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## Clinical Cases and Studies

## Naïve Beliefs About the Natural World in a Case of Childhood Onset Amnesia

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## Abstract

The individual profiled here (M.S.) suffered an episode of severe oxygen deprivation (anoxia) at the age of eight, damaging memory relevant structures in the mid-temporal lobes, including the hippocampus bilaterally. The resulting anterograde amnesia was characterized by profound deficits in autobiographical memory, but also a compromised ability to acquire new facts and information (semantic memory), resulting in the formation of idiosyncratic and naïve beliefs about the natural world that have persisted into his adult years. This article presents an interview with M.S. in which many of these idiosyncratic beliefs are detailed, and argues that they can be broadly viewed as the interaction of, 1) intact frontal lobe functioning that supports the application of rational analysis to his lived experience, and 2) an impoverished factual knowledge base upon which to construct sophisticated and evidence-based models of his lived experience and of natural world processes.

**Keywords:** amnesia, childhood onset, naïve beliefs

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## Introduction

The critical role of the hippocampus in the formation of new long-term memories was first documented in seminal papers reporting the now famous case of Henry Gustav Molaison, who until his death in 2008 was known in the psychological literature simply as H.M. (e.g., Corkin, 1984; Corkin, 2002; Scoville & Milner, 1957). In an attempt to remediate his severe epileptic condition, Molaison underwent radical resection of the mid-temporal lobes (including most of the hippocampus bilaterally), resulting in an intractable amnesic condition, affecting his ability to form new memories for facts and information (semantic memory) and personally experienced events (autobiographical memory) post-operatively, and one year pre-operatively (Corkin, 1984; Corkin, 2002). In the years since these reports, cognitive neuroscience has definitively established that injury to structures in the mid-temporal lobes, notably the hippocampus and surrounding cortex, produces a relatively isolated impairment of long term memory, a condition known as *anterograde amnesia* (see Gabrieli, 1998; Squire, 1992; Squire & Zola, 1998; and Squire & Zola-Morgan, 1988; for reviews).

An amnesic condition similar to the one produced by mid-temporal lobe damage can also be produced by damage to the thalamus, specifically midline thalamic nuclei (Squire, 1982; Squire, 1992; Victor, Adams, & Collins, 1989).

Damage to this area of the thalamus location produces a condition known as Korsakoff's syndrome, which has been determined to be a consequence of long term alcohol abuse (Butters, 1985; Moscovitch, 1982; Shimamura, Janowsky, & Squire, 1990; Squire, 1982). In addition to anterograde amnesia, Korsakoff's syndrome is characterized by deficits such as an impaired sense for the temporal order of events and a tendency toward confabulation (Moscovitch, 1982; Shimamura, Janowsky, & Squire, 1990; Squire, 1982).

In addition to amnesia due to structural brain damage, amnesia due to psychogenic etiology has long been recognized; this condition is currently categorized in the Diagnostic and Statistical Manual of Mental Disorders (5th edition) as "dissociative amnesia" (American Psychiatric Association, 2013, p. 291).

In contrast to amnesia of psychogenic origin, this article considers the case of M.S., whose amnesia has been documented as a consequence of identifiable brain damage, specifically hippocampal atrophy due to an anoxic episode suffered at eight years of age; as such he is one of the relatively few known cases of amnesia with childhood-onset. Most of the amnesics known to psychological science have sustained their precipitating injury during adulthood, and thus have had the opportunity to establish vocabularies, language skills, and a general storehouse of knowledge about the world appropriate to their years. In contrast to these adult-onset cases, M.S. was deprived of an uninterrupted course of cognitive development during middle childhood, including the opportunity to establish an integrated set of factual information about the natural world and its processes.

The case of M.S. was originally reported by Broman and her colleagues (Broman, Rose, Hotson, & Casey, 1997); additional studies include Winter (1995, 2001, 2002), and Winter, Broman, Rose, and Reber (2001). During preparation for these latter studies, M.S. would occasionally voice certain naïve beliefs about the natural world. The most striking of these concerned his superficial comprehension of the fact that sun was a "star". M.S. understands that the earth revolves around the sun and that this is responsible for the change of seasons, but is confused about the concept of "star" as it applies to celestial bodies, apparently more familiar with graphical representations of stars, such as those found, for example, on national flags. To illustrate the cause of the progression of seasons, he drew a five pointed star on a piece of paper, explaining that as the earth revolves around the sun, it approaches one of the points of the star, bringing warmer weather, and then summer. The movement of the earth between points brings cooler weather; the depth of winter arrives when the earth reaches its greatest distance between the points of the star.

Another instance illustrating M.S.'s naïve conceptual framework occurred during a day trip to a science museum. One of the exhibits allowed visitors to view single celled organisms through a microscope. After looking through the microscope, M.S. was voiced confusion as to what these creatures might be, and how they could be so small as to be invisible to the naked eye. "What are they, bugs?" he inquired in a puzzled tone, apparently lacking an established mental category that could account for them.

Prompted at least in part by these observations, the intention of this paper is to describe and discuss the idiosyncratic constructs and natural reasoning processes employed by M.S.

## Case History

The following information concerning M.S.'s background and early medical history was provided by his parents. Born in New York in 1962, M.S. manifested asthmatic symptoms from the age of about 11 months. This condition required extensive medical attention throughout early childhood, including several emergency room visits. At the age of 8, M.S. experienced his first tonic-clonic seizure; a second episode occurred 3 months later, resulting in

status epilepticus accompanied by respiratory arrest, rendering him comatose for approximately 12 hours. His immediate post recovery condition involved a generalized confusion, disorientation, and an inability to recognize family members. While this condition proved to be transitory, severe anterograde amnesia remains as a permanent consequence of this event.

M.S.'s scores on the Wechsler Adult Intelligence Scale – Revised (WAIS - R, see [Wechsler, 1981](#)) as reported in [Winter, Broman, Rose, and Reber \(2001\)](#) are as follows: Verbal scale – 78, Performance scale – 94, full scale – 82 (see [Table 1](#)). While the Full scale value of 82 places him in the low normal range, virtually all evaluations that tap long term memory demonstrate profound deficiencies. His long-term retrieval score in the Woodcock Johnson – Revised Battery ([Woodcock & Johnson, 1977](#)) ranks in the 3rd percentile (see [Table 2](#)), and delayed recall score for both Visual-Auditory, and Memory for Names subtests rank in the 1st percentile. [Broman, Rose, Hotson, and Casey \(1997\)](#) reported severely deficient performance in the Wechsler Memory Scale – Revised ([Wechsler, 1987](#)) in both the verbal memory (score = 51; -3 *SD*) and visual memory (score = 57; -2 *SD*). Moreover, the authors note that for many basic language skills, such as reading and word fluency, M.S. performs as if these capabilities were developmentally arrested at the time of his trauma. Other functions were marginally less compromised; basic mathematical skills appear to have achieved a fifth grade equivalence. Interestingly, conceptual language abilities, as assessed by tests of sentence comprehension, grammatical capability, and complex ideational material, have progressed to adult levels ([Broman, Rose, Hotson, & Casey, 1997](#); [Winter, 2001, 2002](#)). His immediate attention, planning and organizational capacity is strong. Verbal and nonverbal logic and problem solving skills have also progressed to adult levels. This last point is exemplified by his strong performance (50-75%tile) on the Raven Matrices, an evaluation which loads heavily on nonverbal perceptual and logical skills ([Penrose & Raven, 1936](#); [Raven, 1938](#)). The capabilities impaired in M.S. are those that are dependent upon long term memory for their normal development ([Broman, Rose, Hotson, & Casey, 1997](#); [Winter, 1995](#); [Winter, Broman, Rose, & Reber, 2001](#)). The most severely compromised long term memory function in M.S. is his ability to form new explicit memories, especially for personally experienced events. In fact, it appears that M.S. has virtually no residual ability to form memories of an autobiographical nature. On the other hand, he retains some ability to learn new general facts and information (semantic memory), although this capability is highly degraded, as evidenced by his deficient scores on tests of vocabulary, memory for names, and fact learning evaluations ([Broman, Rose, Hotson, & Casey, 1997](#); [Winter, 1995](#); [Winter, Broman, Rose, & Reber, 2001](#)). The new information that he has been able to acquire has been relatively sparse, isolated, and occasional. He learned for example, that Jay Leno replaced Johnny Carson on the Tonight Show, and that Tetris was the name of a computer game he enjoyed, despite the fact that these two developments came after the onset of his amnesia. Also, as it has been demonstrated with many amnesics, M.S. has been shown to have preserved implicit (non-declarative) memory ([Broman, Rose, Hotson, & Casey, 1997](#); [Winter, 1995](#); [Winter, Broman, Rose, & Reber, 2001](#)). This is the type of memory that supports motor and cognitive skill learning, as well as priming and conditioning effects. His amnesic condition, as it is typically the case with irreversible hippocampal injury, has not improved, and has remained relatively stable since the precipitating incident.

M.S. shows none of the behaviors that are thought to typify frontal lobe pathology, such as confabulation, perseveration, disinhibition, or amotivation. Bilateral atrophy of the hippocampal formation was confirmed by MRI, using a technique introduced by [Press, Amaral, and Squire \(1989\)](#). Additional technical information regarding the MRI imaging can be found in the complete clinical report by [Broman, Rose, Hotson, and Casey \(1997\)](#). M.S. remains in the care of specialists and is under medication for both asthma and seizure disorder.

Table 1

*Wechsler Adult Intelligence Test-Revised*

Scale	Score
<b>WAIS-R Subtests</b>	
Information	5
Digit Span	8
Vocabulary	4
Arithmetic	6
Comprehension	6
Picture Completion	11
Picture arrangement	8
Block Design	13
Object Assembly	10
Similarities	8
<b>Verbal IQ</b>	78
<b>Performance IQ</b>	94
<b>Full Scale IQ</b>	82

Table 2

*Woodcock Johnson - Revised: Summary Scale*

Scale	Age Equivalent	Percentile Score
Broad Cognitive Ability	13.2	16th %tile
Long-Term Retrieval	5.2	3rd %tile
Short-Term Memory	14.3	35th %tile
Auditory Processing	9.0	18th %tile
Visual Processing	12.2	16th %tile
Comp-Knowledge	11.1	2nd %tile
Fluid Reasoning	11.8	24th %tile
Knowledge-Aptitude <sup>a</sup>	—	25th %tile
Oral Language Aptitude <sup>a</sup>	—	1st %tile
Basic Reading Skills	7.9	0.3 %tile

<sup>a</sup>The Woodcock Johnson battery of tests provided no age equivalents for both Knowledge and Oral Language Aptitude at the time of testing.

## Method

Several studies by Piaget (1951, 1967, 1969, 1970) explored the development of naturalistic reasoning in children; as in those studies, the method employed here is that of structured interview, in part, mirroring the specific queries that appear in those publications. This interview, as with previous published work with this individual by this author, was conducted with the written permission and consent of M.S. and his parents, and with the formal approval of the Institutional Review Board of the institution in which the research was conducted. At the time of this writing, M.S. is 54 years old.

The majority of the interview questions and responses by M.S. (in italics) are reproduced in the section Results. The remaining questions are listed in the [Appendix](#).

## Results

Q. What is the sun made of? *Fire – a star. I don't know what is burning.* How far away is it? *I don't know.* Can you take a guess? *A hundred thousand miles or more – further than that.* Why is it yellow? *I don't know. Fire is sort of yellow – yellow or red. I know that the sun is yellow and the sky is blue. You put yellow and blue together and you get green – that's why nature is green! I don't know if that's true.* Does the sun move across the sky? *It doesn't really move across the sky. The planets move around the sun. The sun doesn't really rise and set – it looks like it but it doesn't.* Does it follow us when we walk? *I follow my parents [laughs]! No it doesn't.* Does the sun spin around in a circle? *I don't know.* Is the sun alive? *No, [laughs] but Channel 11 is alive!* [referring to a tag line from a New York television station]. Can it feel pain? *No.* Does it know that it gives light? *No.*

Q. Why do the seasons change? *The earth gets further away from the sun.* [draws 5 pointed star, and explains progress of earth in circular fashion around the points] Why is it pointy? *Because it's a star.* So how do the seasons change? *Sometimes the South pole has sun, and sometimes the North Pole has sun.* Why are the North and South poles so cold? [deliberates] *Because they are pointing away from the sun. Yes, that's it.* What causes the night to come? *The earth moves around the sun in a certain way, so that sometimes it's facing the other way.*

Piaget (1951) noted that younger children would often give agentic, volitional, or anthropomorphic reasons to explain natural phenomena, while older children – usually by the age of eight – would provide explanations that refer to natural processes. For example, while a 4 year old child may say that the sun rises because it wants to wake up, or to fly across the sky, etc., an older child will provide a reason that invokes the turning or movement of the earth. The above section of interview is typical of M.S. in that he does not adopt agentic, volitional or anthropomorphic explanations. His explanations are occasionally naïve, but firmly naturalistic. He laughs off the suggestion that the sun is alive, or that it can feel pain; moreover, he explains that “It doesn't really move across the sky. The planets move around the sun. The sun doesn't really rise and set – it looks like it but it doesn't”. He states that the sun is made of fire, but admits that he does not know “what is burning”; he does not offer the simplistic explanation that the sun's fire is fueled by wood.

He proposes a charming rationale for why “nature” (by which he clearly means vegetation) is green, based on his knowledge of the mixture of the colors blue and yellow. But he offers this tentatively, quickly adding “I don't know if that's true”.

M.S.'s explanation of the changing of the seasons continues to be dominated by his belief that because the sun is a star, it must have the shape of a cartoon-like, five-pointed figure. He holds this belief despite the fact that when observed at sunrise, sunset, or dimly through cloud cover, the shape of the sun is obviously circular, a perception that M.S. is probably familiar with. It may be that he maintains this naïve belief because it allows him to create what he regards as a satisfying explanation for the changing of the seasons. It is also possible that M.S. is deliberately rejecting the visual evidence that the sun is round in favor of an abstract, geometrical representation which he believes to be more scientifically accurate. In any case, he is clearly attempting to create a model based on natural conditions and processes, albeit one based upon his faulty understanding.

M.S. is self-aware of his memory deficit, as well as his epileptic and asthmatic conditions, and understands that he is unable to live as an independent adult. His remark that he “follows his parents” is likely a darkly comic reference to this fact.

Q. What are germs? *Like a bug, insects.* Can you see them? *No, but with a microscope you can.* What do they [germs] do? *It depends on what germ it is. They can kill you sometimes, certain germs, or cause you to get sick. They come from Germany [laughs].* How do they cause disease? *I don't know – we could be allergic to them? Some germs are worse than others.*

Here M.S. is perfectly comfortable responding to questions about germs, acknowledging that they are invisible to the naked eye but can be viewed through a microscope. This is in marked contrast to his alarmed reaction after viewing single celled organisms through a microscope in the science museum several years earlier. It is possible that since then he has been able to create a viable mental representation for such organisms. Another possibility is that the word *germs* primes a specific set of familiar concepts – that these are the invisible bugs that sometime will make you sick, or can kill you, etc., – but that no such familiar representation is primed during the actual experience of watching tiny organisms swimming about in a drop of water. It may be that his confusion concerning the creatures viewed through the microscope would have been ameliorated had I used the word *germs* to explain what he saw. His crack about germs coming from Germany is typical of his fondness for puns and wordplay.

Q. How did humans come to be on the earth? *Humans? How did we get on earth? What do you mean, like the missing link?* Well yes, what does that mean? *I don't know. They say that Adam and Eve were the first. First there was Adam and then Eve came from him – that's what they say.* Were humans always in the form we are now, or did we change? *I don't know.* Some people say that humans evolved. *I don't know what that means.* Do you know what evolution means? *No. I don't know what they mean by that.* That humans started out in a certain way but then changed over many, many years. *Yeah, but how could you prove that?* So you believe that we started out with Adam & Eve, and that they had children, and their children had children, all the way down to us? *Yes, that's what they say.*

Q. Why are some people tall and other people short? *I don't know. Some people don't grow, I don't know why.* Why do some people have blue eyes and other people brown? *I don't know why.* Why do some people have blonde hair and others brown? *I don't know why.* Why does hair turn gray? *I don't know – changes in life? I don't know.* Why are some men bald? *I don't know. Changes in the body – I don't know what causes changes in the body.* Why do we need to eat food and drink water? *To keep growing, because you are always growing in a way. Changes in your body.*

Q. What are fossils? *Not really sure. It has to do with the sink?* [apparently thinking of 'faucet']. *I heard of that word but I don't know what it is.* Fossils are like the bones of buried dinosaurs. *I heard they lived thousands, even millions of years ago. They say they were here one time.*

M.S. has apparently heard of such terms as *missing link*, and *evolution*, but states flatly that he does not understand what they mean. He quickly, and perhaps defensively, defaults to the Biblical explanation to account for human presence on the earth. This is the only area of questioning in which he does not attempt to provide a naturalistic explanation. When asked whether humans may have changed over time, he responds with the question: “Yeah, but how could you prove that?” signaling some comprehension of the evolutionary position, but also a ready skepticism. His endorsement of the Biblical account is not unequivocal; in response to the suggestion that we are



all descendants of Adam and Eve, he does not say, “That’s what I believe”, but the more tentative “Yes, that’s what they say”. His response concerning differences in hair and eye color demonstrates that he lacks an understanding of the mechanisms of inheritance. Asked about why hair turns gray or why some men are bald, he does not mention aging or genetics, but refers with uncertainty to “changes in life”, or “changes in the body”. He is so unfamiliar with the term *fossils* that he confuses it with the word faucet (unless he was attempting another pun), yet he is aware of the opinion that dinosaurs may have lived upon the earth long ago, offering, “They say they were here one time”.

Q. What is the moon made of? *Don’t know – rocks?* How far away is it? *Sometimes further than the sun.* Why is it white? *I don’t know – because it’s so far away you can’t see any color?* Does it move across the sky? *Yep, it goes around the earth as the earth goes around the sun – people don’t know that!* What happens in an eclipse of the sun? *The moon blocks the sun.* Is the moon alive? *No.*

Q. Is a stone alive? *No. It doesn’t move by itself. But it could change in the earth. I don’t know... what stone is it that makes gold? What stone makes diamonds?* Can it (a stone) have feelings? *No.* What if I hit it with a hammer? *It would just break – no feelings.* What would happen if I threw it in the fire? *It wouldn’t feel pain.* Would it burn? *Yeah, probably would burn, but it depends on how hot the fire is. It would melt after awhile.* Does it burn or melt? *It doesn’t really burn, it melts together.* Where does iron come from? *It’s like rocks from the earth – it’s mixed with other things in the earth, other rocks. After awhile it changes.* What’s the difference between things that are alive and things that aren’t? *Something that isn’t alive doesn’t grow. Nothing’s changing.*

M.S. knows that the moon moves around the earth as the earth moves around the sun, and assumes this to be a relatively rare insight, stating, “people don’t know that!” He also accurately explains that a solar eclipse results from the imposition of the moon between the earth and the sun. Curiously, he asserts that the moon is sometimes more distant than the sun; this may be his way of accounting for the “moon illusion”; the moon appears very large at horizon (and may be interpreted as close), but becomes smaller as it approaches zenith (and therefore apparently distant).

He is confident that neither the moon nor stones are alive or that a stone could feel pain, but he does assert that a stone could “change in the earth”, hinting at a basic awareness of geomorphology. This is echoed in his questions about rocks turning into gold or diamonds (which he asked with definite interest). Also, he knows that iron occurs in a mixture with other rocks in the earth. He provides succinct distinctions between living and non-living things: “It doesn’t move by itself”, and “Something that isn’t alive doesn’t grow. Nothing’s changing.”

Q. Do animals have feelings? *Yes, like a dog. If you train it well it can be very nice to you.* Do animals in the woods have feelings? *Yes. Usually the mother takes care of them.* Can some animals think? *Yes, especially skunks* [laughs]. *Oh! Think! Like remember things? Yes I guess. A dog knows its master, if you think of it that way. A dog remembers smells...maybe it’s just smelling.*

He has no problem with the possibility that animals have feelings and can think, although he is not sure whether a dog’s sense-based memory qualifies as true cognition.

Q. What is rain? *It’s water.* Where does it come from? *The sky – clouds.* Where do clouds come from? *From the ocean, from water.* Why does it rain? *I don’t know – the clouds get heavy?* What is fog? *It’s like a low cloud –it’s water.* Where does it come from? *The ocean, then it evaporates.* What is ice? *Frozen water.* What is snow? *Also*



water. What is the difference between them? *I don't know, but you know it is water because when you hold it in your hand it will melt.*

Q. What is lightning? *Electricity – it can cause a fire. Where does it come from? Clouds cause it. Dark clouds. I don't know what's in the clouds that causes it. The clouds touch each other? What is thunder? Clouds touch each other. First it causes lightning and then it causes thunder. Why is the sky blue? I don't know, but that's why the ocean is blue, because it reflects the sky. What is the sky made of? Just air. There's no ending to it. The sky never ends.*

M.S. explains his knowledge of the relationship between snow and water by referring to an empirical test: snow held in the hand will melt into water. He grasps the essentials of the rain/water cycle, citing the origin of clouds and rain to be evaporated from the oceans. He knows that lightning is electricity, and conjectures that it occurs when dark clouds touch one another. He correctly refers to a common causation for lightning and thunder, and the temporal relationship between them. He knows that the sky is nothing more than air, but cannot account for its color, an accurate explanation of which would require a sophisticated comprehension of differential absorption of wavelengths of light. He understands that the ocean is blue because it reflects the color of the sky.

Q. Where does wood come from? *Trees. Why do trees and plants grow? I don't know. Weeds grow but nobody plants them. How? Plants need water and light. Tree bark is brown from dirt. The sun makes it bloom. Are they, plants, alive? Yes.*

He grants that plants are alive, requiring water and light, but is unsure as to what initiates the growth process, mentioning that weeds grow even though nobody plants them. His assertion that tree bark gains color from dirt is another example of what appears to be an implicitly held belief that functional interrelationships of nature are reflected in color admixture.

Q. What is at the center of the earth? *I don't know – the devil? [laughs]. I don't know – ground? Dirt? I don't know how to explain it – is it sand? At the bottom of the ocean is sand, and we have more water than land. The center of the earth is probably sand.*

Q. How big is the earth? *Twenty four thousand miles around the equator. You know how I know this? I remember that when you fly from NY to Denver [he attended a school for asthmatic children in Denver before his anoxic episode] it is 2,000 miles and also 2 hours difference. California [Where his brother lives] is 3,000 miles and also 3 hours difference. So it must add up to 24 hours because there are 24 hours in a day. How old is the earth? I don't know. Thousands and thousands – probably millions of years old. Why do objects fall to earth? Because of gravity. I don't really know what gravity is, but I know that on the moon there is less gravity, but I don't know why.*

In contrast to his previous earnest reference to Adam and Eve, M.S. jokes about the devil being at the center of the earth. Moreover, he makes a probabilistic (and naturalistic) inference about what might be found at the center of the earth: He reasons that because most of the earth is covered by ocean, and that sand is at the bottom of the ocean, it is likely that sand is found at the center of the earth.

Based on his knowledge of the distances and time differences between points, M.S. has (upon his own initiative) developed a method to estimate the circumference of the earth at 24,000 miles. The estimate given by the United States National Aeronautic and Space Administration (NASA) is 24,873.6 miles at the equator ([National Aeronautic](#)

and Space Administration, n.d.). He knows that gravity impels objects to fall to earth, and that the gravity on the moon is less than on earth, but does not know why.

## Discussion

M.S. became amnesic due to brain injury that occurred at the age of eight. The quality of his responses in the interview described above is consistent with Piaget's developmental principle (Piaget, 1951) that by eight years of age, children will offer naturalistic (as opposed to anthropomorphic) explanations for physical processes of the world. This developmental milestone, once achieved, appears to be resistant to subsequent compromise of long term memory.

The extent and severity of M.S.'s amnesia may seem anomalous when compared to some other reports of childhood amnesics, including those with specific hippocampal injury (see, Baddeley, Vargha-Khadem, & Mishkin, 2001; Benedict, Shapiro, Duffner, & Jaeger, 1998; Ostergaard, 1987; Vargha-Khadem, 2001; Vargha-Khadem et al., 1997; Vicari et al., 2007; Wood, Brown, & Felton, 1989). In those cases, semantic memory is reported to survive at normal or near normal levels despite impairments in episodic memory. This relative sparing of semantic memory has led to the theoretical interpretation that episodic and autobiographical memory is directly dependent upon the hippocampus, but that semantic memory is separately dependent upon surrounding structures, such as perirhinal and entorhinal cortices (e.g., Vargha-Khadem et al., 1997). The task of disambiguating the roles of these mid-temporal lobe structures is, however, complicated by the indeterminacy of the extent of brain injury revealed in an imaging study. For example, ancillary lesions of functional importance may be too small to visualize with current brain imaging techniques; these lesions may remain undiscovered until postmortem neuropathological examination (Rempel-Clower, Zola, Squire, & Amaral, 1996; Squire & Zola, 1998). The MRI study reported by Broman, Rose, Hotson, and Casey (1997), revealed that M.S.'s brain injury appeared to be limited to bilateral hippocampal atrophy. The possibility remains that the unusual severity of his memorial deficit owes to as yet undetected brain pathology to memory relevant structures.

Unlike amnesia due to damage to midline thalamic nuclei (as in Korsakoff's syndrome, referenced above), medial temporal lobe amnesia tends not to be complicated by behaviors usually associated with frontal lobe pathology (Moscovitch, 1982; Squire, 1982; Squire, 1992). The behavior of M.S. honors this distinction in that he does not confabulate, perseverate, or show other signs of frontal lobe dysfunction, such as disinhibition, disorientation, or inappropriate affect. In contrast, his manner is composed and organized; his communications are lucid, direct, relevant and non-tangential. He is in fact, almost painfully veridical in his responses; as shown above, he appropriately and readily admits when he does not know (or is unsure of) an answer. His ability to concentrate and focus is strong, and he shows normal release from proactive interference (Winter, Broman, Rose, & Reber, 2001). It is highly unlikely, for example, that M.S.'s belief that the sun is a five pointed star is evidence of psychotic delusion or confabulation, but rather a naïve conceptualization owing to his impoverished factual knowledge base. In spite of this, he retains robust analytic and logical powers, as it has been shown in numerous formal and informal evaluations (see Broman, Rose, Hotson, & Casey, 1997; Winter, Broman, Rose, & Reber, 2001). His ability to devise a novel method of estimating the circumference of the earth is an example of his willingness and ability to employ logical analysis, as it was his ability to discover an algorithm for the Tower of Hanoi puzzle (Winter, Broman, Rose, & Reber, 2001). What has been most fundamentally compromised is his ability to compose stable, explicit

long term memories for newly introduced complex information, thus resulting in the often naïve interpretations of natural phenomena as described above.

The original contribution and significance of the research reported here is to document that intact long-term semantic memory is necessary to create and sustain veridical cognitive representations of natural world processes.

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The author has declared that no competing interests exist.

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## Appendix

(M.S.'s responses appear in italics.)

How many seconds in a minute? *Sixty.*

Minutes in an hour? *Sixty.*

Hours in a day? *Twenty Four.*

Days in a year? *Three hundred sixty five, except for leap year, that's 366 and we have February 29th.*

Years in a decade? *Ten.*

In a Century? *100.*

In a millennium? *One thousand.*

Why is grass green? *All nature needs sunlight, but some things grow better in shade.* You said before that the yellow sun plus the blue sky make nature green. Do you think that's true? *That's the only thing I can think of.*

What causes shadows? *Light – when you are blocking the light.*

Where does cloth come from? *It comes from string or thread. But where does that come from? Does that come from trees? I don't know if it comes from plants or not.*

Where does paper come from? *It comes from trees. It comes from wood, trees.*

### About the Author

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