behaviors therefore lack a *sine qua non* aspect of creativity—demonstrable value or usefulness in the real world. To overcome that limitation, Study 1 examined whether Henry's experimental results extend beyond the laboratory to the comprehension of novel and useful information during real-world conversational interviews. Specific operational hypotheses in Study 1were that relative to normal interviewees, Henry would ask his interviewer more questions indicating comprehension difficulty, but no more questions requesting other types of information.

2.1. Method

2.1.1. Participants and procedures

Using detailed transcripts readily available on the web, we analyzed extensive interviews in which Henry M. and 16 normal "guests" had participated. All participants were minor celebrities, including Henry, because National Public Radio had interviewed him. However, only Henry had (known) brain damage: His 1953 surgery removed bilateral parts of the hippocampus and adjacent midbrain structures: the entorhinal cortex, the dentate gyrus, the subicular complex, and the perirhinal cortex [27]-[29]. Table 1 lists the approximate date of the interviews, the source of the interview transcripts, and the names of the interviewers and interviewees. When interviewed, Henry was 44 years old, and the mean age of the normal guests was about 53, with standard deviation (*SD)* = 14.

Table 1. List of the interviewers, their guests, date of the interviews, and the source of the original transcripts analyzed in Studies 1 and 2.

Approximate Date of the Interviews	Original Source of the Transcripts	Interviewer	Guest	Age of the Interviewee
May 24th, 1970	MIT (*Massachusetts Institute of Technology*)	William Marslen-Wilson	H.M.	40
December 7th, 1970	Pacifica Radio	Richard Friedman	John Cage	58

April 14th, 1971	Pacifica Radio	Celeste Ware	Odetta	41
April 30th, 1974	Southern Oral History Project	Jack Bass	Rita Jackson Samuels	N/A
April 11, 1992	Henry Hampton Collection (Washington University Libraries)	Stephen Stept	Maya Angelou	64
March 16th, 1999	Southern Oral History Project	Pamela Grundy	Ned Irons	18
December 28th, 2003	*60 Minutes*	Ed Bradley	Michael Jackson	45
December, 2010	*O Magazine*	Oprah Winfrey	Tyler Perry	41
December 23rd, 2012	NBC (*National Broadcasting Corporation*)	David Gregory	Wayne LaPierre	63
May 2nd, 2013	Monmouth University	Veronica Dehais	Patricia Armstrong	61
June 28th, 2013	*Privacy Surgeon* (online publication)	Simon Davies	Michael Hayden	68
December 6th, 2013	CNN (*Cable News Network)*	Piers Morgan	Rick Warren	59
January 10th, 2014	NPR (*National Public Radio*)	Steve Inskeep	John Inglis	59
February 21st, 2014	CNN (*Cable News Network*)	Piers Morgan	Jordan Belfort	52
May 1st, 2014	*Point Reyes Light*	Samantha Kimmey	Don MacKay	72
May 25th, 2014	*60 Minutes*	Anderson Cooper	Liam Neeson	62
N/A	Scholastic.com	Unnamed Student	Judy Blume	N/A

2.1.2. Dependent measures

Our dependent measures were two types of questions that participants asked their interviewers: content questions and questions indicating comprehension difficulties. Content questions called for additional information from the interviewer without suggesting a problem in comprehension, e.g. "Which time are you referring to?" and "Why should I have listened?" Comprehension questions called for help in understanding what an interviewer said, e.g., "What do you mean?" None of the guests knew that their questions would later be analyzed from transcripts, and we excluded from all analyses questions reflecting inability to hear a word or phrase, e.g., "Did you say *gentleman*?"

2.1.3. Interviews

The interviews occurred on a single day for the normal speakers but spanned several days for Henry, whose transcript was 182 pages long. To control for transcript length, we calculated the

probability of content versus comprehension questions per word that a guest uttered—effectively equating extensiveness of the interviews and interviewee responses in our analyses.

2.2. Results

2.2.1. Preliminary analyses

We first computed how many words the guests produced and how many questions they asked (excluding mishearing questions). H.M. produced 30,074 words and asked his interviewer 45 questions, or 0.0015 questions per word of response. Each normal guest produced a mean of 4,275 words and asked a mean of 16 questions, or 0.0037 questions per word of response (*SD* = 0.0047; see Table 2). Questions per word uttered therefore differed by less than 1 *SD* for H.M. versus the control mean, a non-reliable difference under the standard convention that reliable differences between patient and controls must equal or exceed 2.0 *SD*s. H.M. and the normal interviewees therefore did not differ in overall inquisitiveness. However, subsequent analyses by type of question asked indicated that H.M.'s questions exhibited an abnormal pattern.

2.2.2. Main results

Table 2 shows the frequency of comprehension versus content questions (raw number and number per word uttered) for each guest, with means and *SD*s for the 16 normal speakers. Of the 45 questions that H.M. asked his interviewer, 11 were content questions requesting new information, and 34 were comprehension questions soliciting help in understanding what his interviewer said (see Table 2).

Controlling for interview length, the mean proportion of content questions to total words uttered was 0.00037 for H.M. versus a mean of 0.00393 for the controls (*SD* = 0.00367), a less than 1 *SD* difference that indicates normal use of content questions. However, the mean proportion of comprehension questions to total words uttered was greater for H.M. (0.00113) than the controls (0.00007, *SD* = 0.00017), a reliable 6.24 *SD* difference indicating a comprehension deficit relative to the normal speakers.

Table 2. The Frequency of Comprehension versus Content Questions (raw number and per word of response) asked by Henry versus the 16 Normal Interviewees (with means and *SD*s).

Participants	Content Questions (raw number)	Content Questions (number per word of response)	Comprehension Questions (raw number)	Comprehension Questions (number per word of response)
H.M.	11	0.00037	34	0.00113

Normal 1	9	0.00291	2	0.00065
Normal 2	14	0.00865	0	0
Normal 3	6	0.00219	0	0
Normal 4	14	0.00410	0	0
Normal 5	7	0.00202	0	0
Normal 6	51	0.00436	0	0
Normal 7	5	0.00075	0	0
Normal 8	13	0.00188	0	0
Normal 9	7	0.00244	0	0
Normal 10	8	0.00143	0	0
Normal 11	7	0.00176	1	0.00025
Normal 12	39	0.00866	0	0
Normal 13	16	0.01421	0	0
Normal 14	14	0.00500	0	0
Normal 15	5	0.00168	0	0
Normal 16	4	0.00082	1	0.00021
Normal Means and (*SD*s)	13.69 (12.99)	0.00393 (0.00367)	0.25 (0.57)	0.00007 (0.00017)

Was Henry's interviewer aware of his struggles to comprehend? Probably, because he asked easier questions than the other interviewers. We divided interviewer questions into two categories: *easy* questions requesting a simple fact, e.g. "Is there a Burnside Avenue in Manchester?" or "Have you been in Canada before?" versus *difficult* questions requesting an opinion, e.g. "What does that say about West Charlotte, do you think?" or "What do you think about this whole debate that's going on?" For every difficult question that Henry received, his interviewer posed 35 easy questions, whereas for every difficult question that normal guests received, their interviewers posed a mean of 1.5 easy questions (*SD* = 0.74). Henry therefore received a higher ratio of easy (fact) to difficult (opinion) questions (35) than the mean for normal interviewees (1.5 with *SD* = 0.74), a reliable 45 *SD* difference. Given this help, it seems reasonable to assume that Henry's comprehension deficits would have been much greater if he and the control interviewees had received equally difficult questions.

2.3. Discussion

As expected, Henry asked more comprehension questions in face-to-face interviews than did normal interviewees (with controls for interview and response length). However, Henry was not simply more curious than the normal guests because he asked no more content questions than the normal guests.

Present results therefore replicate and extend Henry's deficits in comprehending novel information in earlier experiments (see Appendix A), indicating a link between *creative comprehension* and the HR. Unlike Henry, listeners with intact HR structures such as our normal controls can readily understand grammatical contributions to conversations without repeatedly asking "What do you mean?" This ability gave them new and potentially useful ways to relate to their conversational partners, and perhaps also new ways to see and act in the world. Such usefulness renders novel internal representations *creative* during real-world face-to-face conversation—in ways not possible in laboratory settings.

However, Henry exhibited selective rather than across-the-board comprehension difficulty in Study 1. He readily understood *familiar* words and phrases. For example, when Henry's interviewer asked him to name someone he had labeled "a seditionist," Henry answered with a man's name, indicating comprehension of the familiar phrase "his name" (see Conversational Excerpt 2).

Study 1 therefore replicates and extends available experimental evidence indicating that Henry suffered selective deficits involving the comprehension of unfamiliar but not familiar phrases, unfamiliar but not familiar visual objects, and unfamiliar but not familiar episodic and semantic information (see Appendix A; also [30]-[32]).

Henry's pattern of selective deficits explains why he exhibits normal repetition priming in stem completion tasks involving familiar words, e.g., *complaint*, but not unfamiliar words introduced into English after his 1953 operation, e.g., *frisbee* [33]. After processing the familiar word *complaint*, Henry will later produce *complaint* rather than some other *com*- word as the first word that comes to mind for completing the stem *com*-. Why? Because he can re-activate his preformed cortical representation for *complaint* without HR involvement—the basis for normal repetition priming. However, after processing *frisbee*, Henry (unlike normal individuals) will complete the stem *fri*- with an "unprimed" word such as *Friday*. Why? Because he couldn't create a new internal representation for *frisbee* that the stem *fri*- could prime in the stem completion task.

However, present results extend previous findings, adding conversational phrases and propositions to the many other types of novel internal representations that HR mechanisms are known to create: internal representations for events personally experienced in unique space-time contexts (so called episodic memories); for familiar objects embedded in novel visual contexts (unfamiliar scenes); for self-produced and other-produced errors; for the meaning, pronunciation and spelling of novel or newly encountered words (a type of semantic or fact memory); and for facts rendered permanently irretrievable due to aging, infrequent use, and non-recent use, including forgotten aspects of low frequency words that normal older adults (but not amnesics) can easily relearn (see Appendix A and B; [1], [30], [32], [34], [35]).

Henry's selective comprehension deficits in Study 1 call for a distinction between *routine comprehension processes*—which quickly retrieve information, e.g., familiar phrase meanings independent of their novel sentence contexts, and do not require HR engagement, versus *creative comprehension processes*—which are slow, and require HR engagement to integrate familiar

information into novel contexts. For normal listeners, these slow creative processes form the end product of language comprehension—new cortical representations for the meanings of novel phrases and propositions (For studies that distinguish between routine versus *imaginative* processes, see [36]-[37]).

2.3.1. Creativity, planning, problem solving, imagining, and punning

Internal representations and the present results are relevant to recent findings linking amnesia to problems in planning future events, generating humorous puns, solving novel problems and imagining hypothetical states (see e.g., [36], [38], [40]- [47]). Like comprehending novel sentences, these activities entail engagement of the HR to form new internal representations. However, to qualify as *creative* under the new-and-useful definition, such activities must also carry value in the real world. For example, without further evidence, *counterproductive* imagining, as in hypochondria and psychosis, solving *inconsequential* problems (e.g., unrealistic chess puzzles), and *inscrutable* punning, as in schizophrenia, can't be considered creative under new-and-useful definitions of creativity. Divergent thinking (generating unusual uses of common objects) and convergent thinking (responding to words such as *fly*, *man*, *place*, with a single word combinable with each, e.g., *fire*) likewise can't be considered creative unless research with these experimental tasks proceeds to the next step: demonstrations of usefulness in the real world.

2.3.2. Decision biases and the HR

Internal representations and the present results also suggest a critical role for the HR in decision strategies such as the availability bias. Kahneman [48] attributes such biases to the substitution of "fast" (heuristic) processes for the "slow" (evaluative) processes that are often essential when making optimal judgements under uncertainty. In our framework, Kahneman's *slow evaluative processes* reflect HR involvement, although we prefer the descriptor *slow creative processes* to highlight the new and useful nature of the internal representations that the HR typically forms.

2.3.3. Comprehension errors and the HR

Internal representations and the present results likewise suggest that the HR plays a critical role during comprehension in the Moses and Armstrong illusions. These illusions occur when fast but routine retrieval processes substitute for slow but creative representational processes—causing spectacular errors in comprehending specially constructed sentences such as *How many animals of each kind did Moses take on the ark?* [49]-[50].

3. Study 2: The Creative Production of Discourse

Study 2 resembled Study 1 in procedures, participants and interview transcripts, but examined different dependent measures (ungrammatical sentences and immediately repeated filler words) and asked a different question: Does HR damage impair non-routine *production* of face-to-face discourse? We suspected so because of Henry's deficits involving ungrammatical sentences in six prior experimental studies reviewed in Appendix B.[3]

3.1. Hypotheses in Study 2

Based on these prior results, we expected sentence planning deficits in Henry's responses to interview questions in Study 2. As specific operational hypotheses, we predicted relatively more ungrammatical sentences and immediate filler word repetitions for Henry than normal interviewees.

Study 2 also determined whether ungrammatical responses facilitated or disrupted ongoing communication in Henry's interviews. This was the logic. Ungrammatical sentences such as "I want some her" are clearly *novel but inappropriate* when experimenters ask for *grammatical* responses. However, unusual, ungrammatical and incomplete sentences can support brevity and ease of communication in ordinary conversations—as the present conversational style is intended to illustrate. As a result, Henry's ungrammatical sentences can only qualify as non-*creative* if they can be shown to disrupt communication in real life conversations.

To measure communicative disruption, we examined how often the transcribed interviews of Henry and the normal guest spiraled off topic or degenerated into circularity when interviewers called for clarification. Excerpt 2 illustrates a conversation that veered off topic after Marslen-Wilson (W.M-W.) asked Henry to explain why he called a famous pastor "a seditionist." Note how Henry's response triggered further calls for clarification until the conversation shifted off-topic (a seditionist pastor) to the (then) President of the United States and his wife.

Conversational Excerpt 2: An Off-topic Spiral

W.M-W.: How do you mean?

H.M.: Well, in a way that he.. well.. everything was, I guess.. we.. er…better explain it.. the way…everything was OK for everyone else but.. er…just what he's done, it's got to be just right….their .. they can do anything, it doesn't make any difference, but what I do is **right**, that's .. it .. (emphasis in the original)

W.M-W.: I'm not…so what was he saying, what was he doing?

H.M.: Well, in a way, he was just.. telling the people in a way that no matter they could think of things they wanted to and everything but .. er .. his way was **the** way. (emphasis in the original)

W.M-W.: What was his name?

H.M.: I think of Nixon right off. (After this mention of Nixon, the conversation veered further off topic to Pat Nixon, who was Nixon's daughter rather than wife according to H.M.)

Excerpt 3 illustrates a conversation that spiraled into circularity after W.M-W. asked Henry to clarify his alleged love of classical music by the composer "Jerome Kern." (Kern, who died in 1945, actually composed *popular* rather than classical music). Note how Henry's responses to subsequent calls for clarification circled the conversation back to the original topic: his penchant for "symphony music."

Conversational Excerpt 3: A Circular Spiral

W.M-W.: Oh yes, I know…Jerome Kern?

H.M.: ……. And that's what I was thinking of, I was trying to think of the first name and I couldn't.

W.M-W.: That's the guy you mean? ….is it ?

H.M.: ……..It is and it isn't…

W.M-W.: It might have been somebody else?

H.M.: It might have been somebody else… because I think of.. uh.. Jerome Kern as.. uh.. playing in an orchestra (In fact, *Jerome Kern* did not play in orchestras).

W.M-W.: What sort of music is this? …..I mean,…operas…symphonies…musicals.. what?

H.M.: I guess you could go the whole length, all of them…. I wasn't very.. I wasn't particular… about… well there was.. uh.. I guess you could say the mid-twenties that.. uh.. that kind of music I didn't care for at all. (*Note the shift here away from H.M.'s alleged love of classical music, the original topic*)

W.M-W.: Jazz?

H.M.: Jazz…that kind.. I like the.. uh.. in a way…the symphony music. (*Note the return here to the original topic: classical music*)

3.2. Method

3.2.1. Participants and transcripts

Participants and transcripts were identical to Study 1.

3.2.2. Procedures

We computed two measures of sentence planning difficulty: the relative frequency of ungrammatical sentences and immediately repeated filler words, i.e., "um….um"s and "uh…. uh's. Also analyzed was a measure of conversational disruption: the relative frequency of off-topic and circular spirals. Responses to yes-no questions were excluded from analysis.

3.3. Results

3.3.1. Sentence planning measures

Consistent with prior experimental observations, Henry's ungrammatical responses usually involved omission of grammatically necessary words, as in this typical example: "He knocked down……of course" instead of "He *was* knocked down……" or "He *got* knocked down……." Henry produced 167 grammatically incorrect and 353 grammatically correct responses, for an ungrammatical-to-grammatical ratio of 0.47 versus a mean ratio of 0.12 (*SD* = 0.14) for the normal interviewees—a 2.6 *SDs* difference indicating reliably more ungrammatical responses for Henry than the normal interviewees.

Typical examples of immediately repeated filler words (double "um's" and "uh's) were**:** "I think of her.. uh.. uh.. peace.. er.. talking……;" and **"**but.. uh…uh**.**. well it was more of a fighter-squadron for the Eagle Squadron." Henry produced 0.00077 immediately repeated filler words per spoken word versus a mean of 0.000016 for the normal interviewees (*SD* = 0.000063), a reliable 11.94 *SD* difference.

3.3.2. Conversational spirals

Collapsed across circular and off-topic spirals, 49 conversational spirals followed calls for clarification in Henry's transcript, yielding a relative frequency of 0.0016 spirals per word for Henry versus a mean of 0.00026 (*SD* = 0.00047) for the normal interviewees , a reliable 2.85 *SD* difference.

3.4. Discussion

As predicted, Henry produced relatively more ungrammatical sentences and immediate repetitions of filler words than the normal interviewees in Study 2 (with interviewee responses and interview length controlled). These findings comport with Henry's reliable sentence planning deficits in earlier experiments, including the *selective* nature of his production deficits: Henry had difficulty integrating familiar word meanings into novel sentence plans, but no difficulty retrieving familiar isolated words (e.g., on the Boston Naming Test; [51]). The same selectivity was observed in Study 2. Henry had difficulty producing *novel* aspects of conversational speech, e.g., responding to the question "In what ways was the pastor a "seditionist?" in Excerpt 2, but easily produced *routine* clichés such as, "It is and it isn't" and "you could say" (see Excerpt 3). In short, present results strengthen the theoretical distinction between *routine* processes versus *creative* processes. Producing clichés involves routine retrieval of familiar phrases, whereas producing the novel phrases and propositions that one wishes to communicate requires HR engagement to form new and useful cortical representations.

How do present results extend the experimental findings reviewed in Appendix B? Previous experiments did not tap into what makes novel discourse creative: usefulness in the real world. However, Henry's off-topic and circular spirals in Study 2 link the HR to *useful creativity* in

conversational discourse: Unlike Henry, speakers with intact HR structures can form novel, coherent and grammatical answers to requests for clarification—without driving conversations off topic or into circles.

But wait, wrote a colleague. What about the verbal IQ and education levels of your normal participants—well controlled in prior experimental research, but not in the present studies? In response, we could neither measure those factors nor determine what hypothesis they favored, but factors we could measure clearly favored the null hypothesis. For example, Henry was younger than our normal interviewees (age 44 versus about 53) and answered easier questions (see Study 1)—factors associated with *increased* rather than *reduced* grammaticality and coherence in conversational speech, e.g., [52].

3.4.1. Duff et al., amnesia and the routine-novel distinction

We now discuss a curious experimental observation in [40] that on the surface seems to contradict our distinction between routine versus creative processes and the present results. However, this seeming exception actually proves the rule as this review of the Duff et al. procedures shows. On trial one of their experiment, a "director" described a random sequence of 12 tangrams (abstract, never-previously-encountered objects) hidden behind a screen, and a listener tried to reconstruct the sequence using duplicate set of the tangrams. The experimenter then re-shuffled the sequence of tangrams and the participants repeated this sequence communication game 23 more times.

Half the directors were amnesic and half were memory-normal, but the listeners were all memory-normal friends, spouses or relatives of the directors. The main dependent measure was how successfully the normal listeners reconstructed the 24 tangram sequences as communicated by amnesic versus normal directors (see also [53]-[54] and [2]).

The curious result? Normal and amnesic directors described a tangram using labels that became progressively shorter *at the same rate over the 24 trials*—as if the amnesics recalled a tangram label used up to a day earlier and then shortened it for subsequent use [40].

Was this an instance of new learning and creative communication in amnesia as Duff et al. suggest [40]? Two aspects of the Duff et al. procedures suggest a simpler explanation. First, the amnesic directors could encode the tangrams without HR involvement—using internal representations created long before the onset of amnesia. Although never-previously-encoded as overall patterns, tangrams contained features reminiscent of familiar objects with familiar labels such as "a camel" or "a Viking ship." As a consequence, preformed memory representations of the characteristic visual features of camels and Viking ships may have sufficed to successfully identify the tangrams in this task and to communicate the tangram sequence using labels learned as children—without forming new internal representations.

The task of identifying *fragmented figures* illustrates an analogous situation where never-previously-encountered stimuli engage preformed internal representations without HR involvement. Amnesics (including H.M.) can recognize and name, say, an elephant depicted with varying degrees of fragmentation, as readily as normal controls. Why? Although never previously encountered *per se*, fragmented line drawings of elephants contain characteristic visual features reminiscent of, say, a trunk or tusks, with internal representations that everyone acquires as a child— which enable amnesics to respond "elephant" without forming a new internal representation for the overall fragmented pattern [32].

However, the need to form new internal representations is both task- and stimulus-specific. If the task in [40] had been to *draw* the tangrams *from immediate memory* rather than to name them, amnesics with HR damage would have produced more distorted drawings than the normal controls. Why? Because amnesics (including H.M.) can't form the new cortical representations necessary to accurately represent and draw a never-previously-encountered figure, e.g., [32]. Moreover, if someone had named a tangram "camel" in another version of this hypothetical draw-from-memory experiment, preformed internal representations of the visual features of camels would have *distorted* how both amnesics and normals drew that particular tangram (see e.g., [55]).

But wait, wrote a colleague: To me, a Rorschach-like tangram that reminds me of a *Viking ship* seems "quite similar to the creative process involved in producing *Juliet is the sun*." It is not. First, reminding involves activation of already existing internal representations—not the creation of new ones. When you see a stone on the beach that reminds you of a cannonball, features of the stone, e.g., hard and round, simply activate your preformed internal representation of a cannonball.

Second, reminding often has counterproductive effects that violate the *usefulness* criterion for creativity. To illustrate, if Shakespeare had written "Juliet reminds me of the sun" instead of "Juliet is the sun" with no other changes in *Romeo and Juliet*, this hypothetical sentence would almost certainly have negative rather than useful real-world consequences. Why? Because a critic would have written something like "Romeo reminds me of an idiot," and the play would never have been staged again.

The second factor that almost certainly contributed to the progressively shorter descriptors adopted by amnesic directors in [40] is repetition learning. Amnesics with HR damage can form internal representations of novel information via repetition, e.g., [56]-[57], [33], [31], [58]-[67]—as when H.M. learned post-lesion about Americans fighting in Vietnam—information massively repeated in the media from 1965–1975.

So amnesic directors in [40] could have acquired their progressively shorter tangram labels without HR involvement—the normal means of creating new internal representations. Why? Because both members of the amnesic-normal pairs in Duff et al. freely discussed the tangram labels and used them at *least* 24 times across the experiment.

Two related notes on memory and language. First, when re-introducing a previously mentioned tangram label, normal directors in [40] reliably more often than amnesic directors used the

appropriate definite article, e.g., *the* in "Next comes *the* windmill." However, the fact that amnesics misuse definite articles may have nothing to do with their *language* abilities *per se* because recall of what tangram label was used previously is a prerequisite to appropriate use of *the*. Because episodic memory deficits in amnesics have been well established for over 50 years and are built into the *definition* of amnesia, demonstrating that amnesic directors misuse *the* adds nothing new.

Second, the distinction between novel versus familiar internal representations is age- and person-specific, as well as task- and word-specific. For example, internal representations of the meaning, pronunciation, and spelling of familiar low frequency words may be functional at age 20, but dysfunctional at age 65: Aging, non-recent use, and infrequent use over the lifetime can destroy internal representations formed as a child, so that on subsequent encounters with a once familiar word, new internal representations of its phonological, orthographic, and semantic properties must be formed, a relearning process that is easy for normal older adults but not for same age amnesics [1], [35].

3.4.2. General discussion

Two fundamentally different theoretical frameworks have guided recent research on relations between the HR and creativity in language use: the Duff-Brown-Schmidt and binding theory frameworks. Without naming them, we earlier discussed the differing definitions of creativity adopted in these frameworks. Here we directly compare the theoretical frameworks themselves.

3.4.2.1. The Duff-Brown-Schmidt framework

Under the Duff-Brown-Schmidt framework [2], [68], the hippocampus has two critical functions related to language use: to bind and store declarative (fact and event) memories involving "arbitrary relations across modalities and domains." So HR damage causes amnesia by preventing storage and retrieval of fact and event memories. How does this impair language use? Because the hippocampus deploys declarative memories to the cortex when needed for on-line linguistic processing, as when event memories call for definite articles to mark tangram labels as previously mentioned.

However, hippocampal facilitation of language processing is limited in the Duff-Brown-Schmidt framework. First, language processing also engages non-hippocampal (i.e., non-declarative) memory systems, e.g., the procedural or habit memory system thought to underpin syntactic priming and the learning of statistical regularities in grammars—phenomena that remain "intact in patients with hippocampal amnesia" [68]. Second, hippocampal facilitation is time-limited: After weeks, years or decades, declarative (e.g., semantic) memories for supporting lexical access deploy or migrate permanently from the HR to the neocortex, where they slowly consolidate, independent of the hippocampus [68]. The Duff-Brown-Schmidt framework does not specify how memories travel such great distances, but given that synaptic biochemistry is the generally accepted brain basis for

memory, this hypothetical migration process seems unlikely. After all, synapses and synaptic boutons are neuron-specific, and don't travel far from home.

Also problematic for the Duff-Brown-Schmidt framework are Henry's deficits in reading novel sentences and describing novel scenes. Because these tasks engage neither fact nor event memories, these results suggest direct involvement of the HR in language processing *per se*. Equally problematic is the extensive literature indicating that the HR responds directly to novel but not familiar stimuli (see [69]-[76]. For example, Duncan et al. showed in [69] that fMRI responses in human hippocampus following a probe stimulus co-varied with participants' expectations, as if the HR continuously computes the overlap between expected and novel events, and the ERP-lesion study in [76] extended this novelty-HR link to amnesics. Why the HR responds to novelty is not obvious in the Duff-Brown-Schmidt framework where the hippocampus serves to temporarily store declarative memories that "come to the aid of" cortical processes when needed.

3.4.2.2. The binding theory framework

The binding theory framework guided the present research on the HR and linguistic creativity. Here conceptual memories reside in the synapses between cortical units and the HR isn't a bank for storing memories, either episodic, semantic, linguistic or procedural. Rather, the HR contains thousands of *combinatorial activating mechanisms* (known as binding nodes) that "convince" cortical units to represent novel conjunctions of already formed units in specific conceptual categories. For example, one binding node can "commit" or compel a fresh (uncommitted) cortical unit to represent noun phrases that combine the conceptual categories adjective and noun, as when someone creates *de novo* the noun phrase *Alaskan lobsters.* Another binding node can commit or "convince" an uncommitted cortical unit to represent verb phrases that combine the categories verb, prepositional phrase and adverbial noun phrase, as when someone creates *de novo* the verb phrase *ate Alaskan lobsters at Scalia's last night*.

Analogous but separate binding nodes in the HR create novel declarative memories in the cortex. For example, to create a memory for the Scalia *experience* last night, a binding node "convinces" an uncommitted cortical unit to represent in combination the memory for the event {*eating Alaskan lobsters*}, the place {*at Scalia's*} and the time {*last night*}. Although the units representing the prepositional phrase *at Scalia's* in language cortex connect with this preformed event memory linking visual, spatial, auditory, and temporal representations of the original *Scalia* experience, different HR binding nodes create cortical representations for events versus prepositional phrases, and those for creating the sentence *We ate Alaskan lobsters at Scalia's last night* cannot *in principle "*come to the aid of" the independent HR binding nodes for creating the episodic memory of the original experience.

This brings us to a general question relevant to all forms of creativity: *How* do binding nodes conjoin two or more preformed conceptual units to form a new or never previously formed unit in the

cortex? Although beyond the scope of the present discussion, interested readers can find detailed answers to this theoretical question in [30] and [77]-[78].

What else distinguishes the two frameworks? Unlike the passive HR-independent consolidation process assumed in Duff-Brown-Schmidt, the HR plays an active role in memory consolidation in binding theory—and this explains why HR amnesics forget at a faster-than-normal rate "recent" memories formed in the years immediately before their brain damage (Ribot's law). The reason is that normal individuals but not amnesics actively re-learn forgotten information that has been rarely used over the lifetime: HR damage prevents the renovation of recently formed (and therefore rarely used) internal representations eroded by disuse and aging, e.g., [1].

Also unlike the Duff-Brown-Schmidt framework, binding theory readily explains why the HR responds to novelty, but doesn't retrieve already formed memories [32]. Under binding theory, activating mechanisms in the frontal lobe known as sequence nodes retrieve familiar information without HR involvement (for details on how retrieval occurs, see [20] and [78]). So why does fMRI activity sometimes accompany memory retrieval, e.g., [79]? After retrieving information X, people typically form new internal representations resembling {I retrieved information X in context Y}.

But wait, wrote a colleague: "Structural priming" remains intact despite HR damage, e.g., [80]. Doesn't this show that amnesics can form new internal representations? It does not. Structural priming involves *re-activation* of the set of sequence nodes representing, say, a passive sentence structure, a process that does not differ in principle from lexical priming (see [20] pp. 39–61). As in [33], repetition priming occurs with *preformed* internal representations, but not with *new* ones (as with novel words and syntactic structures in a foreign language).

Again unlike the Duff-Brown-Schmidt framework, binding theory does not restrict the HR to linking "unrelated" concepts "in rich, multi-modal contexts … across modalities and domains." This is important because forming arbitrary relations, as in memorizing a sequence of unrelated nouns, is rare in real life. The HR *usually* conjoins *related* concepts in non-arbitrary ways—as the regularities in Henry's speech and reading errors illustrate. For example, consider again Henry's uncorrected misreading of *The boys who were fed hot dogs got stomach aches:* "The boys were fed hot dogs got stomach aches." Here Henry omitted the subordinate conjunction *who* because, under binding theory, HR engagement is necessary to form an internal representation of the novel but logical (non-arbitrary) relation between main and subordinate clauses, here, *The boys got stomach aches*, and *who were fed hot dogs*, respectively, e.g., [61]-[62].

And forming *non-arbitrary* internal representations is the essence of real world creativity. For example, Shakespeare's *Juliet is the sun* is useful (and, when newly minted, *creative*) because it satisfies a range of non-arbitrary constraints involving, e.g., its semantic context in *Romeo and Juliet*, the shared knowledge of English theater-goers at the time, and the rules of English syntax.

Personal problem solving likewise requires non-arbitrary creativity. Choosing an appropriate and surprising birthday present for your mother-in-law must satisfy many non-arbitrary constraints in

order to win her over. And the same applies to artistic creativity. To develop his new and extremely influential (valuable and useful) "cubist" depictions of the world, Picasso had to satisfy many non-arbitrary constraints that art historians are still studying—just as linguists are still studying the plethora of non-arbitrary constraints that govern the creation and acceptance of newly coined words and grammatical sentences in English.

3.4.3. Directions for Future Research

Findings with Henry discussed here suggest new directions for future research on insight problem solving and the brain. For example, the "Aha" reactions of normal participants but not Henry in [81] (see Appendix A) suggest a simple paradigm for investigating whether brain mechanisms underlying the "Aha" experience reflect insight into how to solve a problem, or just emotional responses to having discovered a successful solution (see [82]). No previous research on insight has focused on the HR in addressing this issue (see [82] for a review), but MacKay's observations suggest that a sudden increase in HR activity will precede normal "Aha" reactions and the "yes" responses that signal discovery of the second interpretation of ambiguous sentences. However, neither "Aha" reactions nor increased HR activity should precede solutions to *routine*, familiar or previously solved problems, as when normal participants "discover" the second meaning of a familiar ambiguous word or phrase presented in isolation (see Appendix A).

The present concept of internal representation also suggests new directions for research on relations between the brain and *creative* versus *routine* planning, imagining, problem solving and punning. Just as H.M. can use preformed internal representations to comprehend *familiar* puns as isolated words (see Appendix A; also [31]), amnesics should be able to use internal representations formed before the onset of amnesia to generate familiar puns, to plan routine acts (e.g., getting ready for bed), to imagine routine situations (e.g., sitting in an automobile), and to solve familiar problems (e.g., circumnavigating obstacles on the sidewalk).

Other research directions concern the links established with Henry between the HR and error detection, error correction, the abnormally rapid degradation of well-established memories with aging, the perception of unfamiliar but not familiar aspects of visual scenes, and the comprehension and production of novel but not routine aspects of experimentally constructed sentences and real world conversations (see [1], [31]-[32], [61], [83]; also Appendix A and B and Studies 1-2). Verifying these links with fresh amnesics and carefully matched controls is an important follow-up step. Tests of the hypothesis that creative processes for comprehending and producing *novel* phrases are inherently slower than *routine* processes for retrieving phrases with preformed internal representations represent another research direction. Nonetheless, the need for further research must not mask the significance of Henry's profound deficits in creative comprehension and production. As Ramachandran [84], p. xi notes, "most of the syndromes in neurology that have withstood the test of time … were initially discovered by a careful study of single cases."

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Footnotes

[1] Deliberate violations of APA guidelines in our conversational style include first person pronouns to designate the first author (*I* and *my*) and both authors jointly (*we*), and the use of present tense verbs. H.M.'s data were in fact gathered in past tense —at least nine and as many as 41 years before his death in December, 2008.

[2] For didactic reasons, we have simplified our illustrations of the materials in [85]. The actual stimuli were *garden path* sentences—which start off ambiguous, but later flip to the non-dominant interpretation of the ambiguous words, as in *The horse raced past the barn fell*.

[3] No prior experiments looked at immediately repeated filler words, the second measure of sentence planning difficulty in Study 2.

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Appendix

1. Appendix A. Eight Prior Sentence Comprehension Experiments with H.M.: A Review

We organize this review of prior sentence comprehension experiments with H.M. by the type of information comprehended: ambiguous sentences, unambiguous sentences, ambiguous words, metaphoric sentences, and thematic roles in sentences. We review control results that rule out Henry's cerebellar damage as the basis for his sentence comprehension deficits, but refer the reader to the original studies for control results that exclude explanations based on explicit or declarative recall, response biases, excessive memory load in the tasks, failure to comprehend or recall the instructions, forgetting, poor visual acuity, motor slowing, time pressure, deficits in visual scanning or attentional allocation, and lack of motivation/interest in the tasks.

1.1. Comprehending ambiguous sentences

In my 1966 comprehension study in [81], Henry and control participants (Harvard undergraduates) saw 32 ambiguous sentences one at a time on cards. This is an example: *I just don't feel like pleasing salesmen*, which can mean either, "I don't want to please salesmen" or "I don't want agreeable salesmen around." The task was to find both meanings for each sentence as quickly possible, say "yes" as soon as they found the second meaning, and briefly describe both meanings.

The results? Henry detected both meanings of the sentences significantly less often than Harvard undergraduates. He also interpreted the sentences in bizarre, inaccurate and ungrammatical ways. For example, this was how Henry explained the two meanings of *I just don't feel like pleasing salesmen* in [86], a replication of my 1966 study: "The person doesn't like salesmen that are pleasing to him. Uh, and that personally he doesn't like them and and [*sic*] personally he doesn't like them [*sic*] and then I think of a phrase that he would say himself, he doesn't, uh, pleasing, as conglamo [*sic*], of all of pleasing salesmen."

Other differences in results for Henry and the Harvard participants in [81] were more qualitative. The undergraduates often caught their breath and uttered an audible "Aha" or "ah" before responding "yes" to indicate discovery of the second meaning. And when questioned after the experiment, participants suggested that their "Aha's" accompanied a click of comprehension—a sudden shift from vague to clear and from hesitancy to certainty about both meanings of the sentence. Some also wondered why the sudden comprehension shift—so obvious in retrospect—took so long to come.

However, Henry didn't catch his breath, uttered no "Aha's" and never expressed certainty about comprehending the second meanings. Indeed, when the experimenter explained second meanings that Henry *did not* detect, he expressed *uncertainty* with the phrase "Í wonder," as if he still didn't understand. And he never once said "Yes" (as instructed) to signal when he detected the second meaning for timing purposes.

As a graduate student in 1966, I did not expect these results, but I suspected that something was amiss with Henry's sentence comprehension—including his comprehension of sentences that he himself produced. I just had no idea what that something was, or its relation to creativity and HR damage. What follows is the story of how I later connected the dots.

My first step? To replicate my surprising results with modified procedures. By shuffling the 32 ambiguous sentences in my 1966 study, I had randomly intermixed three different types of ambiguity. What if Henry received the three types of ambiguous sentence in separate blocks and the experimenter ensured that he understood each sentence within a block before proceeding to the next? By the end of a block, could Henry comprehend that type of ambiguity without help?

No he couldn't. In [86], a replication of my 1966 experiment that adopted this procedural change, Henry virtually never discovered the two interpretations of the ambiguous sentences without

help from the experimenter. Moreover, he couldn't even repeat sentence interpretations that the experimenter explained to him after he failed to discover them on his own.

Perhaps Henry's age, IQ, background or education was the problem? No. In subsequent studies (e.g., [86]), Henry understood reliably fewer ambiguous meanings than memory-normal adults who closely matched him in age, education, verbal and performance IQ, native language, and socio-economic background (semi-skilled labor).

Did forgetting cause Henry's comprehension difficulties? To find out, I created a new and simpler version of my original task. On each trial, Henry saw a target sentence, e.g., *When a strike was called, it surprised everyone*, plus a single interpretation that was either possible for that sentence, e.g., "The umpire unexpectedly called the pitch a strike", or impossible, e.g., "The umpire quickly called the coaches to the mound." His task? To say 'yes' if the simultaneously presented interpretation could fit the sentence, and 'no' otherwise [31].

Did this procedure help Henry choose possible interpretations and reject impossible ones? No it did not—indicating that forgetting one interpretation after discovering the second cannot explain Henry's difficulties in my original experiment.

Was the problem the particular interpretations that Henry received? No. Henry responded incorrectly to both ways of interpreting the sentences, e.g., responding "No" on the next day when he saw the sentence *When a strike was called, it surprised everyone* coupled with its other possible interpretation: "The union workers unexpectedly went on a labor strike" (rather than the initial interpretation: "The umpire unexpectedly called the pitch a strike").

Did Henry's ability to comprehend differ for one-word ambiguities, e.g., *tank* in *The soldier put the gasoline in the tank,* versus multi-word ambiguities, *e.g., on top of everything* in *On top of everything there was a tarpaulin*? No difference. Could Henry comprehend short ambiguous sentences better than long ones? No difference. Memory load defined as the number of words in the sentences also did not matter.

What aspect of Henry's brain damage caused his deficit in comprehending ambiguous sentences? Although he had virtually no neocortical damage, medicines Henry took for many years had damaged his cerebellum [27]-[29]. Did this cerebellar damage cause Henry's ambiguity comprehension deficit? This question is important because [85], a functional magnetic resonance imagery (fMRI) study of normal speakers, reported more cerebellar activity during comprehension of structurally ambiguous sentences (e.g., *Pavlov fed her dog biscuits*) than during comprehension of otherwise similar *unambiguous* sentences (e.g., *Pavlov fed him dog biscuits*[2]).

Does the cerebellum comprehend sentences? Not likely. Rather, the results in [85] almost certainly reflect the well-established timing functions of the cerebellum (see, e.g., [87]). By way of illustration, consider the special role of timing pauses in comprehending structurally ambiguous sentences such as *Pavlov fed her dog biscuits*: Repeat this sentence over and over to yourself with two different timing patterns in your internal speech: *Pavlov fed her ___ dog biscuits* versus *Pavlov*

fed ___ her dog ___ biscuits. As you alter the timing, note how the meaning of the sentence changes—indicating a critical role for timing in comprehending this type of ambiguous sentence.

Similar timing pauses occur during internal speech, e.g., [20], and it is noteworthy in [85] that greater fMRI activity for ambiguous than unambiguous sentences occurred not just in the cerebellum, but in areas associated with internal speech—which suggests that the increased cerebellar activity when people comprehend structural ambiguities reflects self-inserted timing pauses in internal speech.

Can timing difficulties related to Henry's cerebellar damage explain his comprehension deficits involving *our* ambiguous sentences? No. Henry also exhibited large deficits in comprehending *lexically* ambiguous sentences (see [86]; also [88]), a type of ambiguity that pauses cannot disambiguate. To illustrate, alter your between-word pauses as you repeatedly produce this *lexically* ambiguous sentence via internal speech: *The soldier put the gasoline into the tank*. You will see that the word *tank* remains ambiguous despite any timing changes that you make. Timing deficits associated with Henry's cerebellar damage cannot therefore explain his deficits in comprehending lexical ambiguities. And reinforcing this conclusion, HR amnesics *without cerebellar damage* experience the same difficulties as Henry when comprehending lexically ambiguous sentences [89].

Finally, non-amnesic patients with cerebellar damage exhibit no deficits when reading ambiguous and unambiguous sentences aloud, conclusively ruling out cerebellar damage as the basis for Henry's sentence reading deficits in [30] and [34].

1.2. Comprehending isolated ambiguous words

If Henry couldn't understand the two meanings of *tank* in sentence contexts such as *The soldier put the gasoline in the tank*, could he understand *tank* as an isolated word—independent of sentential and real world contexts*?* Yes! Finally a procedural modification that paid off! Henry discovered the two interpretations of isolated lexical ambiguities without difficulty [31], despite his deficits when the identical words appeared in sentences [30]-[31]. Why? Because sentence processing involves more words? No. For lexically ambiguous words and phrases presented alone without context, Henry understood long items such as *on top of everything* as readily as short ones such as *tank*. Memory load for the isolated ambiguous words and phrases had no effect.

The conclusion? Because Henry can readily comprehend isolated ambiguous words and phrases with preformed internal representations, understanding familiar words and phrases out of context must be a routine process that does not require HR engagement for creating new internal representations. However, creative processes are needed to comprehend the two meanings of ambiguous *sentence*s that listeners have never previously encountered. Why? Because new internal representations are necessary to integrate the meanings of ambiguous words with their novel context in those sentences.

This conclusion suggests that Henry couldn't form the new internal representations for comprehending *either* meaning of my ambiguous sentences, and that he should have difficulty comprehending novel aspects of *any* sentence! The next three sections review my subsequent tests of this hypothesis.

1.3. Comprehending metaphoric sentences

Metaphors are not just enjoyable—the stuff of poetry and great art. They are pervasive and fundamental to our everyday thinking, learning and understanding—a way of comprehending one type of concept in terms of another. Without our knowing it, metaphors shape how we perceive, learn and think about the world. For example, war and battle metaphors determine how Americans conceptualize everyday disagreements. We think of arguments as verbal battles that we can win or lose. As in real wars and battles, we can gain or lose ground in arguments, we can take positions and defend them in arguments, and we can abandon indefensible positions and adopt new lines of attack. We can even demolish, wipe out or shoot down an "opponent's" arguments [90].

So metaphors are important in the real world. Can Henry understand them? A famous anecdote suggests that he can. This is the anecdote. Dr. Suzanne Corkin encountered Henry working on a crossword puzzle and commented, "Henry, you're the puzzle king." To which Henry replied "Yes, I'm puzzling", as if he fully understood Corkin's *puzzle king* metaphor and wanted to advance the conversation with a double reference to his crossword puzzle habit and his profound amnesia—an existential condition that puzzled him even in old age.

But wait. Does Henry's "Yes, I'm puzzling" really indicate that he comprehended Corkin's *puzzle king* to mean {You are a king among solvers of crossword puzzles}? Dominating at solving puzzles, being puzzling, and working on a puzzle represent distinct concepts. Distracted by his puzzle, Henry perhaps misunderstood Corkin's "puzzle king" to mean "puzzling"—a type of conceptual confusion he frequently exhibited in my sentence comprehension experiments. Or maybe Henry *misheard* Corkin's "puzzle king" as "puzzling"—in which case, his "Yes, I'm puzzling" is appropriate and makes perfect sense. The hypothesis that Henry can comprehend novel metaphors demands better data.

I therefore gave Henry and memory-normal controls the standardized Test of Language Competence (TLC; [91]). In the metaphor comprehension subtest of the TLC, participants saw three alternative interpretations for short, never-previously-encountered sentences containing metaphors, e.g., *Maybe we should stew over his suggestion*. Their task was to choose the correct interpretation, here, *Let's think about it some more,* rather than *Maybe we should put more meat into his suggestion*, or *Let's make sure to cook the stew long enough.*

The results? Henry's performance (38% correct) did not differ from chance guessing (33% correct) and was reliably worse than for closely matched normal individuals his age. Henry also displayed a curious bias in his choice of *incorrect* interpretations. He preferred wrong interpretations

containing a word from the target sentence, *e.g.*, *stew* in *Let's make sure to cook the stew long enough*, over interpretations with no overlapping words, here, *Maybe we should put more meat into his suggestion* [31].

Why this preference for lexical overlap between target sentence and interpretation? Consistent with his intact comprehension of isolated ambiguous words, Henry could understand familiar words such as *stew* independent of their sentence context. So he based his responses on word-level overlap without understanding either the target sentences or their possible interpretations *as sentence*s! Why? Because he couldn't integrate familiar word meanings with their sentence context to form novel internal representations—a creative process that yields different interpretations for *stew* in the contexts *cooking a stew* versus *stewing over a suggestion.*

Our conclusion? The same as for explaining Henry's deficits in comprehending ambiguous sentences but not in comprehending isolated ambiguous words. Comprehending familiar words *per se* involves routine or non-creative processes that do not engage the HR. However, HR mechanisms are essential for creating the new internal representations required to comprehend one kind of event—*taking the time to talk and think about something*—in terms of another—*slowly cooking, as with a stew* in sentences such as *Maybe we should stew over his suggestion*.

1.4. Comprehension when reading ambiguous and unambiguous sentences aloud

In [86], the replication of my 1966 experiment with Henry, the experimenter had Henry read aloud ambiguous sentences such as *I just don't feel like pleasing salesmen*. The results? Henry often misread the sentences, mainly by omitting one or more words. For example, he misread *I just don't feel like pleasing salesmen* as "I don't like pleasing salesmen," omitting the words *just* and *feel*. The experimenter then asked Henry to read the sentence again. Henry's response: "I just don't like pleasing salesmen." Experimenter's feedback: "You're leaving out a word." Henry's response: "I just don't feel like pleasing, yep." The experimenter: "Read it again, then." Henry had to read one sentence six times before including each of its words.

Did Henry's reading mistakes reflect forgetting? No. The sentence to be read always remained in front of him, so nothing needed to be remembered. Did the ambiguities contribute to his reading difficulties? Perhaps. Henry's reading errors usually transformed the original sentences from ambiguous to unambiguous. For example, Henry misread *John is the one to help today* as "John is the one that helped today"—eliminating the second interpretation, "John is the one for us to help today."

So my next questions were: What if I removed the ambiguities? Would Henry misread *unambiguous* sentences more often than normal? And if so, why? To address these questions, I ran an experiment where the task was to read unambiguous sentences aloud "as quickly as possible without making errors" [30]. The results indicated reliably more errors in unfamiliar phrases for Henry than normal individuals, and reliably longer pauses between words in unfamiliar phrases, but

not familiar phrases such as *police station*. Why? Because HR engagement is unnecessary when reading familiar phrases with pre-formed internal representations, but essential when reading unfamiliar phrases requiring the formation of new internal representations that integrate the word meanings in the phrases.

Henry also produced abnormal pauses when reading unpunctuated sentences, but paused normally when commas or periods marked the boundaries between phrases in the text. Why? Because Henry learned to pause after periods and commas in grade school, but without punctuation to guide him after his lesion, he couldn't create the novel internal representations required to determine the major between-phrase boundaries that required pauses [30].

Now, unusual pauses and general slowness have been linked to cerebellar damage (for a review, see [92]). Does Henry's cerebellar damage explain his abnormal pauses when reading sentences aloud? No. A general or across-the-board cerebellum-linked timing disorder can't explain the *selective* nature of Henry's pause pattern: longer than normal pauses between the words in unfamiliar phrases and at major syntactic boundaries unmarked by commas, but not between words in familiar phrases or at major syntactic boundaries marked by commas.

What about Henry's reading errors? Did his cerebellar damage cause *them*? No. Unlike Henry, patients with bilateral damage restricted to the cerebellum in the reading experiments in [30] produced no more reading errors than memory-normal controls.

Moreover, detailed analyses of Henry's reading errors pointed to the same conclusion as before: Henry could easily read familiar phrases, but due to his HR damage, he experienced deficits when reading novel phrases and sentences. Why? Because HR engagement is necessary to form new internal representations for comprehending and producing *novel* phrases and sentences, but not *familiar* ones.

Henry produced many different types of reading errors in [30], [34] and [93], but one especially interesting type of error cried out for further research. To illustrate, this was how Henry misread *the* cartoon caption, *I tell you, Edith, it's not easy raising the dead*: "I tell Edith, it's not… easy, the-raising the dead." What explains Henry's uncorrected omission of the pronoun *you* in this example? Did Henry think that the speaker shown talking *to* Edith was talking *about* "Edith"—some third person not in the cartoon? Couldn't Henry grasp the most important information in a sentence—who did what to whom? This question motivated the research reviewed next.

1.5. Comprehending who-did-what-to-whom in sentences

In my 1966 experiment, alternate ways of interpreting who-did-what-to-whom in ambiguous sentences were especially difficult for Henry to comprehend [81]. Examples are *Mary just doesn't feel like pleasing salesmen* (where "Mary is pleasing salesmen" in one interpretation, and "salesmen are pleasing Mary" in the other), and *John is the one to help today* (where "John is helping others" in one interpretation, and "others are helping John" in the other).

Was Henry's difficulty with who-did-what-to-whom relations confined to ambiguous sentences, or did it extend to any novel sentence? To find out, I gave Henry and closely matched memory-normal controls the "thematic role" subtest of the TLC [91]. Their task on each trial was to read a sentence such as *The daughter that the mother adored fed her baby*, and answer a multiple-choice question, here, *Who fed the daughter*: *the mother, the baby,* or *nobody?* Henry chose reliably fewer correct interpretations than the controls, e.g., responding that "the mother" rather than "nobody" fed the daughter in *The daughter that the mother adored fed her baby* [31].

Why? Was the word *nobody* difficult for Henry to comprehend? No. Henry experienced the same difficulty with other response alternatives. For example, Henry mistakenly responded "the young child" rather than "the mother" spilled the water in the sentence *The water that the mother spilled surprised the young child.*

Detailed analyses indicated that Henry based his responses on familiar associations stored in memory without computing the novel who-did-what-to-whom relations in the sentences. Asked whether *mother* or *young child spilled water*, Henry responded "young child" because preformed associations in memory linked *children* with spilling and *mothers* with mopping up. Asked whether *mother* or *daughter* fed a baby, Henry chose "mother" because preformed associations in memory linked *mother*, not *daughter*, with feeding babies. Henry's problem in understanding who-did-what-to-whom in the sentences reflected his problem in creating *new* internal representations, not in activating familiar associations stored in memory [31].

What about the dozens of other types of grammatical relations between the words in sentences that normal speakers understand, e.g., time relations (e.g., *Yesterday he made it* is grammatical but *Yesterday he make it* is not), number relations (*two horses* but not *two horse*), and gender relations (*She cut herself* but not *She cut himself*). Did Henry have difficulty understanding other relations besides who-did-what-to-whom? For example, could he integrate the word *she* with its sentence context to comprehend that *She cut herself with a knife* is grammatical whereas *She cut himself with a knife* is not?

To find out, I ran a new experiment in which Henry and closely matched controls saw 31 grammatical sentences intermixed in semi-random order with 31 ungrammatical sentences that violated a wide range of different types of relations, including time, number, and reflexive relations. The task was to respond "Yes" to grammatical sentences, e.g., *Sally and I are happy that you could make it*, and "No" to ungrammatical ones, e.g., *Sally and I am happy that you could make it*. Henry said "yes" to only 59% of the grammatical sentences—reliably worse than the memory-normal controls, and not significantly different from chance (50%) [31]. Why? Because Henry's HR damage prevented him from forming new internal representations for comprehending who-did-what-to-whom and many other types of relations in novel sentences.

To summarize the main results of prior sentence comprehension experiments, Henry had no difficulty comprehending phrases and sentences with pre-formed internal representations but had major difficulties comprehending phrases and sentences that required the formation of novel internal

representations. (For follow-up studies with other amnesics and completely different stimuli that support our distinction between new versus pre-formed internal representations, e.g., [94]-[98].

2. **Appendix B. Six Prior Sentence Production Experiments with H.M.: A Selective Review**

We review H.M.'s prior sentence production experiments by order of publication.

2.1. MacKay, Burke et al. (1998) [77]

On trials in the main task in [77], memory-normal controls carefully matched with H.M. received an ambiguous sentence typed on a card, found its two meanings, and briefly described them. They had no difficulty with this task, and quickly produced brief, grammatical, comprehensible, and coherent meaning descriptions resembling this typical response to the ambiguous sentence *I just don't feel like pleasing salesmen:* "I don't want to please salesmen," and "I don't want agreeable salesmen around."

However, Henry found this task difficult, as *his* response to the same sentence illustrates: "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."

Ten judges blind to speaker identity rated the grammaticality of each participant's transcribed responses to the 32 ambiguous sentences. The results? Mean grammaticality ratings were significantly lower for Henry than the controls.

Were multi-word ambiguities, *e.g., on top of everything* in the sentence *On top of everything there was a tarpaulin*, more difficult for Henry to describe than single-word ambiguities, e.g., *tank* in *The soldier put the gasoline in the tank*? No. Grammaticality ratings for Henry's descriptions did not vary with complexity or memory load, defined as the number of ambiguous words that required description.

2.2. MacKay and James (2001) [30]

In [30], Henry and memory-normal controls read novel sentences aloud in four experiments. The results? Henry misread more sentences than the controls, and he almost never corrected his reading mistakes—even when they rendered his sentences ungrammatical. For instance, this was Henry's uncorrected misreading of *The boys who were fed hot dogs got stomach aches:* "The boys were fed hot dogs got stomach aches."

As in this example, Henry's reading errors usually involved uncorrected omission of short, high-frequency function-words such as *who* in *The boys who were fed hot dogs got stomach aches*. Were function words *per se* difficult for Henry to read? No. When we later presented the same

sentences one word at a time in scrambled word order, Henry read the function words without difficulty. He only had a problem integrating function words into their novel contexts in sentences.

Did Henry's cerebellar damage contribute to his reading errors? No. Henry misread reliably more words than another closely matched control group in the MacKay and James experiments: patients with bilateral cerebellar damage resembling Henry's. Other factors without impact on Henry's sentence reading errors included ambiguity, sentence length, speed-accuracy-trade-off, general-slowing, general cognitive-decline, target reading rates in the tasks (fast versus normal), left-to-right reading processes, and working-memory limitations [30].

The conclusion? Henry's reading errors reflected inability to integrate familiar word meanings into novel phrase and sentence contexts, a problem echoed in many other domains: comprehending and generating novel sentences, reading isolated low frequency words and pseudo-words aloud, recalling novel events (episodic memory), and comprehending novel visual scenes (see [30] and [35]).

2.3. MacKay, James, Hadley & Fogler (2011) [83]

In [83], Henry and memory-normal controls described captioned cartoons and explained why they were funny. Again, judges blind to speaker identity rated Henry's descriptions as reliably less grammatical than those of controls. Why? Because Henry's sentences contained large numbers of uncorrected errors such as "it's wrong for her to be"—which rendered his sentences ungrammatical.

Subsequent analyses indicated that Henry's errors differed from normal slips of the tongue. Normal errors, as in "Older men choose to tend, I mean, tend to choose younger wives," don't disrupt ongoing discourse because speakers easily correct them, either on their own or in response to a listener's "What?" However, Henry couldn't even explain his uncorrected, dialog-stopping errors when listeners explicitly asked for clarification. For example, Henry described the protagonist in one cartoon as "making a double correction," and when the experimenter asked what he meant, Henry couldn't say. We called uncorrected, anomalous and conversation-killing errors "major" because they disrupted ongoing communication, and when expressing novel ideas in this and other sentence production experiments, Henry produced reliably more major errors than normal controls [83].

Henry's major errors took two forms: omissions (his most common error type) and category concatenation errors, where he combined two or more words from inappropriate categories. A single utterance in Henry's transcript illustrates both error types: Henry intended to say something like *I would like some of what she had*, but instead said "I like some her." The missing *would* in "I like some her" is an omission error, and the word combination "some her" is a category concatenation error because indefinite determiners such as *some* cannot combine with pronouns such as *her* in grammatical English phrases.

Besides being uncorrected and anomalous, Henry's major substitution errors often violated the "syntactic class regularity"—the fact that speakers making normal errors usually substitute words in the same syntactic class, e.g., substituting verbs with other verbs (rather than with adjectives, prepositions, nouns or adverbs), as in our earlier example, where *choose* substituted for *tend* and vice versa. Substitution errors in [83] violated the syntactic class regularity reliably more often for Henry than normal controls.

The conclusion? Unable to create new internal representations, Henry couldn't combine appropriate words and word categories into novel phrases in coherent sentence-level plans, and lacking a plan against which to compare his erroneous outputs, Henry couldn't correct or repair the incomplete and inappropriate phrases in his erroneous outputs. In contrast, normal slips-of-the-tongue reflect activation in error of cortical units represented in a pre-formed sentence-level plan that provides the basis for correcting everyday errors [83].

2.4. MacKay, James and Hadley (2013) [99]

On each trial in [99], participants tried to create a single grammatical sentence that contained one or two pre-specified target words and accurately described a never previously encountered picture. Normal participants found this task easy, as illustrated by this typical (error-free) description of a clothing store scene with the target words *wrong* and *although*: "The woman decided to buy the suit *although* it looked *wrong*" (target words appear in italics).

However, Henry found this task difficult, as illustrated by *his* description of the same clothing store scene and target words: "Because it's *wrong* for her to be he's dressed just as this that he's dressed and the same way." Here Henry failed to include the target word *although*, he produced ungrammatical strings such as "he's dressed and the same way," and his paragraph-like description violated the instruction to produce a *single* grammatical sentence.

Across all 20 word-picture stimuli, Henry produced reliably fewer target words and grammatical sentences than the controls. Why? Because Henry couldn't conjoin the target word meanings into novel internal representations that accurately and grammatically described the pictures. However, as in [83], Henry produced error-free clichés reliably more often than normal individuals, e.g., the clichés "in a way" and "it's wrong" in his clothing store description.

2.5. MacKay and Johnson (2013) [32]

In the experiments in [32], Henry exhibited identical effects of repetition and familiarity in five domains: semantic memory, visual perception, sentence-comprehension, sentence reading and word reading. Likewise in all five domains, Henry adopted deliberate repetition strategies to compensate for his difficulties in forming new internal representations of never previously encountered and completely forgotten information. These findings comport with results in [61], where Henry had no

difficulty producing *any* frequently repeated phrase, including novel phrases rehearsed immediately before speaking.

To summarize, Henry had no deficits when expressing pre-formed internal representations, but he had major deficits when forming novel internal representations in all six sentence production experiments.

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