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# Narrative construction is intact in episodic amnesia

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ABSTRACT

Autobiographical remembering and future imagining overlap in their underlying psychological and neurological mechanisms. The hippocampus and surrounding regions within the medial temporal lobes (MTL), known for their role in forming and maintaining autobiographical episodic memories, are also thought to play an essential role in fictitious and future constructions. Amnesic individuals with bilateral hippocampal damage cannot reconstruct their past personal experiences and also have severe deficits in the ability to construct coherent fictitious or future narratives. However, it is not known whether this impairment reflects a failure to generate details from autobiographical episodic memory to populate personal narratives or an inability to bind such details into coherent narratives. We show that four individuals with hippocampal damage and episodic amnesia can construct narratives when the relevant details of the story are provided in a picture book and that their narratives maintain overall coherence on several measures. These findings indicate that individuals with hippocampal damage can bind details into coherent narratives when details are available to them. We conclude that the hippocampal system instead likely plays a role in the generation of details from which narratives are constructed.

## 1. Introduction

A growing body of research emphasizes the close connection between autobiographical remembering (and the structures that mediate it) and other cognitive capacities, such as future imagining and narrative construction (Buckner and Carroll, 2007; Hassabis et al., 2007b; Schacter et al., 2007; Suddendorf and Corballis, 2007). These capacities all plausibly involve mental imagery (Rubin et al., 2003), emotional comprehension (Greenberg and Rubin, 2003), retrieval of semantic information and multi-modal details (Wheeler et al., 1997) and the capacity to organize events in space, time, and causal sequence (Greenberg and Rubin, 2003). Further, neuroimaging studies suggest that both reconstructive and constructive processes activate similar brain regions within the so-called default mode network, including medial prefrontal cortex and medial temporal lobes (MTL), parietal regions, lateral prefrontal cortex, and occipital cortex (Buckner and Carroll, 2007; Spreng et al., 2008).

Departing from traditional storage-based hypotheses, which limit the role of the hippocampus in autobiographical episodic memory to retrieving details from memory (Squire, 1992), many recent binding-based[1] hypotheses propose a central role for the hippocampus in constructive, organizational processes that combine episodic details into narratives (Schacter and Addis, 2007; Schacter et al., 2007) and, in particular, in providing the spatial context for events (Hassabis et al., 2007b; Hassabis and Maguire, 2007). To date, observations using narrative construction tasks based on single picture, word, or sentence cues suggest that amnesic individuals with hippocampal damage are impaired at constructing coherent fictitious and future narratives (Andelman et al., 2010; Hassabis et al., 2007b; Klein et al., 2002; Race et al., 2015; Rosenbaum et al., 2009). These findings are also supported by fMRI studies showing MTL activation in healthy subjects when they construct fictitious or future narratives (Addis et al., 2007; Hassabis et al., 2007a; Okuda et al., 2003; Szpunar et al., 2007). However, neuroimaging studies do not settle whether the observed activations reflect the generation of details, their binding in space and time, or some other function. Similarly, amnesic individuals with hippocampal damage might exhibit deficits in narrative construction either because they cannot generate episodic details fluidly or because they cannot bind those details in space, time, and context. In fact, Dede et al. (2016) and Kwan et al. (2016) have recently shown that the narrative

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[1] Note that we use the term "binding" to refer specifically to combining semantic and episodic details into a coherent narrative, not in the sense of "relational binding" that some other researchers use (e.g. Eichenbaum, 2004, Ryan et al., 2000).

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performance of amnesic individuals can be improved with extensive cuing/probing, which suggests that amnesic individuals might be able to construct narratives if a sufficient number of story details are provided externally (see also Kirk & Bernsten, 2017, this issue). Moreover, generation of details might be facilitated in adult-onset amnesic individuals when an organizing theme or structure is available to them, such as in the form of a life chapter if it had the chance to emerge over many years (Grilli, Wank, & Verfaellie, 2017, this issue). Overall, existing studies cannot evaluate whether the brain areas integral to autobiographical episodic memory are involved in generating the details for narratives or, as many current theories emphasize (Hassabis et al., 2007b; Hassabis and Maguire, 2007; Schacter and Addis, 2007; Schacter et al., 2007), in binding those details into narratives.

To test detail binding independently of detail generation, we studied the ability of amnesic individuals to construct narratives from a children's picture book. This narrative construction task addresses two limitations of current methods for testing narrative construction. First, unlike cue-based tasks, the construction of narratives from a picture book places minimal demands on memory, as the pictures supply the details. This task thus allows one to examine detail binding without the confounding influence of detail generation. Second, in autobiographical memory and spontaneous narrative tasks, participants each begin with different stories (or variants of stories), making it impossible to compare narrative accuracy, detail, and coherence across participants directly.

We therefore compared amnesic individuals with damage to the hippocampus and extended hippocampal system ($n$ = 4) to healthy, demographically matched controls ($n$ = 11) on the “Frog Where are You” (Mayer, 1969) task of narrative construction. In this standardized test of narratives designed for children (Reilly et al., 1998) and cognitively impaired individuals (Ash et al., 2006; Norbury and Bishop, 2003), participants are asked to tell a story from a 24-page children's picture book. The story follows the adventures of a boy and his dog as they look for their lost pet frog. The frog escapes in the middle of the night. When the boy and his dog wake up and learn of the escape, they first search their bedroom and then continue searching in a nearby woods. Along the way, the boy and his dog encounter various animals before finding their frog, now with a female frog and a brood of baby frogs. The story concludes with the boy and his dog waving goodbye to the frog family as they head home with one of the baby frogs. If the hippocampal system indeed plays a central role in detail binding (as opposed to detail generation), then individuals with hippocampal damage should tell fragmented stories, with particular deficits in producing context and relating the events in the story to each other. If, alternatively, the hippocampal system does not play a role in binding but instead in generating episodic details from which the story will be bound, then individuals with hippocampal damage should tell coherent stories comparable to controls.

## 2. Methods

### 2.1. Participants

Four individuals with episodic amnesia and damage to the hippocampus and extended hippocampal system were compared to eleven demographically matched, right-handed, healthy controls (7 men; age: mean = 51 years, SD = 3.03 years; education: mean = 14.3 years; SD = 1.38 years). All cases were tested at least two-years post-injury at which point their recovery was stable. Demographic and neuropsychological profiles of the four cases are summarized in Table 1, their episodic memory and prospection performance is summarized in Table 2 and MRI images of key memory structures damaged in D.A., S.N., and M.H. are presented in Fig. 1 (an implantable cardioverter-defibrillator following D.G.'s cardiac arrest prevented him from undergoing MRI examination). Neuropsychological and neuroanatomical analyses of D.A., D.G., and S.N., with detailed documentation of hippocampal and other neural pathology, are published elsewhere (Kwan et al., 2015, 2013; Rosenbaum et al., 2011) and summarized below, together with a description of M.H.'s case.

D.A. is a 59-year-old, right-handed male with 17 years of education. He contracted herpes simplex encephalitis, resulting in extensive bilateral damage to MTL structures with more extensive damage to the right hemisphere (including MTL and regions outside of the MTL – posterior temporal, ventral frontal, occipital, anterior cingulate and posterior thalamus). Damage to the left hemisphere was relatively restricted to the MTL region. His resulting neuropsychological profile reveals a selective and severe deficit in episodic memory with normal intelligence and intact cognitive function.

D.G. is a 47-year-old, right-handed man with 16 years of education. He suffered a cardiac arrest which resulted in subsequent anoxia. An implantable cardioverter-defibrillator following his cardiac arrest prevented him from undergoing MRI examination. D.G. has temporally graded retrograde amnesia with anterograde amnesia for personal experiences and mild dysarthria in the context of intact intellectual and other cognitive functions.

S.N. is a 46-year-old man with 12 years of education. He suffered a left thalamic hemorrhage which resulted in bilateral damage to the dorsolateral thalamus and left pons. Examination of MRI also revealed smaller lesions to right pons, right putamen, left occipital lobe and a localized left hippocampal lesion. S.N. has average intellectual functioning with deficits in verbal fluency, inhibitory control, and episodic memory.

M.H. is a 56-year-old man with 13 years of education. He contracted herpes simplex encephalitis, resulting in extensive atrophy along right medial occipital and inferortemporal cortex and within his MTL bilaterally. Performance on neuropsychological testing revealed deficits selective to episodic memory, with otherwise intact intellectual and cognitive functions.

### 2.2. Stimuli and Task

Participants were asked to tell a story from the 24-page children's picture book, *Frog, Where are You?* (Mayer, 1969). All print material from the book was covered. Each participant was asked to look through the book and become familiar with the story. When they were ready, they were asked to start at the beginning and tell the story as if they were reading it to a child. The participants' narrations were audio recorded and later transcribed. All transcriptions were validated by an independent reviewer.

#### 2.2.1. Measures

*2.2.1.1. Content*. Each narrative was judged against a standard 30 events of content established prior to the experiment by independent raters (Ash et al., 2006). See the appendix for the list of 30 events. For each of the 30 events, participants' narratives were judged as *accurate* if they conveyed the full content of the event, *incomplete* if they conveyed only part of the essential content, *error* if they narrated something inaccurately, and *missing* if they did not mention the event in their narrative.

*2.2.1.2. Semantic score*. The semantic score (Norbury and Bishop, 2003) was calculated by comparison with a list of 51 plausible propositions describing the relevant information in the story. Participants were awarded two points for every complete and accurate proposition in their stories, giving a maximum score of 102 points. One point was awarded for partial and inaccurate information.

*2.2.1.3. Local connectedness*. Using the standard 30 events of content, each event from the participants' narratives was scored as locally connected if it presented some relation to the elements that preceded it (Ash et al., 2006). There are four ways to connect the events: sequencing adverbials (e.g., by, at, after, before, first, second, third,

**Table 1**
Demographic and neuropsychological data on individuals with amnesia.

| Case | Age | Sex | Etiology | Chronicity | Ed | FSIQ | Executive function | | Verbal memory | | Visual memory | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | WCST | LF | AQ | LDFR | C | DR |
| DA | 62 | M | HSE | 20 | 17 | 117 | 6 | 8 | 0 | 0 | 18 | 0 |
| DG | 48 | M | Anoxia | 3 | 16 | 92 | 6 | 6 | 5 | 5 | 8 | 1 |
| SN | 46 | M | Stroke | 2 | 12 | 114 | 3 | 8 | 3 | 1 | 8 | 3 |
| MH | 56 | M | HSE | 7 | 13 | 110 | 6 | 8 | 6 | 4 | 12 | 5 |

Notes: Age = age in years; HSE = herpes simplex encephalitis; Chronicity = years since injury; Ed = education in years; FSIQ = Full Scale IQ, based on Wechsler Adult Intelligence Scale – Revised for D.A. and D.G, Wechsler Abbreviated Scale of Intelligence–III for S.N., and Wechsler Abbreviated Scale of Intelligence–IV for M.H.; WCST = Wisconsin Cart Sort Test, number of completed categories /6. All other measures are reported in scaled scores: LF = COWAT verbal fluency; Verbal Learning and Memory, AQ = acquisition, LDFR = long delay free recall, based on California Verbal Learning Test-II for D.A., D.G., and M.H., Kaplan Baycrest Neurocognitive Assessment, Word List Learning for S.N.; C = copy, DR = delayed recall.

**Table 2**
Episodic memory and prospection performance in the amnesic cases and controls.

| Case | Episodic memory | | Episodic prospection | |
|---|---|---|---|---|
| | Internal | External | Internal | External |
| DA | − 1.74<br>$p$ = 0.049 | − 0.48<br>$p$ = 0.320 | − 1.60<br>$p$ = 0.064 | − 0.70<br>$p$ = 0.247 |
| DG | − 3.100<br>$p$ = 0.003 | − 1.67<br>$p$ = 0.056 | − 2.38<br>$p$ = 0.014 | − 1.79<br>$p$ = 0.046 |
| SN | − 1.71<br>$p$ = 0.052 | 3.02<br>$p$ = 0.003 | − 2.01<br>$p$ = 0.030 | 1.19<br>$p$ = 0.125 |
| MH | − 2.30<br>$p$ = 0.017 | − 0.96<br>$p$ = 0.175 | − 2.21<br>$p$ = 0.021 | − 1.43<br>$p$ = 0.086 |
| Controls | 35.32 (9.95) | 27.9 (12.3) | 26.68 (9.97) | 26.0 (11.38) |

Episodic memory and episodic prospection were in response to Galton-Crovitz cues. Participants were asked to remember past (or imagine future) personal events up to 5 years ago (or in the future). On each trial participants were presented a single cue word and asked to recall (imagine) a specific personally experienced event in as much detail as possible. Values for the four amnesic cases represent results of modified *t*-tests of participants' internal (episodic) details and external (non-episodic) details, along with p-values. Control data represent mean number and standard deviation of details generated. Values for D.A., D.G., S.N., and controls based on Kwan et al. (2015).

then, next, finally), pronomial reference to preceding events, definite vs. indefinite reference (e.g., given vs. new information), and cause and effect. Events are scored as not connected if no such devices are present and the reported event does not logically follow from the preceding utterances. Lastly, events scored as missing in the content analysis are scored as not connected.

*2.2.1.4. Global connectedness*. The global connectedness measure (Ash et al., 2006) assesses the overall point of the story, that the boy and his dog search for and find the escaped frog. Participants achieved global connectedness if they explicitly recognized that the frog at end of the story is the same frog the boy and his dog set off to find. Participants failed to demonstrate global connectedness if they did not explicitly state that boy and dog found *their* frog at the end of the story.

*2.2.1.5. Search theme*. The search theme score (Reilly et al., 1998) is a second measure of the overall coherence in which the participant maintains the theme of searching for the frog throughout the narrative. The search theme ranged from 0 to 4 points, with participants gaining one point for including each of the following: noting that the frog is missing, noting that the boy is searching for the frog, including one or two further mentions of the search theme, and lastly, any additional mentions of the search theme.

Using the written transcripts, each variable was tallied by an independent coder who was blinded to participant status. A second coder performed reliability analysis and achieved better than 80% reliability. Disagreements were discussed until resolution was achieved.

## 3. Results

Data were analyzed with nonparametric Mann-Whitney-Wilcoxon test in order to test whether the population distributions were identical without assuming them to follow the normal distribution and a modified *t*-test designed to compare performance of individual cases with a small control group (Crawford and Garthwaite, 2002). All participants were able to construct narratives from the picture book. Their stories ranged from 259 to 964 words (Table 3). Narratives from each group contained the same average number of words (U = 14, $p$ = 0.207). We assessed narrative accuracy by comparing participants' stories with a template of 30 salient events established prior to the experiment by independent raters (Ash et al., 2006). No participant produced erroneous content, and there were no differences in the average number of missing events (U = 23.0, $p$ = 0.830), the average number of accurate events (U = 14, $p$ = 0.192) or the average number of incomplete events (U = 37.0, $p$ = 0.153). However, two of the four amnesic individuals (DG and SN) did differ from controls in the number of fully accurate events and the number of incomplete events. In a more fine-grained analysis, we calculated a semantic score (Norbury and Bishop, 2003) by rating participants' narratives against a predefined list of 51 plausible propositions expressing the informational content of the story. Amnesic individuals did not differ from controls in their semantic score (U = 22.5, $p$ = 0.806); each provided as many full and accurate descriptions of the 51 predefined semantic aspects of the story as did controls. In short, the stories of amnesic individuals contained as many relevant details as do control stories.

We also used several measures to assess the coherence of participants' narratives (Table 3). The first measure is local connectedness. Using the standard 30 events of content, each event in a participant's narrative is scored as *locally connected* if it is presented in relation to the elements that preceded it (Ash et al., 2006). Amnesic individuals did not differ from controls in local connectedness (U = 13.5, $p$ = 0.158). The second measure is global connectedness, which assesses the overall point of the story, that the boy and his dog search for and find the escaped frog. Amnesic individuals again did not differ from controls in global connectedness (U = 17.5, $p$ = 0.217). A separate measure of global coherence, search theme, assesses the maintenance of the search for the runaway frog throughout the story. Amnesic individuals did differ from control participants in the frequency with which they mentioned the search theme in their narratives (U = 12, $p$ = 0.048). Two of the four amnesic individuals (DG and SN) received a score of three out of four, while only one control participant received a three on search theme (Table 3). Sample excerpts from controls and amnesic individuals are provided in Appendices A and D.

## 4. Discussion

Drawing on standardized methods to study language development in children, we provide evidence that narrative construction remains intact in episodic amnesia if the details of the story are provided in a

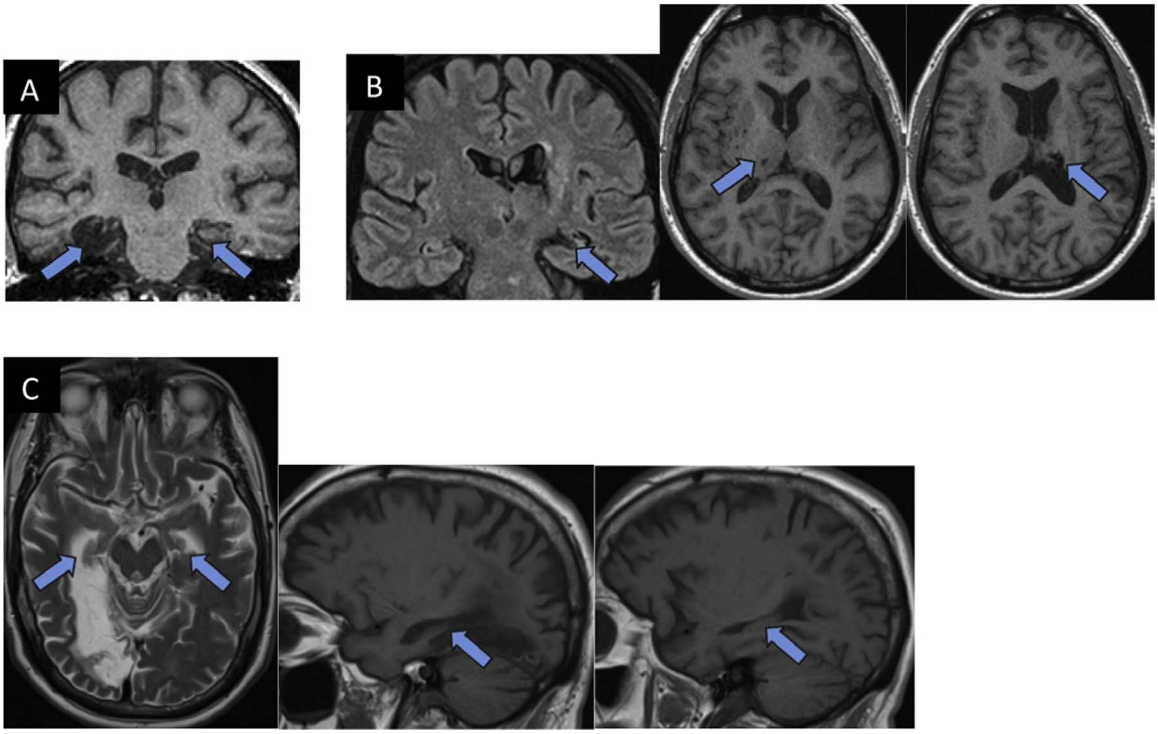


**Fig. 1.** MRI images of amnesic cases. (A) T1-weighted image for D.A. in coronal view showing bilateral hippocampal damage (greater on the right); (B) T1-weighted images for S.N. in coronal view (left) showing left hippocampal lesion, and in axial view (middle, right) showing bilateral lesions of the dorsolateral nucleus of the thalamus; and (C) T2-weighted axial image (left) and sagittal images (middle, right) for M.H. showing bilateral hippocampal volume loss and extensive inferotemporal cortex atrophy. Images are presented according to radiological convention (right hemisphere is presented on left side of image). D.G. could not be scanned because of an implantable cardioverter defibrillator.

picture book. Amnesic individuals' narratives did not differ from control participants' with regards to narrative content and coherence. They included as many full and accurate details as did controls. Individuals with amnesia were also able to relate events in the story to previous events and to bind all the events together into a coherent narrative. The only difference between amnesic and comparison participants is that individuals with amnesia could not maintain the search theme throughout the story at the same level as the controls did.

Closer scrutiny, however, reveals that two amnesic individuals (DG and SN) drive this effect. Although DG and SN mentioned that the frog was missing, that the boy was searching for the frog, and although both mentioned the search theme one or two times more, they didn't include any additional mention of the search theme. DG and SN also produced significantly fewer fully accurate and significantly more incomplete events than controls. Perhaps their lower search theme score is a function of a general reduction in the number of details in their narratives. Although speculative, this may relate to lower verbal fluency in DG, and executive function in SN, as confirmed with standardized neuropsychological tests (Kwan et al., 2016). A similar conjecture was offered recently to explain atypical performance on tests of autobiographical episodic memory and prospection in the same two individuals (Kwan et al., 2016). DA and MH, on the other hand, were indistinguishable from the controls on all measures despite their dense amnesia and profound deficits in imaging the future (See Table 2). The neurological events that led to DA's and MH's amnesia occurred many years before those that led to DG's and SN's amnesia, which might also have contributed to better performance. Nevertheless, it should be emphasized that performance in all 4 amnesic individuals was virtually indistinguishable from that of controls on the majority of measures, particularly those signaling the integrity of narrative coherence.

Our results stand in stark contrast with many recent studies that report a constructive impairment in amnesia (Andelman et al., 2010; Hassabis et al., 2007b; Klein et al., 2002; Race et al., 2015; Rosenbaum et al., 2009). Several factors might account for these differences. First, in most prior studies, participants are asked to construct a narrative based on a sentence or a one-word cue. These cues often provide insufficient information to generate narrative details (Kwan et al., 2016). Hence, these tasks place significant demands on detail generation from memory, a capacity known to be severely disrupted in amnesic individuals (Rosenbaum et al., 2009).

Second, more recently Race et al. (2011, 2015) used a picture description task and found that amnesic individuals are able to generate episodic details from a single picture, yet they still cannot construct coherent narratives. Even though a picture provides more details than a sentence or a one-word cue, it is still not possible to construct a narrative based on just those episodic details. The material in a single scene is likely not complex enough to evoke a rich narrative. Participants in a picture description task need to generate more details from memory for what comes before and after the given scene to be able to construct a story. In contrast, a picture book description task eliminates the need for detail generation entirely, as all the required details are provided in the book.

Third, there are inherent challenges in the analysis of spoken narratives and their coherence, and different methods can yield different results. To minimize the effects of interpretation, we adapted a standardized test for children (Reilly et al., 1998) and cognitively impaired individuals (Ash et al., 2006; Norbury and Bishop, 2003). Narratives consist of temporally and causally related sequences of events and usually contain a setting, a triggering event, a set of attempted solutions, and a resolution (Labov and Waletzky, 1967). Our content measures assess the presence or absence of relevant details by judging participant narratives against norms established independently of the speakers' narrations. Our local connectedness measure assesses the binding of events into meaningful sequences by using rhetorical devices such as sequencing adverbials, pronominal reference to preceding events, and statements of cause and effect. More importantly, narratives organize events into a whole by interpreting and connecting a series of events in order to get an outcome, namely the goal (i.e., finding the

**Table 3**
Mean (SD) and individual performances on measures of discourse.

| | Controls | MTL | DA | DG | SN | MH |
|---|---|---|---|---|---|---|
| Event report accuracy, 30 events total | | | | | | |
| Fully accurate | 19.27 (3.58) | 13.5 (6.61) | 17 − 0.61 | 9* − 2.74 | 7* − 3.28 | 21 0.46 |
| Incomplete | 9.73 (3.07) | 15.75 (6.40) | 13 1.02 | 21* 3.52 | 21* 3.52 | 8 0.30 |
| Error | 0.00 (0.0) | 0.00 (0.00) | 0 | 0 | 0 | 0 |
| Missing | 1.00 (1.41) | 0.5 (0.58) | 0 0.26 | 0 0.26 | 1 0.5 | 1 0.5 |
| Semantic score | 65.82 (13.84) | 66.5 (15.55) | 80 0.98 | 61 − 0.33 | 47 − 1.30 | 78 0.84 |
| Story-level connectedness | | | | | | |
| Global connectedness, 0–1 | 0.91 (0.30) | 0.75 (0.5) | 1 0.29 | 1 0.29 | 0* − 2.89 | 1 0.29 |
| Maintenance of search theme, 0–4 | 3.91 (0.30) | 3.5 (0.58) | 4 0.29 | 3* − 2.89 | 3* − 2.89 | 4 0.29 |
| Local connectedness, 30 events total | | | | | | |
| Connected | 27.82 (1.33) | 27.25 (1.5) | 29 0.85 | 28 0.13 | 26 − 1.31 | 26 − 1.31 |

*Note*. Asterisks indicate significant difference from control performance using the Crawford's single case study *t*-test (Crawford and Garthwaite, 2002). Additionally, t-scores calculated from the Crawford's single case study *t*-test are included below each individual score. The Event Report Accuracy (Ash et al., 2006) judged each narration to a standard of 30 events of content. Each narrative was judged for whether the content was full content (Fully Accurate), partially full of the essential content (Incomplete), factually inaccurate (Error) or if they did not mention the essential content at all (Missing). The Semantic Score (Norbury and Bishop, 2003) was calculated from a list of 51 plausible propositions that determined the amount of relevant information conveyed. Participants were scored on a 3 point scale from 2 – complete and accurate to 0 – missing for each proposition giving participants the ability to score between 0 and 102 points. The global connectedness measure (Ash et al., 2006) assesses the overall point of the story, that the boy and his dog search for and find the escaped frog; to receive a score of 1, participants needed to explicitly identify the frog at the end of the book as the same frog from the beginning. The local connectedness score (Ash et al., 2006) identified whether the 30 events were connected to preceding story elements. Scores could range from 0 (no connections) to 29 (all events connected).

frog). The goal provides an over-arching theme for the story. Our global coherence measures assess the binding of story events around the main goal.

It could be argued that a picture book task provides a built-in scaffold for narrative coherence and so requires little or no additional cognitive contribution from participants. It is true that the picture book presents the events of the story in an orderly fashion and that this likely assists narrative construction. However, prior studies demonstrate that individuals with specific cognitive deficits regularly fail to construct coherent narratives despite this scaffolding. The test has been used to demonstrate deficits in narrative construction among individuals with nonfluent aphasia and semantic dementia, as well as in nonaphasic individuals with Lewy Body dementia, Parkinson's disease with dementia, and in disorders of social comportment and executive functioning (Ash et al., 2006, 2011). In each of these cases, individuals displayed both a limited grasp of the story's overall theme and poor connectedness between specific events in their stories, even though lexical and grammatical aspects of word and sentence use were relatively preserved. If the picture book provides a built-in scaffold for narrative coherence, then all of these individuals with different cognitive impairments should be able to tell coherent stories as well.

Our results make sense in the context of recent studies demonstrating that individuals with impaired autobiographical episodic memory often have preserved cognitive function in other domains. In particular, amnesic individuals are able to generate episodic details from pictures (Race et al., 2011). In our task, these details include information about characters, settings, and events. Narrators must infer certain spatiotemporal relations between events, protagonists' motivations, and the overall theme of the story. Semantic memory could support these kinds of inferences, allowing individuals to extrapolate beyond the content available in the stimulus picture. Morever, the ability to make inferences about characters' relationships, thoughts, feelings, and motivations throughout the story relies heavily on theory of mind capacities, which are also largely preserved in amnesic individuals (Rosenbaum et al., 2007).

In addition to making inferences beyond what is available in the pictures, narrative production involves higher-level processing for planning and organization. Narrative production requires a binding process to manage an extended story represented in a sequence of pictures. This process likely involves a working memory component to keep elements of the narrative in an active state during narrative production (Troiani et al., 2008). Prior studies have shown that amnesic individuals are able to provide the gist of a story (Rosenbaum et al., 2009). Our task requires further that amnesic individuals bind diverse events in space and time and relate them to the story's search theme. This might be achieved by coordinated activity in multiple neocortical areas, perhaps mediated by online binding capacities of prefrontal cortex (Prabhakaran et al., 2000).

To conclude, individuals with episodic amnesia and deficits in autobiographical remembering and future imagining are nonetheless able to construct coherent narratives when the details are provided in the form of a picture book. It follows that this autobiographical episodic system, and the hippocampal system thought to subserve it, are not required to bind details into coherent narratives. Though a precise characterization of the cortical systems required for the construction of imagined experiences awaits further work, our results are consistent with a role for the hippocampal system in generating details but not in the binding of those details into coherent narratives.

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**Appendix A. Sample excerpts from the MTL and control groups**


| Group | Name | Example |
|---|---|---|
| MTL | DA | And they look down in what might have been a a hole used by mice or a weasel or something, and and then the dog’s barking up at a beehive, which you should try to avoid, and the maybe it was a skunks hole (laughs) ‘cause the boy's pinching his nose: "Oh I don't like that." |
| | DG | The boy goes looking for the frog, calling for the frog, and they come across a bee’s nest. The boy looks in the gopher’s hole. The gopher comes out and scares the boy, and the dog is barking at the bees. |
| | SN | Then he looks down the hole. There’s the bee’s nest again. The dog’s still playing. He looks down. A squirrel pops out of the hole. |
| | MH | The dog is looking up at the the hive trying to catch, looks like trying to catch one of the bees and the boy's looking at a little hole in the ground, which I think is a gopher hole. Um…. while he's yelling down the hole, a gopher comes up and nips him on the nose. |
| Controls | Best | They go over to where the bees are. The dog starts barking up at the beehive. The boy’s looking into a groundhog hole. The groundhog comes up, nips him in the nose. The dog is shaking the tree where the beehive is. There’s still no frog. |
| | Worst | Beehive. Rufus wanted to play with the bees, while Tommy called down a hole. Uhh, it was a groundhog. Not Freddy. |

**Appendix B. Content analysis**

| Episode | Role | Page | Event | |
|---|---|---|---|---|
| 1 | O (rientation) | 1 | 1 | A boy and his dog are looking at a frog in a jar in the boy’s bedroom. It’s nighttime; the moon is seen through the window and the boy is wearing pajamas. |
| | A(ction) | 2 | 2 | The boy and dog are asleep, and the frog climbs out of the jar. |
| | R (esolution) | 3 | 3 | It’s morning. The boy and dog wake up and see that the frog is gone. |
| 2 | O | 4 | 4 | The boy and dog look for the frog. The boy has gotten dressed and is looking in his boot. |
| | A | 4 | 5 | The dog puts his head in the jar. |
| | A | 5 | 6 | The boy opens the window and calls out. The dog is in the window with his head stuck in the jar, about to fall. |
| | A | 6 | 7 | The dog falls out of the window. |
| | R | 7 | 8 | The jar is broken on ground. The boy is holding the dog and looking angry while the dog licks his face. |
| 3 | O | 8–9 | 9 | The boy and dog are outside the house near a stand of trees. The boy is calling out. |
| | A | 10 | 10 | The boy peers into a hole in the ground, still calling to the frog. |
| | R | 11 | 11 | The boy recoils from the hole, with his two hands holding his nose, and a groundhog is partway out of the hole (having nipped, licked, or otherwise touched the boy on his nose). |
| 4 | O | 8–9 | 12 | The boy and dog are outside the house near a stand of trees. The dog is eying a stream of bees forming a line to a hive on a nearby tree. |
| | A | 10 | 13 | The dog jumps up towards the beehive. |
| | A | 11 | 14 | The dog is barking at the beehive, with his front feet on the tree. |
| | A | 2–13 | 15 | The beehive has fallen on the ground, and the dog is standing on his hind legs with his two front paws against the tree, while the bees are coming out of the hive towards the dog. |
| | R | 14–15 | 16 | The dog is running away from the bees, which are swarming after him. |

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| 5 | O | 12–13 | 17 | The boy has climbed onto a large tree branch and is peering into a hole in the tree. |
| | A & R | 14–15 | 18 | An owl emerges from the hole in the tree with wings spread, and the startled boy falls backwards onto the ground. |
| 6 | O | 16 | 19 | The boy fends off the owl and begins to climb up onto a large rock. |
| | A | 17 | 20 | The boy stands on top of the big rock, leaning against a branch of a shrub and calling out, while the owl watches from a nearby tree. The dog comes slinking back with its head down and its tail between its legs. |
| | A | 18 | 21 | The boy is lifted up on the head of a large deer; what appeared to be branches were actually the deer's antlers. |
| | A | 19 | 22 | The deer runs towards the edge of a drop-off with the boy on its head, while the dog runs alongside,barking. |
| | A | 20–21 | 23 | The boy and dog fall over the edge of the bank into a pond, while the deer remains at the edge. |
| | R | 22 | 24 | The boy and dog land in the water, with the deer at the edge of the drop-off above looking smug. |
| 7 | O | 23 | 25 | The boy sits up in the water and cocks his ear; the dog has climbed up onto his shoulders and head. |
| | A | 24 | 26 | The boy approaches the edge of the water next to a large hollow log and shushes the dog. |
| | A | 25 | 27 | The boy and dog lean over the log; we see their backs. |
| | R | 26 | 28 | On the other side of the log, the boy and dog find their frog with a lady frog. |
| | A (Coda) | 27 | 29 | The boy and dog see eight baby frogs emerge from the brush next to the log. |
| | R (Coda) | 28–29 | 30 | The boy and dog wave a cheerful goodbye to the frog family as they wade back across the pond, carrying one of the baby frogs |

## Appendix C. Semantic score

1. Boy had pet frog and dog
2. Frog in jar
3. Frog got out/escaped/etc.
4. In the night/while boy asleep
5. Next day/in morning/when boy woke
6. Boy finds frog has gone
7. Look for frog in boot
8. Look for frog in jar
9. Look everywhere
10. Dog head stuck in jar
11. Call frog/say/'frog where are you'
12. Call/look out of window
13. Dog falls out of window
14. Jar broken
15. Boy goes out of house/window
16. Boy picks up/cuddles dog
17. Dog licks boy
18. Boy angry/says dog is naughty
19. Boy (+dog) calling/looking for frog
20. Boy and dog go into the woods/forest
21. Boy looks in/shouts in hole
22. Creature comes out of hole
23. Creature bites boy's nose
24. Dog jumps at tree
25. Dog barks at bees
26. Bees come out
27. Bee swarm (hive) falls/knocked down
28. Boy looks in hole in tree
29. Owl comes out of tree
30. Bees chase dog
31. Boy falls down
32. Owl frightens boy
33. Boy climbs/looks over rock
34. Boy calls for frog
35. Boy holds on to antlers
36. Boy doesn't realize it is a deer
37. Deer picks up boy
38. Deer carries/runs with boy
39. Dog runs after
40. Deer stops suddenly
41. Deer ducks/tosses/throws boy
42. Boy and dog go over cliff
43. Dog on boy's head
44. Falls into water
45. Boy hears frog sound
46. Boy says shh/tells dog to be quiet
47. Boy + dog look over/climb over log
48. Find his/the frog
49. Frog family (mum dad + babies)
50. Take home baby frog
51. Say goodbye to frogs

## Appendix D. Sample narratives of amnesia and control cases

*DA (Best MTL performance)*

Well, I see a little boy, lets say his name's Jacob, had a pet dog and a pet frog. And he always loved looking at his pet frog in hi- the little jar that he kept him in. So its time for bed, so off to bed he went, and during the night the frog climbed out of the jar that he kept him in, and the boy woke up and looked down and the dog's sitting on top -s just both frowning. "Where has the frog gone?" So he turned ah his boots inside out and he looked inside the jar, under the beds, looked out the window and called for frog. I don't know if he can speak frog (laughs), and the dog still has the jar on his head. And the weight of the jar pulled the dog right the window 'cause he leaned too far, and when he crashed the ground, the jar broke and the boy was pretty unhappy while the dog seemed happy and kissed him anyway. And they kept calling for the frog, but they don't hear a croak or a ribbit from anywhere, and they keep wandering off into the woods, trying to find him. And they look down in what might have been a hole used by mice or a weasel or something, and and then the dog's barking up at a beehive, which you should try to avoid, and the maybe it was a skunks hole (laughs) 'cause the boy's pinching his nose: "Oh I don't like that." And the dog uh- after knocking the beehive down he said, "I better get out of here too" (laughs), and so the boy climbed up a tree branch that was a nearby tree and looked down a hole in the tree. And he could find nothing, but an owl stuck his head out so he fell down to the ground and meanwhile as he's falling down, the bees are chasing the dog away. And the owl screeches and he the boy climbs up a pile of rocks and he keeps calling out for his pet and the owl. s- He climbs back up, flies back onto a branch, and the dog cringes and creeps along near where the boy is. And finally a reindeer pokes his he thought he was holding onto a tree branch but was really antlers of a deer. (laughs) And uh when he when he raised his head right up, the boy was sitting right on top the head of the deer, and so the deer started moving towards the cliff edge, and the dog's barking away at him. And both the be- deer stops but the boy didn't, the dog didn't, and they go falling down in what might have been looks like a pond below. Sure enough, splash they went, and the dog climbed up on the boy's head and lucky it was pretty shallow, so the boy just sat up in the water, smiled, and he said, "shhh" to the dog because he saw oh this hog, this log here has a hollow end on it. So they climbed over ‘cause I guess they wanted to take a look inside. Ohp, and in behind they found two frogs, I think one was his fro- pet frog and one was his mate, and over to the right he goes, "Ah there's all the baby frogs." So he wa- the boy and his dog walked back across the creek and waved goodbye to his old pet frog. Now he has his own family; I guess we don’t need to take him home now. And that's the end.

*SN (Worst MTL performance)*

It's all my book, eh? Okay, so the photo's in order of what it's supposed-Alright. So all the same pictures we saw. This is like going back to kindergarten. Okay, so now they’re playing with the dog in his room with the frog. Frog jumps out as he goes to sleep. They wake up in the morning. Frog's gone. They don’t know what's happening. So he gets dressed. The dog's looking for the frog inside the jar; then they’re looking out the window. Frog jumps out, he breaks the thing, he jumps down to scold the dog, but the dog could be in dog, he's licking the guy being happy. Then they’re outside, doing their f**king thing in the morning, sorry for swearing, and they see the bee's nest. And he the dog looks at the bees. Aaaaaaaand kindergarten. Then he looks down the hole. There's the bee's nest again. The dog's still playing. He looks down. A squirrel pops out of the hole. Squirrel looks back at the dog looking at the bees. He's looking at the tree for some reason. Oh, the owl comes out of the hole, scares him, and falls down. And the bees all come out of the thing, out of the hive, and they’re chasing the dog. The owl comes back, into his, where his home is. There's the owl now waiting in the tree. He's looking. There's a dog sitting down here. What's he looking for? He's still looking for a frog. Heh! And he goes up, gets caught in the tree, ‘cause it was on the rock. I don’t know where the deer came from, but now- oh that's why, that's where the antlers came from, that's why he's in there, that looks like a tree. Sorry. And the deer goes with the dog to the cliff, stops, and they fall off, lands in the water. Dog's on his head, and there's the hole again. He's saying “quiet” to the dog looking over the empty log, the driftwood log, where they see the frogs! And the frogs are there with the little frogs. Froglets, you call ‘em? So he's playing with the little frogs in the water. The other frogs are watching. I don’t know what the f**k he's talking to frogs for and that's the story.

*Good comparison performance*

A little boy is in his bedroom. He's got a frog in a jar. Sitting on a stool, and both him and his dog are looking at the frog. He's dressed in his pajamas, his clothes are on the floor, and its night time with the moon in the window. The little boy goes to sleep, and the little dog is sleeping at his feet. The frog slips out of the jar. The boy wakes up in the morning, and the frog is gone. He starts looking for the frog after getting dressed. He's looking in his boots. The stool is turned over. The dogs got his nose in the jar, well his head is in the jar, and so him and the dog are both looking for the frog. They go to the window. The boy's calling out, “Frog, Frog, where are you?” The dog still has his head stuck in the jar. The dog accidentally falls out the window. When he hits the ground, the jar breaks but the dog is OK. The dog licks the boy, the boy looks concerned, but everything's ok. There's still no frog. Where could it be? The boy and the dog go out to a hill and they start calling out for the frog, “Frog, where are you?” And the dog looks like he's howling or looking at bees. They go over to where the bees are. The dog starts barking up at the beehive. The boy's looking into a groundhog hole. The groundhog comes up, nips him in the nose. The dog is shaking the tree where the beehive is. There's still no frog. Since the dog is shaking the tree, the beehive falls. Meanwhile the boys climbs up a bigger tree and is looking in the hollow of the tree for the frog. Seems like the dog is distracted, and he's forgotten about the frog, and only the boy is looking for the frog. Suddenly an owl pops out of the hollow of the tree, and the boy falls down the tree. The bees start chasing the dog. Uh oh. Looks like there's a little bit of a problem going on. The owl starts chasing the boy. The boy is running. You don’t see the dog and the bees anymore, so maybe the bees have given up. Now the boy's on top of the rocks calling out for the frog, “Frog, where are you?” The owl seems to be curious is up on the tree looking at them. And the dog seems to be sniffing around the rocks also looking for the frog. Suddenly a stag pops up from behind the rocks and the boy is stuck on the stag's head. The boy, sorry, the dog is still looking for the frog behind the rocks. You can see the little dog here. The stag and the dog run to the edge of a cliff, and the boy is still on top of the antlers of the stag's head. Suddenly, the stag stops and the boy falls of the stag's head and the dog falls off the edge of the cliff. Uh oh. But still there's no frog. The dog and the boy fall into the water. The boy now looks happy. He's thinking, hmm maybe the frog is somewhere here in the water since frogs like water. There's an old dead tree trunk, a hollow tree trunk. The boy tells the dog to be quiet, he's going to peek over the tree trunk. Now the dog is also peeking over the tree trunk. They’re looking for the frog, yet there's still no frog. When suddenly behind the tree trunk the boy and the dog see two frogs. They look like maybe mommy and daddy frogs. Over here we see that it is a mommy and daddy frog with lots of little frogs with them, so we have now a family of frogs perhaps the little frog ran from the boy's room to meet up with his family or maybe they were friends. Now the boy takes the frog and is heading back home with his dog. The family of frogs, the mommy and the daddy and all of the baby frogs are sitting on the tree trunk, but they’re smiling, so it seems ok that the boy is taking the frog back home, cause they’re smiling, so they seem to have reached an agreement. So now we have a boy and a dog and his little found frog. The end.

*Poor comparison performance*

Ok, so this is the story of Freddy Frog and he goes missing. One night Tommy and his dog Rufus were admiring Freddy the Frog. They had just captured him that day, and they were very proud of themselves, so they were talking to Freddy, hoping that he had a good night sleep as they were getting ready for a good nights sleep. Tommy and Rufus went to bed and Freddy wanted his freedom immediately. So Freddy climbed out of the jar while everybody was asleep. Next morning, Tommy and his dog Rufus looked in the jar first thing in the morning, and Freddy was gone. Tommy looked everywhere for Freddy in his room. He checked his clothing and Rufus looked into the jar, where obviously Freddy was missing, but Rufus is always getting into trouble. Then they call for Freddy outside the window, thinking that Freddy would respond to his name. They looked all over. Rufus, who still had the jar on his head, fell out, and Tommy had to make sure that Rufus was ok, but Rufus had broken the glass. They kept calling, and they got closer and closer danger. Beehive. Rufus wanted to play with the bees, while Tommy called down a hole. Uhh, it was a groundhog. Not Freddy. Then Tommy looked into a hole in a big tree thinking Freddy might be there. Nope, it was an owl. Meanwhile, Rufus, who's always getting into trouble, was being chased by the bees. Then the owl chased Tommy behind a rock because he was upset at being woken up. Tommy kept calling.

Rufus kept looking. Then they came across a deer. The deer was clearly not Freddy the Frog, much bigger and with antlers. They hitched a ride and Tommy and Rufus fell down deeper into the forest. Splat into the water, the very kind of place that a frog might be. Tommy said, "Be very quiet Rufus cause you've been noisy all day, we don't want to scare Freddy the frog." They looked over an old log. And low and behold there was a friendly family of frogs there, just the kind of place they might find Freddy. In fact, there was Freddy hanging out with his family. Tommy and Rufus said, "Do you mind if we take Freddy with us?" And the family said, "Sure, if you're going to be nice to him." The End.

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