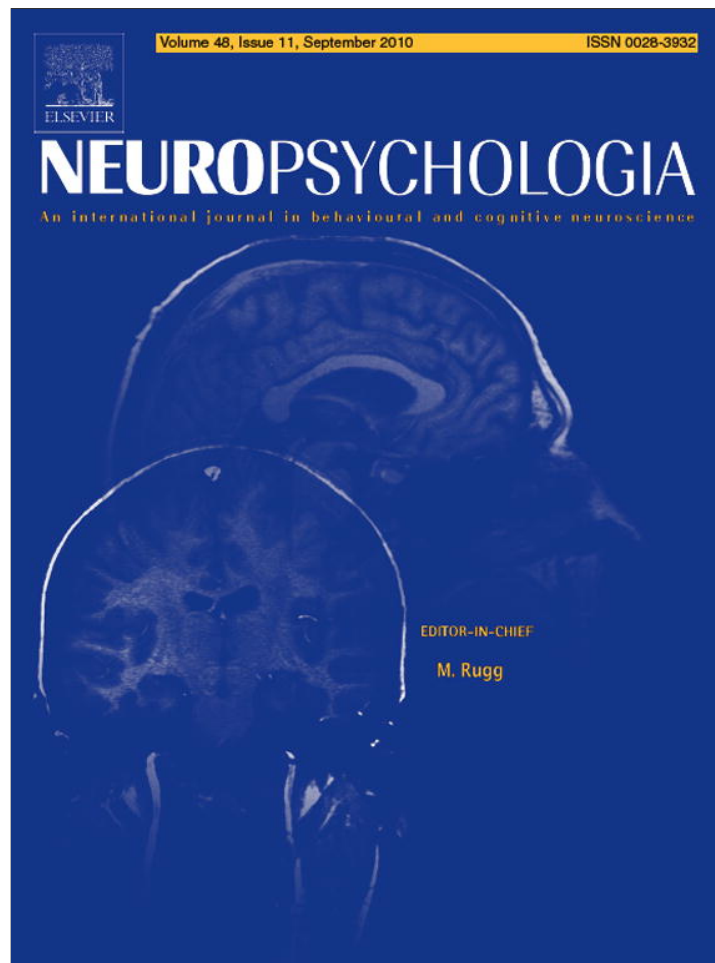


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## Deficits in past remembering extend to future imagining in a case of developmental amnesia

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## ABSTRACT

Patient and neuroimaging studies report that the ability to remember past personal experiences and the ability to envision future personal experiences are interconnected. Loss of episodic memory is typically accompanied by loss of future imagining, and engaging in either activity recruits common brain areas. The relationship between episodic memory and future imagining is also suggested by their co-emergence in ontogenetic development. However, it is unknown whether a failure of one ability to emerge in early development precludes the development of the other ability. To investigate this possibility, we tested H.C., a young woman with amnesia of developmental origin associated with bilateral hippocampal loss, and demographically matched controls on an adapted version of the Autobiographical Interview using Galton–Crovitz cueing. In response to cue words, participants described both past personal events and imagined future personal events that occurred, or could occur, in near and distant time periods. Results indicated a parallel pattern of impairment for both past and future event generation in H.C., such that her narratives of both types of events were similarly deficient. These results indicate that mental time travel can be compromised in hippocampal amnesia, whether acquired in early or later life, possibly as a result of a deficit in reassembling and binding together details of stored information from earlier episodes.

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The ability to recollect specific events from one's personal past as part of episodic memory appears to occupy, and perhaps underlie, much of daily mental activity (Suddendorf & Corballis, 2007; Tulving, 1985, 2002). There is strong evidence to suggest that episodic memory depends on hippocampal function: individuals with extensive bilateral hippocampal damage are unable to re-experience details of personal life events, though semantic knowledge of those events is relatively unaffected. This pattern appears to be true whether the pathology occurs in early childhood (Gadian et al., 2000; Vargha-Khadem, Gadian, & Mishkin, 2001; Vargha-Khadem et al., 1997) or in adulthood (Cipolotti et al., 2001; Gilboa et al., 2005; Maguire, Nannery, & Spiers, 2006; Piolino et al., 2003; Rosenbaum et al., 2005, 2008; Steinworth, Levine, & Corkin, 2005; Viskontas, McAndrews, & Moscovitch, 2000; but see Bright et al., 2006; Kirwan, Bayley, Galvan, & Squire, 2008). A parallel distinction has been noted in the ability to consider the future in studies of patients with adult-onset amnesia: future imagining is

impaired but the conceptual understanding of future time is intact (Klein, Loftus, & Kihlstrom, 2002; Rosenbaum et al., 2005; Tulving, 1985). Findings that both episodic memory and future-regarding behaviour co-emerge by approximately 3–5 years of age further suggest that the two abilities are related (Atance & O'Neil, 2005a, 2005b; Busby & Suddendorf, 2005; Suddendorf & Corballis, 1997). The question that remains is whether the ability to engage in future imagining can develop normally in the absence of episodic memory from early in life.

The idea that processes responsible for the retrieval of past personal episodes also serve other non-mnemonic purposes is not new. James (1890), and later Ingvar (1985) and Tulving (1985), conceived of self-awareness as having both past- and future-oriented components, enabling 'mental time travel,' at least in humans (cf. Clayton, Bussey, & Dickinson, 2003; Tulving, 2002). The suggestion that past and future aspects of mental time travel share a biological substrate initially came from cursory observations that the amnesic case K.C. is unable to imagine future events that he has not yet experienced, much as he is unable to re-experience a lifetime of past personal events in episodic memory (Tulving, 1985). When asked about his future, K.C. reported only a "blank" state of mind. Formal testing conducted more recently has confirmed that K.C.'s re-experiencing and imagining of personal events are similarly impaired (Rosenbaum, Gilboa, Levine, Winocur, & Moscovitch, 2009).

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Findings of impaired future imagining have been corroborated in other cases of episodic amnesia. Klein et al. (2002) described a case, D.B., with presumed hippocampal damage due to hypoxia following cardiac arrest. D.B.'s resulting deficit in past remembering and future imagining was reflected in his inability to answer questions about possible future experiences (e.g., "How did you spend last Christmas?" and "When will be the next time you go on vacation?"). This deficit stood in stark contrast to his preserved ability to answer non-episodic, temporally based questions regarding past and future public events, thus demonstrating that existing dissociations between episodic and semantic memory can extend to future imagining. Hassabis, Kumaran, Vann, and Maguire (2007) showed that imagination deficits in amnesic individuals are not restricted to events in the future: their ability to construct novel scenes in response to verbal cues was impaired relative to controls, with the patients' descriptions lacking in spatial coherence. Interestingly, K.C.'s impairment was found to extend to generating semantic narratives of fairy tales and bible stories (Rosenbaum et al., 2009), further suggesting that the temporal component of future imagining might not be as crucial as the (re)constructive element (see also Addis, Pan, Vu, Laiser, & Schacter, 2009). Healthy and pathological aging due to Alzheimer's disease, which are known to be associated with hippocampal changes of varying extent, have also been associated with compromised episodic memory and future imagining (Addis, Cheng, & Schacter, 2008; Addis, Pan, et al., 2009; Addis, Sacchetti, Ally, Budson, & Schacter, 2009).

Renewed interest in this topic, inspired by findings in patients, has led to several neuroimaging investigations. These studies have generally confirmed that a common neural network underlies autobiographical episodic memory and imagining oneself in future events, with the medial temporal lobe (MTL), and in particular the hippocampus, having emerged as a key area of overlap. In one such study, participants used cue words to construct and elaborate on specific events while scanned with fMRI (Addis, Wong, & Schacter, 2007). Results revealed extensive neural overlap between AM and future imagining conditions, with the left hippocampus specifically engaged when participants constructed personal past and future events. The authors also reported some neural differentiation between remembering and future imagining, such that constructing an event in one's personal future engaged additional activation of the right hippocampus. This and other studies report that in addition to a core network of regions underlying past and future thought, future imagining requires greater cognitive processing than can be accounted for by past remembering alone (Addis & Schacter, 2008; Addis, Wong, & Schacter, 2007; Addis, Pan, et al., 2009; Addis, Sacchetti, et al., 2009; Okuda et al., 2003; Szpunar, Watson, & McDermott, 2007). It has been proposed that additional hippocampal activity may reflect the flexible recombination of details into an integrated event representation – a process recruited when imagining but not when remembering (Addis & Schacter, 2008; Schacter & Addis, 2009). It is also possible that other cognitive processes supporting future thinking underlie this effect (e.g., novelty; Köhler, Danckert, Gati, & Menon, 2005). The relationship between episodic memory and future imagining may also be informed by a parallel line of research within the developmental sciences. Indeed, support for the idea of past and future thought being subserved by a unitary form of consciousness comes from studies showing that children develop the two abilities close in ontogenetic development, between 3 and 5 years of age (Atance & O'Neil, 2001, 2005a; Busby & Suddendorf, 2005; Suddendorf & Corballis, 1997). For example, Atance and O'Neil (2005b) report that early markers of episodic future thought, beyond general language ability, begin to emerge in a primitive form in 3-year-olds. These markers include use of future orientation and uncertainty in speech, which together reflect growth from knowledge of general script-like fixed event sequences (e.g., bedtime routine). These behaviours

steadily evolve into more sophisticated forms of episodic future thinking and, by about age 5, children become more capable of delaying gratification and possibly some aspects of planning and prospective memory, which are believed to involve anticipation of future states (Atance & Jackson, 2009). Although episodic memory and future imagining appear to develop in tandem, it is unknown whether the failure of one ability to develop in early childhood precludes the normal development of the other ability.

One way to answer this question is to see if amnesia of developmental origin results in deficits in both episodic past and future thought that are similar to the pattern typical of adult-onset hippocampal amnesia. Impaired future imagining that parallels known episodic memory impairment in a developmental amnesic person would provide a particularly convincing case that future imagining draws on episodic memory. Any finding of impaired performance in developmental amnesia is all the more remarkable given the typical presence of relatively isolated volume reduction of the hippocampus that is often limited to only 50% of the structure bilaterally. This is coupled with a greater propensity for neural reorganization and compensatory processes when a neurological event occurs in early childhood than in adulthood (Manning, 2008; Martins, Guillery-Girard, Jambaqué, Dulac, & Eustache, 2006).

The current study examined the ability to imagine the future in a developmental amnesic person, H.C., whose autobiographical episodic memory is compromised relative to semantic memory, as documented in a group study by Vargha-Khadem et al. (2003) and verified by Rosenbaum et al. (submitted for publication). H.C.'s episodic remembering and future imagining were tested with an interview previously found to be sensitive to hippocampal function in adult populations (Addis, Wong, et al., 2007; Addis, Wong, & Schacter, 2008; Addis, Pan, et al., 2009; Addis, Sacchetti, et al., 2009). If episodic remembering and future imagining are driven by a common underlying mechanism such as visual-spatial context (Hassabis et al., 2007; Szpunar et al., 2007), detail generation and binding (Addis & Schacter, 2007; Rosenbaum et al., 2009) and/or autothetic (self-knowing) consciousness (Atance & O'Neil, 2001; Suddendorf & Corballis, 1997; Tulving, 1985; Wheeler, Stuss, & Tulving, 1997; see also Buckner, 2010; Buckner & Carroll, 2007), then we expect H.C. to exhibit parallel deficits in both abilities. In other words, her future imagining will be impaired to the same extent and in the same manner as her recollection of episodic memories. An additional possibility that may be viewed as complementary is that if imagining one's future requires greater hippocampal activity than recalling one's past (i.e., constructive episodic simulation hypothesis), then H.C.'s construction of future events may be worse than her episodic memory, which itself is significantly worse than that of controls but not at floor, likely due to compensatory strategies (e.g., semantic learning of repeated event details; Rosenbaum et al., submitted for publication). A third possibility is that H.C. is better able to imagine her future than she is able to remember her past. This effect would be particularly striking given that healthy individuals typically perform in an opposite fashion. We might find this pattern if episodic future thinking is, in fact, a unique cognitive ability that is dissociable from episodic memory and one that can be selectively preserved with early neural plasticity and/or functional reorganization, compensatory strategies, or achieved with residual hippocampal tissue. This prediction is made in light of several findings. First, developmental amnesic people who incur hippocampal pathology before the age of 1 year show some functional sparing and reorganization compared to those whose injury occurs later in childhood (Vargha-Khadem et al., 2001). More recently, residual hippocampal tissue in developmental amnesia has been speculated to sufficiently support imagination of new and future experiences (Maguire, Vargha-Khadem, & Hassabis, in press).

## 1. Methods

### 1.1. Participants

#### 1.1.1. Developmental amnesic person

H.C. is a right-handed, female, native English speaker and was 20 years old at the time of testing. She was born prematurely and experienced reduced hippocampal development resulting in a bilateral volume reduction of approximately 50% relative to healthy controls (see Rosenbaum et al., submitted for publication, for detailed neuropsychological profile and Vargha-Khadem et al., 2003). H.C.'s compromised bilateral hippocampal development precluded normal development of her episodic memory. Her impairment affects her personal and public event memory more than her personal and general semantic memory and her recollection of recognized material more than familiarity on lab-based episodic memory tests (Rosenbaum et al., submitted for publication). This pattern of impaired episodic memory and preserved semantic memory is generally consistent with other developmental amnesia cases (Gadian et al., 2000). H.C. has successfully graduated from a mainstream high school, completed a year of technical college, and is currently enrolled in a post-secondary culinary program.

#### 1.1.2. Controls

Ten female participants, matched for age ( $M=19.4$ ,  $SD=.8$ ) and education ( $M=13.6$ ,  $SD=1.00$ ), served as controls in exchange for monetary compensation. All controls were native English speakers and had no history of psychiatric or neurological abnormality.

All participants gave informed consent in accordance with Baycrest and York University Boards of Ethics.

### 1.2. Materials

#### 1.2.1. Experimental task

The experimental task involved a Galton–Crovitz paradigm in which cue words are used to elicit remembered personal past events and imagined personal future events (see Addis, Cheng, et al., 2008; Addis, Wong, et al., 2008). For each of four time conditions (past few years, past few weeks, next few weeks, and next few years), participants described two events. “Few weeks” and “few years” were defined as within the month and within 3–5 years of the current date, respectively. The trials were blocked by time condition and presented in chronological order. Cue words within each condition were fully counterbalanced. Each trial lasted 5 min, with the cue word and time frame appearing for the duration of the trial.

#### 1.2.2. Experience scales

We included a subset of scales to capture participants' subjective ratings of experience. Included in this subset were scales assessing vividness of experience, emotionality, and personal significance of the given event. Participants rated these aspects of subjective experience on a 5-point scale (1 = low; 5 = high).

### 1.3. Procedure

Participants were given two practice trials (one past and one future), which were excluded from the final analysis. Participants then completed two trials for each condition. For each trial, participants were presented with a single cue word and time period (past few weeks, past few years) on a computer screen. Participants were instructed to use the cue word to help generate a personal event occurring within the specified time period. Events were defined to participants as discrete episodes, specific to a time and place, and occurring over a duration not exceeding a day's length. Participants were also told that cue words were tools to help generate an event, and that the event itself need not be related to the cue. For past trials, participants were asked to recall specific personally experienced events in as much detail as possible. For future trials, participants were asked to imagine specific novel events that they might personally experience in the future in as much detail as possible. For future events, participants were instructed to create details that were plausible and realistic in the context of their lives and envisioned futures. Immediately after each event, participants gave a rating on each of the experience subscales. Sessions were recorded using a digital audio recorder and were later transcribed.

### 1.4. Scoring

The standard scoring procedure for the autobiographical interview (AI) was used to assess the detail and quality of participants' past and future events (Levine, Svodoba, Hay, Winocur, & Moscovitch, 2002). All details were segmented and categorized as either *internal* or *external*. Internal details refer to specific episodic information about the central event. External details are non-episodic details provided by participants that are tangential or unrelated to the central event, semantic facts, repetitions, or metacognitive statements/editorializing. For each time condition, we tallied and averaged the number of internal and external details to determine an overall index for each type of detail generated by each participant. Given that the task was to produce details of a specific event, internal details were expected to outnumber external details on every trial.

Each event also received qualitative ratings on the following dimensions: episodic richness, time, place, perceptual, thought/emotion, and time integration (see Levine et al., 2002 for descriptions). We averaged scores across these dimensions to determine an overall composite of qualitative ratings.

## 2. Results

A priori predictions were tested using a modified *t* test procedure, which compares test scores of a single patient with a control sample (Crawford & Garthwaite, 2002; Crawford & Howell, 1998). The single-case method imposes certain statistical constraints, which limited the analyses we were able to perform. Several procedures have been developed for factorial analysis in single-case studies (Corballis, 2009a,b; Crawford & Garthwaite, 2007, Crawford, Garthwaite, & Howell, 2009), though there has been some debate surrounding their use. We thus restricted our analyses to standard *t* tests modified for single-case studies. It is also notable that with this approach, it was not possible to test within-subject effects (e.g., past vs. future events, near vs. far events) in H.C. alone. In order to examine such patterns, the within-subject difference was assessed in controls using a standard related-samples *t* test, and then the modified *t* test was employed to assess whether the difference score in H.C. differed significantly from the control group pattern.

### 2.1. Temporal direction

#### 2.1.1. Past remembering

To determine whether H.C.'s remembered events differed from those of controls, we collapsed across past time periods (past few weeks, past few years) and compared the number of internal (episodic) details, external (non-episodic) details, and ratings. Analyses revealed that H.C. generated significantly fewer episodic details and achieved significantly lower ratings than controls (internal details:  $t=-2.70$ ,  $p=.01$ ; ratings:  $t=-3.61$ ,  $p=.003$ ). The number of external details generated by H.C. was at the lower end of the range of controls ( $t=-1.35$ ,  $p=.11$ ).

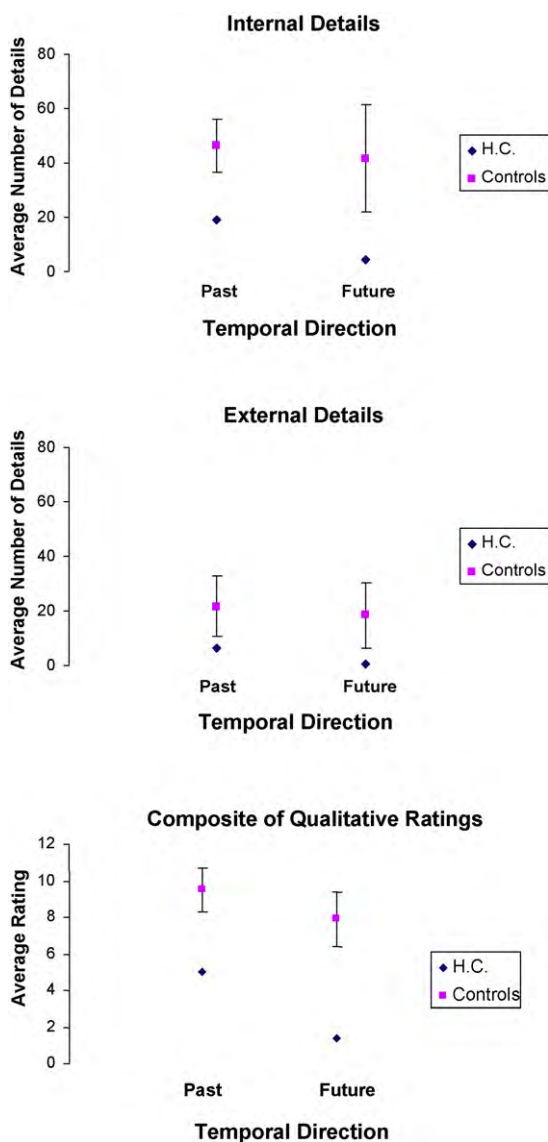
#### 2.1.2. Future imagining

To determine whether H.C.'s ability to imagine future events differed from that of controls, we collapsed across future time periods (next few weeks, next few years) and compared the number of internal details, external details, and ratings. Analyses revealed a significant reduction in the generation of episodic details in H.C. and significantly lower ratings relative to controls (internal:  $t=-1.81$ ,  $p=.05$ ; ratings:  $t=-4.17$ ,  $p=.001$ ). External detail generation was at the lower end of the range of controls ( $t=-1.40$ ,  $p=.10$ ).

#### 2.1.3. Group differences in past vs. future event generation

Due to statistical restrictions with single-case studies, we included a two-step approach to compare H.C.'s past vs. future performance. First, we conducted one-tailed, paired *t* tests comparing only controls' generation of internal details, external details, and an overall composite of qualitative ratings for past vs. future. Results showed no significant difference in generation of internal details ( $t=.87$ , *ns*), but significantly more external details and higher ratings for past over future events (external:  $t=3.25$ ,  $p=.005$ ; ratings:  $t=2.80$ ,  $p=.01$ ). A family-wise error rate of .05 was maintained using a Bonferroni correction.

Next, we used a modified *t* test to assess whether H.C. exhibited a greater past–future difference on the various scores relative to controls. Results indicated no significant past–future difference for internal details ( $t=-.89$ , *ns*), external details ( $t=-.21$ , *ns*), or ratings ( $t=-.41$ , *ns*). The performance of H.C. and controls is illustrated in Fig. 1.



**Fig. 1.** Graphs indicate average number of internal and external details generated H.C. and controls, as well as a comparison of composites of qualitative ratings for past and future events.

**2.1.4. Correlation between past and future internal detail generation**

We examined correlations between past and future internal detail generation to determine if performance variability on this measure of interest was related to individual differences in episodic (re)constructive ability. We included all participants in this analysis because it was statistically unfeasible to correlate H.C.'s individual scores separately. A moderate correlation was found for internal detail generation between past and future conditions ( $r = .66, p = .03$ ).<sup>1</sup>

**2.2. Temporal distance**

**2.2.1. Near and distant past event generation**

To determine whether H.C.'s generation of near and distant past events differed from that of controls, we compared the

number of internal details, external details, and ratings for each condition (past few weeks, past few years). For the near past condition, H.C.'s generation of internal details and qualitative ratings were significantly lower than that of controls (internal:  $t = -2.44, p = .02$ ; ratings:  $t = -2.56, p = .02$ ). We found no significant difference in external detail generation for recent past events (i.e., next few years;  $t = -1.39, ns$ ). For the distant past condition, H.C. also showed significant impairment in generating internal details, which was reflected in significantly lower qualitative ratings (internal:  $t = -1.92, p = .04$ ; ratings:  $t = -3.31, p = .01$ ). The difference in external detail generation for distant past events was not significant ( $t = -1.05, ns$ ).

**2.2.2. Group differences in near vs. distant past event generation**

The same two-step procedure used to assess differences in temporal distance and direction was used here. First, we conducted one-tailed, paired  $t$  tests comparing controls' generation of internal details, external details, and composites of qualitative ratings for near vs. distant past events. Results showed no significant differences in the generation of near vs. distant past events (internal:  $t = -.33, ns$ ; external:  $t = -3.66, ns$ ; ratings:  $t = -.51, ns$ ). A family-wise error rate of .05 was maintained using a Bonferonni correction.

Next, we used a modified  $t$  test to determine whether the near–distant difference in remembering past events was greater for H.C. than controls. Analysis revealed that H.C.'s generation of internal details, external details, and ratings for near and distant past events did not differ significantly from that of controls (internal:  $t = -.42, ns$ ; external:  $t = -.35, ns$ ; ratings:  $t = -.62, ns$ ).

**2.2.3. Near and distant future event generation**

To determine whether H.C.'s near and distant future event generation differed from that of controls, we compared the number of internal details, external details, and ratings for each of the near and distant future conditions (next few weeks, next few years). For the near future condition, H.C. had significantly lower qualitative ratings ( $t = -3.95, p = .002$ ) and showed a trend towards significance for impairment in internal and external detail generation (internal:  $t = -1.63, p = .07$ ; external:  $t = -1.44, p = .09$ ). The distant future condition revealed similar results, with H.C. achieving significantly lower qualitative ratings ( $t = -2.96, p = .01$ ) and showing a trend towards significance for the generation of internal details ( $t = -1.57, p = .08$ ). No difference was found for external details in the distant future condition ( $t = -1.33, p = ns$ ).

**2.2.4. Group differences in near vs. distant future event generation**

The two-step procedure described above was again used to assess differences in near vs. distant future events. First, we conducted one-tailed, paired  $t$  tests comparing controls' generation of internal details, external details, and composites of qualitative ratings for near vs. distant future events. Results showed no significant differences for near vs. distant future events (internal:  $t = 1.64, ns$ ; external:  $t = 1.21, ns$ ; ratings:  $t = .80, ns$ ). A family-wise error rate of .05 was maintained using a Bonferonni correction.

A modified  $t$  test was then used to determine whether the near–distant difference for future events was greater for H.C. than controls. The analysis revealed that H.C.'s generation of internal details, external details, and ratings for near and distant future events did not differ significantly from that of controls (internal:  $t = -.08, ns$ ; external:  $t = -.29, ns$ ; ratings:  $t = -.44, ns$ ).

**2.3. Experience scales**

In order to examine whether subjective experience ratings differed between H.C. and controls, we analyzed these ratings for past

<sup>1</sup> A similar correlation analysis was not included for external details, as the results would be difficult to interpret due to the restricted range of external details generated by participants.

and future events separately (but collapsed across temporal distance). Analyses indicated a trend towards significance for H.C.'s lower vividness ratings of past events, whereas emotionality and personal significance ratings were not found to differ significantly (vividness:  $t = -1.75$ ,  $p = .06$ ; emotionality:  $t = -.9$ ,  $ns$ ; personal significance:  $t = .48$ ,  $ns$ ). Significant effects were not evident for future events in terms of vividness ratings ( $t = .74$ ,  $ns$ ) and personal significance ratings ( $t = -.6$ ,  $p = .28$ ); ratings of emotionality were at the low end of the range of controls ( $t = -1.30$ ,  $p = .11$ ).

### 3. Discussion

Studies of adult patients with hippocampal damage show that deficits in episodic remembering are associated with deficits in the ability to imagine future personal episodes (i.e., mental time travel). The objective of the current study was to assess whether the same pattern is present in a case of developmental amnesia or, alternatively, whether episodic future thought can develop independently of episodic memory. To answer this question, we tested a developmental amnesic person, H.C., who had never developed the ability to fully recollect her personal past but who is nonetheless capable of semantic learning. The current findings indicate that, in fact, the same pattern of impaired episodic memory and future imagining observed in adult amnesic cases can occur in a developmental amnesic person. Thus, unlike other abilities that are resilient to perinatal damage to the hippocampus, future imagining, like episodic memory, necessarily depends on the hippocampus, and possibly episodic memory itself, for its normal development.

Findings from this study extend our understanding of the relationship between the hippocampus, episodic memory, and episodic future imagining. Research with patients and healthy adults has led to a number of theories regarding the nature of this relationship. One explanation is that past and future thought are governed by an overriding *autonoetic* consciousness, which facilitates mental time travel from one's past to one's future (Tulving, 1985; Wheeler et al., 1997). Similarly, Buckner and Carroll's (2007) idea of self-projection also considers past remembering and future imagining to be driven by a common set of processes and an underlying neural network that includes the hippocampus (for an updated account, see Buckner, 2010). This common network is believed to facilitate mental shifting from events in one's immediate environment to thinking about events that are temporally displaced or from alternate perspectives (i.e., theory of mind; but see Rosenbaum, Stuss, Levine, & Tulving, 2007). An alternative view specifies that the role of the hippocampus and other MTL regions is to help create a spatially coherent context to which fragments of experiential details of past memories or imagined novel events may be bound (Hassabis et al., 2007; Hassabis & Maguire, 2007; Szpunar & McDermott, 2008; Szpunar et al., 2007).

The parallel deficit in past and future imagining revealed in the current study supports the idea that a common mechanism that relies on the hippocampus underlies both abilities. One possibility that may be viewed as complementary to the theories described above is that episodic memory and future imagining both rely on the construction of elaborate and cohesive event representations (Schacter, 1999; Schacter, Addis, & Buckner, 2007; Schacter, Addis, & Buckner, 2008). By this *constructive episodic simulation hypothesis*, the hippocampus is believed to make a critical contribution to both episodic memory and episodic future thought by reactivating episodic details from past memories; additional processes are needed to construct a future scenario, such as flexibly recombining the extracted episodic details. It is further argued that these additional recombination processes require greater hippocampal activation to recombine episodic memory fragments into simulated future experiences (Addis, Moscovitch, et al., 2007; Addis,

Wong, et al., 2007; Addis & Schacter, 2007, 2008). The results of this study generally support this hypothesis: hippocampal damage precluded normal construction of detailed past and future events. However, the results suggest that H.C.'s past and future thinking appear impaired to a similar degree. These findings could be considered inconsistent with the idea that future self-imagining requires greater hippocampal activity than past remembering and should thus be more impaired in a hippocampal patient. However we are unable to conclude that uniform impairment across temporal direction found in this study truly reflects equivalent hippocampal engagement during past and future thought. It is possible that the current experimental task lacks sufficient sensitivity to detect temporal direction effects within an impaired individual. Indeed, even when both past and future events are similarly impaired in terms of the amount of detail generated, the degree of recombination and integration of details comprising the imagined events has been found to be deficient in populations with hippocampal dysfunction (e.g., hippocampal amnesics, Hassabis et al., 2007; older adults, Addis, Musicaro, Pan, & Schacter, 2010). We did find a moderate correlation in participants' internal detail generation between past and future conditions, a trend that has been documented previously (Addis, Cheng, et al., 2008; Addis, Wong, et al., 2008; Addis et al., 2010). This suggests that despite high intra-subject variability, there is considerable overlap in the episodic specificity with which each participant is able to remember her past and imagine her future. The correlation may reflect an individual difference in episodic (re)constructive ability, although other individual differences such as verbal fluency or narrative style may also play a role. For external detail generation and qualitative ratings, controls showed the typical trend of better past remembering than future imagining (Addis, Cheng, et al., 2008; Addis, Wong, et al., 2008; D'Argembeau & Van der Linden, 2004), H.C.'s past–future difference did not differ from that of controls, suggesting that she also shows the same past-better-than-future trend on these measures.

There are also several hypotheses regarding temporal distance (near or distant) and how it might modulate impairment of past and future events. For example, D'Argembeau and Van der Linden (2004) report that consideration of temporally near events, irrespective of temporal direction, leads to stronger subjective experience of events compared to consideration of temporally distant events. Similarly, construal level theory argues that temporal distance alters mental representation of events such that events move from concrete and detailed to abstract and gist-like the further that a given event is from the present (Liberman & Trope, 2008; Trope & Liberman, 2003). Temporal distance effects are also observed in healthy aging, where older adults generate temporally distant events with fewer internal details than near events (Addis, Cheng, et al., 2008; Addis, Wong, et al., 2008; but see Addis, Pan, et al., 2009; Addis, Sacchetti, et al., 2009). In line with these theories, a recent neuroimaging study has identified a possible neural correlate responsive to psychological distance, with the bilateral hippocampal activation significantly correlated with the increasing remoteness of events during future imagining (Addis & Schacter, 2008). One might predict based on these findings that an individual with hippocampal pathology would generate fewer episodic details for temporally distant events than for temporally proximal events. However, our results do not show this pattern: H.C. was impaired in generating internal details of both near and distant events. Moreover, paired  $t$  tests in controls showed no near–distant difference, and H.C.'s near–distant difference did not differ from that of controls. H.C.'s parallel performance to controls suggests a similar lack of effect for near vs. distant events. The same caution in interpreting H.C.'s performance across temporal direction applies to interpreting her performance across temporal distance. The null effect of temporal distance might indicate that H.C.'s deficit is truly independent of temporal distance. Alternatively, it is possible that our

methodology or H.C.'s overall poor performance did not allow for detection of extant differences. For instance, it is possible that H.C.'s ability to recombine and integrate key details would decrease with increasing temporal distance of imagined events if an experimental recombination paradigm was used (Addis et al., 2010).

While results of this study show that future imagining is impaired in a case of developmental amnesia, it is possible that the deficit may be independent of time. Recent neuropsychological and neuroimaging studies suggest that the role of the hippocampus may pertain more to non-temporal aspects of imagination in general rather than mental projection in the future specifically (Addis, Pan, et al., 2009; Addis, Sacchetti, et al., 2009; Hassabis et al., 2007; Rosenbaum et al., 2009, see also Buckner, 2010). This idea is bolstered by our current finding that neither temporal distance nor direction seemed to modulate level of impairment. It is difficult to decouple episodic future imagining from general imagining, although it is of theoretical interest whether the two abilities may be dissociable.

Another interesting observation of H.C.'s performance is that her future narratives lacked self-relevant information and did not seem to integrate her present life or future aspirations, unlike controls' narratives. For example, when given the cue word "coffee," H.C. described a future scenario in which she took an order at a coffee shop even though she did not currently work in a coffee shop, had no future plans to do so, and at that point in the future would likely have graduated from college as a trained chef given her current schooling. Her future events, which lacked such self-specific relevance, may instead reflect imagination of more generic events that are not personally contextualized and may not require the same level of hippocampal contribution (Addis, Cheng, et al., 2008; Addis, Wong, et al., 2008). Observations from the current study suggest that H.C. may have difficulty in contextualizing imagined episodes with the use of personal information. One way to test this possibility is to specify to H.C. and controls that they should generate events within the scheme of their probable future lives vs. generate events that are more generic or unlikely to occur.

Subjective ratings of personal significance, emotionality, and vividness might also be informative. H.C.'s phenomenological experience of past remembering and future imagining differed from what one might predict based on her test performance and from previous studies. Evidence from neuroimaging suggests that hippocampal activation is modulated by experiential elements of episodic memory retrieval, particularly vividness or the vivid "re-experiencing" aspect of memory (Addis, Moscovitch, Crawley, & McAndrews, 2004; Gilboa, Winocur, Grady, Hevenor, & Moscovitch, 2004; Rabin, Gilboa, Stuss, Mar, & Rosenbaum, 2010). Neuropsychological studies provide converging support, with cases of hippocampal amnesic individuals reporting lost or impoverished vivid recollection of memories (see Moscovitch, Nadel, Winocur, Gilboa, & Rosenbaum, 2006). H.C.'s self-reported experience of personal significance and emotionality did not differ from that of controls. Importantly, H.C.'s experience of past remembering was reported as only marginally less vivid than controls' experience. More surprising is that the vividness with which she reported experiencing future events was equal to that of controls: even though H.C.'s imagined future events are impoverished in episodic detail and overall quality, she rated them as experientially vivid. What might account for this discrepancy in objective performance and subjective experience? One explanation is that a coherent visual-spatial context was present in H.C.'s narratives and, despite a paucity of episodic detail, intact spatial coherence sufficed in giving rise to vivid experience (Hassabis et al., 2007; Szpunar & McDermott, 2008). This explanation is consistent with a separate investigation of the developmental amnesic case Jon, who showed preserved scene construction and imagining of plausible future scenarios (Maguire, Vargha-Khadem, et al., in press). Differences

between the two studies may be due to the methods used and warrant further investigation. A specific measure of spatial coherence was not included in this study, making it difficult to directly examine spatial contributions to overall experience. However, casual observations of H.C.'s narratives suggest a paucity of reference to spatial elements, which may be difficult to reconcile with the report on patient Jon (Maguire et al., in press). It has been previously reported that, unlike controls, subjective ratings of vividness by patients with hippocampal damage are not always consistent with objective scores of vividness on the Autobiographical Interview, and may even be negatively correlated (Addis, Moscovitch, et al., 2007; Addis, Wong, et al., 2007). Thus, an alternative interpretation is that H.C.'s absolute perception of vividness differs from that of healthy controls. Because she has never fully developed the capacity to re-experience or imagine, we may presume that H.C. has never remembered or imagined in a fashion that healthy controls would describe as vivid. Experiences rated as partially vivid by controls might be experienced by H.C. as fully vivid.

Finally, we found that H.C.'s performance on autobiographical episodic memory for past events in the current study was worse than her previously documented episodic memory performance assessed with the standard Autobiographical Interview (Rosenbaum et al., submitted for publication). The main difference between the two measures is the current study's provision of cue words to probe specific events. A reason why the use of cue words in the present study resulted in fewer detailed episodic memories could be that they constrain the specific events available to H.C. for recall and elaboration. Moreover, those events that were recalled appear to represent generic or repeated memories. Indeed, a post-testing verification session with H.C.'s mother revealed that many of H.C.'s generated past events were stories that had been retold over the years and may have been "semanticized" to some extent.

We found a further discrepancy between H.C.'s current performance and that in a previous study with external detail generation: the present results show that her average score on this dimension is consistently on the low end of the control range, arguably reflecting a borderline impairment. Although H.C. did not demonstrate significant impairment in generating external details, it is possible that this aspect of the test was not sensitive enough to detect impairment, as all participants generated fewer external than internal details. The pattern observed in all participants is a likely consequence of the task instructions, which specified that participants should try to provide details specific to a particular time and place in relation to a past or future event. The instructions, coupled with the fact that detail generation was capped at 5 min per event (see above), likely restricted the number of external details that participants would have otherwise generated. Had participants been given free rein in generating whichever details came to mind, we may have observed a significant deficit in H.C.'s external detail generation relative to controls. Although we are unable to rule out this possibility, the finding that controls all performed better in generating internal than external details of both past and future events serves to emphasize H.C.'s deficiency in producing specific, episode-rich details of personal events, whether real or imagined.

Nevertheless, H.C.'s low external detail generation may be attributable to difficulties accessing semantic information in response to cue words as opposed to a deficit in semantic knowledge per se. This explanation is plausible given H.C.'s lack of levels-of-processing effect in recognition memory performance but otherwise intact semantic memory as documented in a separate study by Rosenbaum et al. (submitted for publication). However, we must note that external details as defined by AI scoring do not necessarily map onto semantic information. The former category can include generic event information that is tangential to the main event while the latter relates to information that lacks and episodic quality. What the collective findings from the two studies do show-

case is the narrow range of remembered events that H.C. is able to recall and describe as well as possible restrictions in semantic access to information outside of a current episode.

The results of this study provide unique insight into the development of abilities underlying mental time travel. Previous work shows that episodic memory and episodic future imagining emerge close in time developmentally (Atance & O'Neil, 2005a, 2005b; Busby & Suddendorf, 2005; Suddendorf & Corballis, 1997). Here, we provide a neuropsychological demonstration that one ability does not develop independently of the other: both abilities are compromised with hippocampal damage even when the injury is acquired early in life and the individual is more likely to be afforded the opportunity for neural reorganization. These findings further suggest that a common mechanism or process may underlie both episodic memory and future thought and that early hippocampal injury precludes the development of this mechanism.

In sum, the current results show that an individual with developmental amnesia is similarly impaired in constructing imagined future personal events and in reconstructing experienced past events. This finding suggests that the development of these two abilities may be intertwined, with full development of both dependent on intact hippocampal function. Results are consistent with the constructive episodic simulation hypothesis and further suggest that the (re)constructive aspect of memory and imagination may be the crux of impairment in hippocampal amnesia, whether acquired in childhood or adulthood. Future investigation is needed to isolate constructive abilities from other aspects of episodic future thought.

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