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Autobiographical memory and episodic future thinking after moderate to severe traumatic brain injury

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Abstract

Converging evidence suggests that autobiographical memory and episodic future thinking share a common neurocognitive basis. Although previous research has shown that traumatic brain injury (TBI) can impair the ability to remember the personal past, episodic future thinking has not previously been systematically examined within this population. In this study we examined the ability to remember events in the personal past and the ability to imagine possible events in the personal future in a sample of moderate to severe TBI patients. We present data on 9 patients and 9 healthy controls, who were asked to report a series of events that had happened to them in the past and a series of events that might happen to them in the future. Transcriptions were scored according to a reliable system for categorizing internal (episodic) and external (semantic) information. For each event described, participants also completed two modified Autobiographical Memory Questionnaire items to assess self-reported phenomenal qualities associated with remembering and imagining. In addition, TBI patients underwent neuropsychological assessment. Results revealed that TBI patients recalled/imagined significantly fewer episodic event-specific details for both past and future events compared to healthy controls ($\eta^2_p = 0.784$). In contrast there were no group differences in ratings of phenomenal characteristics. These results are discussed in relation to theories suggesting that remembering and imagining the future are the expression of the same underlying neurocognitive system.

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Autobiographical Memory and Episodic Future Thinking after moderate to severe Traumatic Brain Injury

Autobiographical memory is a complex and multifaceted phenomenon, which involves different kinds of knowledge pertaining to the self – both episodic and semantic. The episodic component contains personally experienced events situated in subjective time and space while the semantic component contains de-contextualized generic knowledge of one's past (Tulving, Schacter, McLachlan & Moscovitch, 1988). In recent years, it has been argued that the ability to remember the personal past is closely related to the ability to imagine possible future scenarios (Suddendorf & Coballis, 1997; Wheeler, Stuss, & Tulving, 1997). Autonoetic consciousness – the kind of consciousness critically involved in becoming aware of the self in subjective time extending from the personal past through the present to the personal future, is the hallmark of episodic memory and episodic future thinking (Tulving, 1985; Wheeler et al., 1997). Autonoetic consciousness is thought to give rise to a sense of mental time travel, whereby one travels backwards in time to re-experience events in the personal past or forward in time to pre-experience personal events that may happen in the future (Suddendorf & Coballis, 1997).

The idea that remembering the past and imagining the future rely on common neurocognitive processes have been supported by neuroimaging findings demonstrating robust and consistent overlap in neural activity within prefrontal, medial-temporal lobe (MTL), and posterior cortical regions, including the posterior cingulate and retrosplenial cortex, when remembering past events and imagining novel scenarios (Addis, Wong & Schacter, 2007; Botzung, Denkova & Manning, 2008; Okuda et al., 2003; Szpunar, Watson & McDermontt, 2007), supporting the notion of a core brain network underlying both processes (Buckner & Carroll, 2007; Hassabis & Maguire, 2007; Schacter, Addis & Buckner, 2007; Spreng, Mar & Kim, 2009). Additional support is found in neuropsychological studies showing that amnesic patients unable to remember events from their personal past show a corresponding deficit in imagining possible events in their personal future (Hassabis, Kumaran, Vann, & Maguire, 2007; Klein, Loftus, & Kihlstrom, 2002; Tulving, 1985).

In the light of such findings, Schacter and Addis (2007) proposed a connection between the constructive nature of episodic memory and episodic future thinking. According to their *constructive episodic simulation hypothesis* the ability to flexibly recombine features of previous experiences allows one to simulate an endless number of possible future scenarios. This ability to mentally simulate the future provides a unique opportunity to test alternative plans of actions without the potential risks associated with actually carrying out these plans, and thus improving the chances of an adaptive behavioral outcome. In addition, the ability to foresee consequences of planned actions may facilitate behavioral flexibility and self control, in that it makes it possible to postpone an immediate reward in order to achieve long-term goals (Suddendorf & Busby, 2005).

However, behavioral and brain imaging studies have consistently shown some differences between remembering the past and imagining the future, which appear to reflect that the latter requires more constructive effort and a greater reliance on schematized knowledge than is the case for remembering past events (see, e.g., Schacter et al., 2008; Szpunar, 2010; for reviews).

One important issue that still needs to be investigated is the relationship between autobiographical memory and future thinking in people suffering from episodic memory deficits. To date only a few studies exist. The neuropsychological literature describes two amnesic patients, K.C. (Tulving, 1985) and D.B. (Klein et al., 2002), both suffering from a total loss of episodic memory, and both showing severe impairment regarding retrieving past as well as imagining future autobiographical events. K.C. had extensive lesions to the medial temporal and frontal lobe areas following head trauma (Tulving, 1985, 2002), while little

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information was given as to the location of D.B.'s lesion (Klein et al., 2002). In relation to these reports, Dalla Barba, Cappelletti, Signorini and Denes (1997) described patient G.A., who not only confabulated about her personal past, but also about her personal future. Similarly, Hassabis et al. (2007) reported on five amnesic patients with bilateral lesions to the hippocampus, four of whom showed marked impairment in their ability to imagine fictitious as well as possible plausible future scenarios, in that the patients' mental constructions contained markedly fewer details and lacked spatial coherence compared to the ones of healthy controls. The authors suggested that both remembering and imagining novel scenarios rely on an intact hippocampus, which flexibly combines elements from memory into a coherent scene (Hassabis & Maguire, 2007). A recent study by Squire et al. (2010) did not, however, observe deficits in future thinking in their sample of amnesic patients with MTL damage, thus challenging the view that the hippocampus and the MTL is critical for future thinking. However, it is notable that in contrast to prior studies, the amnesic patients in this study did not demonstrate pervasive autobiographical memory deficits (Maguire & Hassabis, 2011; Race, Keane & Verfaellie, 2011). Moreover, multiple studies with a range of different etiologies have since replicated the results by Hassabis et al. (2007), that is patients with MTL damage (Andelman, Hoofien, Goldberg, Aizenstein & Neufeld (2010); Race et al., 2011), Alzheimer's disease (Addis, Sacchetti, Ally, Budson & Schacter, 2009) and mild cognitive impairment (Gamboz et al., 2010) have been showed to have co-occurring deficits in autobiographical memory and future thinking.

Although the majority of studies support the idea that imagining the future relies on intact autobiographical memory, it is not clear whether impairments equally affect both temporal directions, or whether one temporal direction is affected more. In the present study we sought to examine the effects of brain damage on both autobiographical memory and episodic future thinking in the same sample of individuals suffering from traumatic brain injury (TBI). Although growing evidence indicates that TBI can impair the ability to recall specific events from the personal past (Levin et al., 1985; Carlesimo et al., 1998; Piolino et al., 2007; Knight and O'Hagan, 2009) and may lead to deficits in conscious recollection of personal events (autonoetic consciousness) (Piolino et al., 2007), little is known about the corresponding ability to imagine possible future events in TBI patients.

To our knowledge no prior study has sought to investigate both episodic memory and episodic future thinking in people suffering from TBI. However, the potential applied benefits of such an investigation may be considerable in that episodic future thinking is thought to play a pivotal role in successful planning, behavioral flexibility and self regulation (Suddendorf & Coballis, 2007). If individuals suffering from TBI experience difficulties not only in recalling past events but also in simulating future plans of actions, and have problems considering alternative courses of action through future simulations, they might rely on stereotypical and rigid routines to guide behavior. Thus, episodic future thinking deficit may contribute to the behavioral inflexibility and poor goal attainment often associated with TBI.

The Present Study

The main aim of the present study was to examine whether individuals suffering from severe TBI have an impaired ability for autobiographical memory and episodic future thinking. Since no previous study has systematically examined both autobiographical remembering and future thinking in a TBI sample, the present work addresses an important gap in the literature on mental time travel. Provided that autobiographical memory and episodic future thinking rely on common neurocognitive processes, individuals with TBI should experience difficulties in both recalling and imagining specific events.

First, it was predicted that relative to healthy controls, participants with TBI would show impairments in both episodic remembering and episodic future thinking (i.e. would recall and imagine significantly fewer episodic, event specific details).

Second, we expected an effect of future versus past temporal direction, in that future events would contain fewer episodic details than past events, consistent with previous work (Addis et al., 2009). However, since episodic future thinking seems to require more constructive effort, as indicated by reports of higher levels of activation in thinking about the future than the past in functional neuroimaging studies (Addis, Wong et al., 2007; Okuda et al., 2003; Szpunar et al., 2007), we speculated that there might be an interaction, with the TBI group experiencing more pronounced difficulties in imagining future events in comparison with recalling past event due to a greater demand on processing resources.

Third, previous studies have shown a link between increasing temporal distance and diminishing levels of specific details in past and future event representations (D'Argembeau & Van der Linden, 2004; Szpunar & McDermott, 2008), consistent with the idea that temporally remote events rely more on schematized construction; we therefore expected that irrespectively of temporal direction, temporally remote events would contain fewer episodic details. Again, we hypothesized that this main effect might be qualified by interactions due to the additional demands on construction when having to imagine or recall remote events, which might differentially impede the performance of the TBI group compared to the healthy controls.

Forth, if individuals with TBI show impaired episodic remembering and episodic future thinking, this may be reflected in a diminished sense of autonoetic awareness. Thus, it was predicted that individuals with TBI would rate both future and past events as involving less (p)re-experiencing and less sense of travelling in time.

To examine these issues, we adopted a standard method based on D'Argembeau and Van der Linden (2004) which involved asking participants to recall/imagine and describe a series of specific events from the personal past and future; the latter condition corresponding exactly to the former except for temporal reference, making it possible to compare the ability to generate autobiographical representations of past and future directly. The participants' descriptions were analyzed following a standardized scoring procedure developed by Levine, Svoboda, Hay, Winocur, and Moscovitch (2002) which allows assessment of the episodic and semantic aspects of a narrative describing a specific event. This scoring system takes into account that autobiographical memories are constructed from episodic details, as well as from more personal and cultural semantic knowledge (Berntsen & Rubin, 2004; Conway & Pleydell-Pearce, 2000), and that these two kinds of knowledge are closely intertwined when it comes to narrative accounts of everyday memories and future thoughts. Although this task has not yet been used to asses memory and future thinking in TBI patients, it has previously been used with other patient populations including patients with MTL damage and mild Alzheimer's disease (Addis et al. 2009; Race et al., 2011) and in healthy older adults (Addis, Wong & Schacter, 2008).

In addition, participants were asked for subjective ratings on two questions about the phenomenal qualities associated with remembered past and imagined future experiences, specifically, the extent to which participants felt they re-/pre-experienced the event in question and the extent to which they felt they traveled in time whilst recalling or imagining the event. Given that previous research has found patients with TBI to be impaired on measures of executive functioning, suggesting that they present general deficits in strategic retrieval processes (Piolino et al., 2007) additional cognitive tasks of attention, memory and executive function were also implemented.

Methods

Participants

Nine individuals (2 women, 7 men; M_{age} = 38.4 years; SD = 17.3; range 17-69 year) with TBI were selected from patients currently hospitalized at the regional hospital Hammel Neurocenter, a highly specialized rehabilitation center for people with acquired brain damage, on the basis of medical evidence that they had sustained moderate to severe TBI. Six of the TBI participants suffered a severe TBI, defined by a post-resuscitation score of 8 or less on the Glasgow Coma Scale (GCS; Teasdale & Jennett, 1974). The remaining three participants suffered a moderate TBI classified by GCS scores between 9 and 12 ($n = 2$) or by a GCS score higher than 12 accompanied by a positive neuroimaging finding and neurosurgery. All participants experienced an extended period of posttraumatic amnesia (PTA) ($M_{PTA} = 19.33$; SD = 16.84; range 2-56 days), assessed by medical records and clinical questioning of the participants. TBI participants were assessed between 39-117 days after injury ($M = 64.33$; SD = 22.26). All patients were screened on intake, and participants with aphasia or whose gravity of comprehension, attention and behavioral problems would invalidate the assessment were excluded. None of the participants suffered from any pre-injury, psychiatric or neurological disorders or had any history of prior substance abuse. Five TBI participants suffered their head injuries as a result of a motor vehicle accident, three incurred injury from a fall and one TBI participant experienced a blow to the head. Computed tomography (CT) or Magnetic Resonance Imaging (MRI) showed a predominance of diffuse and frontal lobe lesions.

The comparison group consisted of nine healthy participants (4 women, 5 men, $M_{age} = 30.67$ years; SD = 12.35; range = 20-57 year), with no history of neurological or psychiatric disorder, or substance abuse recruited on a voluntary basis. There was no significant difference between groups in age ($t(16)=1.10$, $p=.29$) and premorbid IQ, as estimated by the Danish adaptation of the National Adult Reading Test (DART; Dalsgaard, 1998; ($t(10.73)=-1.10$, $p=.30$). Although not significant, there was a greater age-range in the TBI group, due to one patient being much older (69 years old). Excluding this patient did not change the results, and we therefore elected to include all of the patients regardless of age. The control group included slightly more women (4 of 9) compared to the patients (2 of 9), but this difference was not significant (Fischer's exact test, p=.62). The controls had on average spent more years in school than the TBI participants ($t(8)=-6.11$, $p<.001$), but when examining formal level of education [no education (incl. current student) = 1; short education or apprentice = 2; advanced studies of short or medium length (1-4 yrs.) = 3; longer-term advanced studies > 4 yrs. = 4] no group differences were found (Fisher's exact test, $p=.38$). Due to this possible confound, years in school was included as a covariate in our performance analysis, again this did not change our findings. Ethical approval of the study was obtained from the head of the research department at the regional hospital. All participants gave written consent after detailed information was provided to them.

To characterize the TBI population and highlight those areas in which the patients were experiencing cognitive difficulties, a battery of neuropsychological tests were administered. As can be seen in Table 1, consistent with typical cognitive sequelae of moderate to severe TBI, the TBI participants performed poorly compared to normative data on measures assessing attention and speeded processing (Trail Making Test – Part A, Reitan, 1958) and executive functioning (Trail Making Test – Part B, Reitan, 1958; the Danish version of the semantic (animals) and phonemic (s-words) fluency tasks, Mortensen, Nielsen & Rune, 1994; perseverative errors on the modified Wisconsin Card Sorting Test [mWCST], Nelson, 1976). In contrast to the above performance, the group performed within normal range on immediate and delayed verbal memory (Verbal Paired Associates [VPA] subscale of the Wechsler memory Scale-III [WMS-III], Wechsler, 1997), an attention task (digit span) and two executive functioning tasks (Stroop, Stroop 1935; Zoo Map Test from the Behavioural assessment of Dysexecutive Syndrome battery, Wilson, Alderman, Burgess, Emslie, & Evans, 1996). Standard deviations and the ranges of scores indicated a degree of heterogeneity in the participants' performances. Of note, severity and characteristics of cognitive impairments after TBI are known to be extremely variable (Ponsford, 1995).

Design

Our design distinguished between two different forms of mental time travel – past versus future, each of which was examined for three different time periods. Thus, a 2 (Temporal Direction: future versus past) × 3 (Temporal Distance: 1 month, 5 years and 10 years) × 2 (Group: TBI versus controls) mixed design was used. Participants generated one event in each condition making it a total of six event representations for each participant.

Materials

The autobiographical memory/future thinking task. The participants' ability to simulate representations of specific past and future events was assessed using a standard method adopted from D'Argembeau and Van der Linden (2004). The task was divided in two parts – one for recording memories for past events and one for recording representations of future events. The order in which the past and future condition were completed was counterbalanced across participants. Prior to commencing each condition, participants were provided with detailed written instructions, presented in large writings on a printed text card. The instructions for the past and future recording were the same – except for temporal reference. Participants were instructed to try to recall (or imagine) a series of events from different time periods. It was emphasized that they should try to recall (or imagine) personally experienced specific event, with durations of no longer than a day. The difference between specific and generic events (Barsalou, 1988) was explained and illustrated with an emotionally neutral example (a trip to the mall). The type of response participants were expected to give was clearly stated at the beginning of the test: "You are to describe the situation with as much detail as possible, as if you were (re)experiencing it: what you do and feel, the circumstances, with whom, where, and how it happens". A printed text card of the instructions was placed on the desk in front of the participants throughout the experimental task to act as a reminder if needed. It was explained that after each event described, they would be asked to rate their subjective experience associated with recalling/imagining the event.

In the past and future conditions, participants were presented with cues in the following formats, respectively: “Try to remember an event that happened to you [specified time period]” and “Try to imagine an event that might happen to you [specified time period]”. In each condition, participants were asked to try to remember/imagine events (a) a month into the past/future, (b) 5 years into the past/future, and (c) 10 years into the past/future. There were no demands as to the theme of the event representations, only that they should be clear and vivid to the participant. If the participants did not spontaneously recollect (or imagine) an event, general prompts were provided (i.e. ”do you remember an important event?”, ”do you remember a special day?” or ”what is the most important event, that has happened within the last month?”) to give more details or to be more specific if they had recalled (or imagined) a generic event. After three prompting attempts, the experimenter switched to another cue-condition.

Participant ratings of the remembered/imagined event. Following the description of each event, participants were asked to rate the subjective experience associated with remembering/imagining the event, by responding to the following items on 7-point scales, adapted from the Autobiographical Memory Questionnaire (AMQ, Rubin, Schrauf & Greenberg, 2003). Memories and future events representations were rated for sense of re-/pre-experiencing (i.e. while remembering/imagining the event, I feel as though I am relieving/experiencing it: 1 = not at all, 7 = as clearly as if it was happening right now) and sense of travelling in time (i.e. while remembering/imagining the event, I feel that I travel back/forward to the time when it happened/would happen: 1 = not at all, 7 = completely).

Procedure

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Each participant was tested individually in a quiet environment. Control participants completed all tasks in one experimental session. For TBI patients, all data were obtained in 2-3 experimental sessions, completed on 2-3 consecutive days. The first session consisted of the memory/future thinking tasks and self-ratings of the remembering/imagining experience. Participants were then administered the DART. The other session(s) for TBI patients consisted of a number of neuropsychological tests, administered and scored in accordance with Danish standardized instructions and norms. All responses provided in the memory/future thinking task were audio recorded and then transcribed for scoring.

Scoring of content. Consistent with previous studies of memory and future thinking, the qualities of past and future event descriptions were estimated using a standardized scoring procedure developed by Levine et al. (2002). Participants' event descriptions were segmented into informational bits or details, i.e. unique occurrences, observations or thoughts (typically expressed as grammatical clauses defined by a subject and predicate, such as "I dropped my sandwich"). Details were classified as either internal or external; internal details were those that pertained directly to the main event described, were specific to time and place, and were considered to reflect episodic re- or pre- experiencing, and external details being those that pertained to extraneous information that did require recollection of a specific time or place and was not uniquely specific to the main event. Internal details were further separated into five mutually exclusive subcategories: (a) event (i.e. happenings, people present, actions and weather conditions), (b) time (date, season, time of day), (c) place (information on where the event occurred), (d) perceptual (sensory information) and (e) thought/emotion related to the event. External details were also subdivided into: (a) event (specific details from all of the above categories external to the main event), (b) semantic (general knowledge or facts, ongoing events or extended states of being), (c) repetitions (unsolicited repetitions of details) and (d) other (meta-cognitive statements, editorializing).

The event descriptions were scored by two trained raters, who were blind to the diagnoses of the participants and the hypothesis of the study. The two raters practiced the scoring system on the first 36 transcribed responses and any discrepancy was discussed until consensus was reached. They then scored the remaining 72 representations independently of one another. The inter-rater reliability (*r*) for composite scores was .98 and .95 for internal and external details, respectively. After scoring, cases of disagreement between the two raters were solved through discussion. The ratio of internal-to-total details indicated the proportion of details per memory or future thought that reflected episodic re-experiencing or pre-experiencing unbiased by the total verbal output.

Moreover a 4-point scale for *fluency* was generated by conversely adding up the number of prompts needed for the participant to generate a representation. Thus, a score of 4 were given if the participant recalled/imagined an event spontaneously with no prompts provided. A score of 3 were given if one prompt were needed to generate an event, while provision of two prompts to generate an event scored 2 and provision of three prompts to generate an event scored 1, respectively. If the participant failed to remember/imagine an event after 3 prompts were provided it received a score of 0.

Degree of re-/pre-experiencing the event and degree of travelling in time was rated by the participants on a scale of 1 to 7 for each event description, respectively.

Results

Results concerning group differences in the qualities of autobiographical remembering/future thinking (i.e. in the number of internal and external details, and the ratio of internal-to-total details) will be reported first. Then, group differences in autobiographical fluency will be examined. Finally results regarding group differences in the phenomenological characteristics will be reported. The key findings are illustrated by Figures 1 and 2.

Group Differences in Number of internal and external details

A 2 (Group: TBI vs. controls) × 2 (Details: internal vs. external) × 2 (Temporal Direction) mixed analysis of variance (ANOVA) with Group as a between-subject factor, and Details and Temporal Direction as within-subjects factors, was conducted on the mean number of details produced by TBI patients and controls (see Fig. 1). Results showed a main effect of group that bordered significance $F(1, 16) = 4.451$, p=.051 indicating, that overall patients generally produced fewer details (M=8.87; SD = 4.24), than controls (M = 13.75; SD = 5.49).

The main effect of Details, $F(1, 16) = 50.954$, $\eta^2_p = .76$, $p < .0001$ was significant, indicating that overall, participants produced more internal (M = 15.77; SD = 9.01) than external details (M = 6.85; SD = 4.09). The interaction between Group and Details was significant, $F(1, 16) = 32.324$, $\eta^2_p = .67$, $p < .0001$, showing that controls produced more internal details (M = 21.76; SD = 8.30) than TBI patients (M = 9.78; SD = 4.77), $t(16) = -3.76$, $p < .01$, whereas patients (M = 7.96; SD = 4.41) and controls (M = 5.74; SD = 3.65) produced an equivalent number of external details, $t(16) = 1.16$, $p = .26$. The main effect of Temporal Direction was significant, $F(1, 16) = 21.155$, $\eta^2_p = .57$, $p < .0001$, participants produced more details for past events (M = 14.40; SD =7.92) than for future events (M = 8.22; SD = 3.65). Finally the interaction between Details and Temporal Direction was also significant $F(1, 16) = 19.941$, $\eta^2_p = .56$, $p < .0001$, indicating that more internal details were produced for past (M = 21.65; SD = 13.61) than for future events (M = 9.89; SD = 6.02), $t(17) = 4.58$, $p < .0001$, whereas no difference were found between the number of external details produced for past (M = 7.15; SD = 4.99) and future events (M = 6.56; SD = 3.79), $t(17) = 0.74$, $p = .47$.

To examine the relationship between memory and future thinking narrative performance correlations between internal and external details for past and future events were computed across all participants. In line with previous findings reported by Addis et al. (2008; 2009) and Gamboz et al. (2010) we found a strong correlation between past and future internal details ($r = .63$, $p < .01$) and past and future external details ($r = .73$, $p < .001$). In contrast, past internal and external details were uncorrelated ($r = .30$, $p = .23$) as were future internal and external details ($r = .06$, $p = .82$). The positive correlations between internal and external details for past and future events have been accounted for as evidence for the close overlap between the specificity of past and future events (Addis et al, 2008). However, it should be kept in mind that these correlations are boosted by the large differences between the TBI and control group, and therefore should be interpreted with caution.

Group Differences in Internal-to-total detail ratios

In order to take into account the fact that patients produced fewer details overall and to examine the effect of temporal distance to the remembered/imagined event together with the other factors, we looked at the ratio of internal-to-total details. The ratios were analyzed by means of a 2 (Group: TBI vs. controls) × 2 (Temporal Direction: past vs. future) × 3 (Temporal Distance: 1 month, 5 years, or 10 years) mixed-factor analyses of variance (ANOVA) with Group as a between-subject factor, and Temporal Direction and Temporal Distance as within-subjects factors. As illustrated by Figure 2, a significant main effect of Group was found, $F(1, 16) = 58.18$, $\eta^2_p = .78$, $p < .0001$, together with a significant effect of Temporal Direction, $F(1, 16) = 15.34$, $\eta^2_p = .49$, $p < .001$, and Temporal Distance $F(1, 16) = 12.18$, $\eta^2_p = .43$, $p < .0001$. The main effect of Group reflected, that the TBI participants proportionally reported fewer episodic event-specific details for both past and future events compared to healthy controls across all time periods. The main effect of Temporal Direction indicated that proportionally more episodic event-specific details were produced for past events than for future events. The main effect of Temporal Distance reflected that events closer in time contained a greater proportion of episodic event-specific details than distant events. Importantly, the Temporal Distance × Group interaction was significant. The results of a repeated measures ANOVA performed on each group separately, showed the Temporal Distance effect was significant only for the TBI participants, $F(2, 16) = 10.66$, $\eta^2_p = .57$, $p < .001$, but not for the controls $F(2, 16) = 2.00$, $p = .17$, reflecting that TBI patients produced proportionally fewer episodic, event-specific details for past and future events the further the events were located away from the present.

In sum, this series of analyses showed that TBI patients' representations contained relatively fewer episodic, event-specific details than the ones of the controls, even when controlling for the total number of details. Moreover, while the TBI patients reported proportionally fewer internal details than did the healthy controls, this trend was not symmetrical. Patients performed significantly worse when having to remember or imagine events in the distant past or future, producing proportionally fewer episodic, event-specific details, and relying to a higher degree on semantic information.

Autobiographical fluency scores

The performances of the TBI participants and normal controls respectively on autobiographical fluency according to the time period tested were assessed by a repeated measures ANOVA, which revealed a significant effect of Group $F(1, 16) = 21.57$, $\eta^2_p = .57$, $p < .0001$, reflecting the TBI participants being less fluent than the controls, but no significant effect of Temporal Direction $F(1, 16) = 0.69$ or Temporal Distance $F(1, 16) = 1.48$. Post hoc tests showed that the TBI participants were less spontaneous in generating past and future event representations compared to controls independently of the temporal direction and time period tested.

Participant ratings of the phenomenal characteristics

Participants' reported levels of their subjective sense of re-/pre-experience and their subjective sense of mental time travel showed a different pattern than the objective ratings.

Separate 2 (Group: TBI vs. controls) × 2 (Temporal Direction: past vs. future) × 3 (Temporal Distance: 1 month, 5 years, or 10 years) mixed-factor analyses of variance (ANOVA) were carried out for each phenomenal characteristic. Concerning the subjective feeling of re-/pre-experience associated with remembering/imagining, no group difference was seen, $F(1, 16) = 0.04$. For both groups, sense of re-/pre-experience of the event were affected by Temporal Direction $F(1, 16) = 7.82$, $\eta^2_p = .38$, $p < .05$ and Temporal Distance $F(1, 16) = 7.19$, $\eta^2_p = .36$, $p < .01$, with higher ratings in the past condition than the future condition, and in memories/future thoughts closest to the present. With respect to ratings of sense of mental time travel, no effect of Group was seen, $F(1, 16) = 1.49$. Feeling of travelling in time was affected by Temporal Direction $F(1, 16) = 6.32$, $\eta^2_p = .33$, $p < .05$ with higher ratings in the past condition than the future condition independent of the Temporal Distance to the present, $F(1, 16) = 0.69$. The fact that no difference was found between the ratings of the controls and TBI patients in contrast to the marked differences seen on the objective measures of episodic details suggests that the subjective ratings of the patients may have been unrealistically high.

Discussion

This study was conducted to begin to fill in an important gab in the literature by investigating whether TBI patient exhibit impairments in the ability to engage in episodic future thinking. If episodic future thinking relies on the same processes and structures as remembering past events, as commonly proposed (e.g., D'Argembeau & Van der Linden, 2004; Okuda et al., 2003; Schacter & Addis, 2007), then it would follow that damage that impairs episodic memory should also impair the ability to imagine events in the future. In line with our predictions, TBI patients recalled and imagined significantly fewer episodic, event-specific details compared to healthy controls, reflecting impaired episodic memory as well as impaired episodic future thinking. In contrast, semantic details were unimpaired in TBI patients' simulation of past and future events. Although there were significant between-group differences in performance for all time periods, the TBI patients were significantly worse at producing internal, relative to external, details for distant events, regardless of temporal direction. Both groups produced more internal details for past than for future events, whereas the number of external details was the same, independent of temporal direction. The striking similarity between the pattern of performances on the past and future events tasks (decline in internal details, not decline in semantic details) and the strong correspondence across performance on the tasks, including the positive correlations between the past and the future internal (. 63) and external (.73) scores, replicate the pattern of correlations between past and future internal and external scores previously reported in young and older adults (Addis et al., 2008), mild Alzheimer's disease (Addis et al., 2009) and in people with mild cognitive impairment (Gamboz et al., 2010). This correspondence across past and future is consistent with the idea that common core mechanisms support both episodic memory and episodic future thinking (Schacter & Addis, 2007; Schacter et al., 2007; Hassabis & Maguire, 2009).

Contrary to predictions however, there were no significant differences between TBI patients and controls on the subjective measures of episodic memory and episodic future thinking, derived from the AMQ. Thus, the TBI participants did not report a diminished sense of re-/pre experience or a diminished sense of traveling in time during remembering and imagining, which was in clear contradiction with the objective content-derived scores. The absence of differences for the subjective measures should be interpreted with caution in light of the small number of observations in this study; the power may simply have been too low to detect such differences. However, the finding is in line with existing literature showing that self-report measures may be less reliable in TBI patients. For example, it has been found that individuals with TBI tend to underreport the severity of their deficits, this being especially so for cognitive deficits (Sherer et al., 1998) and to show diminished awareness of their mental state (Henry, Phillips, Crawford, Theodorou & Summers, 2006). One possible consequence of the diminished self-awareness and/or reduced introspective abilities of the TBI patients may be that their ratings on the two AMQ questions do not adequately reflect their actual subjective experience during remembering and imagining. This may provide an explanation of the seemingly contradictory findings between the objective content measures and the subjective ratings. It has previously been shown that patients with hippocampal damage are unable to accurately evaluate their memory and future thinking performances, in that the patients' subjective ratings of vividness were either not consistent with objective scores of vividness on the autobiographical interview (Kwan et al., 2010) or even negatively correlated (Addis, Moscovitch & McAndrews, 2007).

What caused the TBI patients' poor performance to the present tasks?

The specific cognitive deficits that may have contributed to the TBI patients' poor performance on the episodic memory and episodic future thinking task call for further discussion. Obviously, executive dysfunction may be at least partly responsible for TBI participants recalling and imagining less specific events compared to healthy controls. In accordance with our predictions, the TBI participants scored below the norm on a number of executive measures, including phonemic and semantic fluency tasks, indicating difficulties with strategically accessing stored information. This explanation is in line with models of autobiographical memory, where memories and, by extension, future thoughts are mental constructions generated from an autobiographical knowledge base organized at different levels of specificity (e.g. lifetime periods, general events, sensory perceptual details of particular events) (Conway & Pleydell-Pearce, 2000). Episodic recollection and episodic future thinking emerge when sensory-perceptual details are accessed on the basis of search descriptions generated from personal semantic knowledge. Such search and construction processes are mediated by executive functions, including strategic, elaborative and evaluative processes. Following this view, the TBI patients may have employed ineffective search strategies, which might have resulted in retrieval processes being stopped at an earlier stage of the construction of specific events. This explanation is also consistent with the observed interaction between temporal distance and group, given that the construction of temporally distant events may be a cognitively more demanding process. This is in accordance with temporal construal theory (Trope & Liberman, 2003), according to which representations of temporally distant events are more abstract and schema based than are representations of temporally close events, and evidence that temporally distant events are less accessible than events closer in time (Spreng & Levine, 2006). Thus, one possible explanation for the interaction between temporal distance and group may be that the construction of temporally distant specific events puts higher demands on executive processing than the construction of specific events closer in time.

A relationship between reduced event specificity and executive dysfunction has previously been suggested in patients suffering from depression (Williams et al., 1996). More recently, Berryhill, Picasso, Arnold, Drowos and Olson (2010) reported on five patients with unilateral prefrontal lesions, who presented spared autobiographical memory, but moderate deficits on future event construction. The prefrontal patients were included as a control group, specifically selected on the basis of their lesions not affecting the vmPFC or other areas known to be involved in autobiographical memory. The authors suggested that the selective impairment in future thinking after lesions to the ventrolateral and dorsal PFC may be attributed to the involvement of these areas in accessing and selecting elements from long-term memory for working memory manipulation. Similarly, de Vito and colleagues (2012) reported that patients with Parkinson Disease showed impairment relative to controls on the amount of episodic details generated for future events, but not for remembered or fictitious events. These patients presented problems on executive control, while having no difficulties on traditional memory tasks. In both of these studies, problems were limited to future events. This is not the case in our own study; however our patients presented more severe executive dysfunction, which might explain why both memory and future thinking were affected.

In addition to executive dysfunction, goals and motivations held by the self are thought to influence the construction of memories and future thoughts (Conway & Pleydell-Pearce, 2000). Thus, the common behavioral change, such as diminished motivation, apathy and distractibility that occur after TBI may have contributed to impaired episodic memory and future thinking (Piolino et al., 2007). It is also possible that deficits in hippocampal functioning in the TBI patients played a role. There is indeed evidence that the hippocampus plays a critical role in scene construction (Hassabis et al., 2007) and hippocampal atrophy is a well-documented consequence of TBI (Ariza et al. 2006; Hopkins, Tate & Bigler, 2005; Tate & Bigler, 2000; Tomaiuolo et al., 2004). In the present study, the TBI patients' scores on the relational memory task (VPA from WMS) were within the normal range. Nonetheless, there were big differences within the group, with two patients scoring two standard deviations below the norm. Individual variability on the relative contribution of executive versus relational memory deficits to the TBI patients' impaired episodic future thinking is therefore likely.

Finally, another possible interpretation of the present finding is that some of the reported group differences in performances are due to different narrative styles. Recent findings have indicated that deficits in narrative construction may underline future thinking impairments in older adults (Gaesser, Sacchetti, Addis & Schacter, 2011). This raises the possibility that TBI patients pose a more general inability to integrate information in working memory during narrative construction, regardless of the actual quality of the representations themselves. In the present study, the TBI patients tended to produce fewer details overall, although this difference was not significant. Importantly, however, the TBI patients and

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controls did not differ on the number of external details generated, only on the number of internal details, indicating that impairments were not merely an effect of impaired verbal production in general. However, since we did not include a non-temporal description task in our study, we cannot rule out the possibility of a more global deficit in the ability to produce specific descriptions underlying our results. Measures of performance on non-temporal description tasks were included in two recent studies of future thinking in patients with medial temporal lobe damage (Race et al., 2011) and Parkinson's disease (deVito et al., 2012). Both reported that deficits in future thinking could not be accounted for by narrative construction performances.

In the current study, patients were required to construct specific events; however, outside of being plausible and lasting less than a day, there were no demands as to the content of these events. This raises the possibility that participants were able to construct simulations based on well-established scripts in semantic memory or more generalized memory for routine events, which do not place demands on episodic memory (Maguire, Vargha-Khadem, & Hassabis, 2010; Cooper, Vargha-Khadem, Gadian, & Maguire, 2011). In line with this suggestion, Race et al. (2011) reported that amnesic patients generated a greater number of details, when imagining more frequent and scripted events (a birthday celebration) than less frequent events (winning the lottery), although future thinking was impaired for both types of future event construction. These results suggest that, if the TBI patients in the present study indeed relied on semantic memory when having to construct future events, this should have improved their performance relative to what would have been observed under conditions controlling for this option. Thus, in the latter case, their deficits would have been even more pronounced than what we observed here.

In short, the specific cognitive and neural deficits that may contribute to the reported difficulties in episodic memory and episodic future thinking in TBI patients include reduced executive functioning, motivational problems, problem with constructing a narrative, and problems with drawing upon relevant schematic/semantic knowledge. The relative contributions of these different factors cannot be decided based on the present findings and warrant further investigations.

Limitations of the present study

The present study holds two main limitations, which should be taken into account when interpreting the findings. Because of the small sample size, conclusions should be drawn only tentatively, and specifically null findings should be interpreted with caution.

A second limitation of the study concerns the relatively short time span between the time of the injury and the memory assessment of the TBI participants (between 39-117 days after the injury). It is likely that the performance of the TBI patients would have improved with the passage of time due to spontaneous recovery. Studies of episodic memory problems in individuals with TBI however, have found these problems to be persistent four and five years after the trauma (Piolino et al., 2007).

Conclusion

In summary, our study shows that patients with TBI exhibit impaired episodic memory as well as impaired episodic future thinking. The TBI patients presented even more pronounced difficulties in episodic event representations, when having to recall or imagine events further back or forth in time, indicating that mental time travel into the distant past or future is a cognitively more demanding process. In our study it seems likely that impaired executive functioning at least partly underlies the deficits in the ability to remember specific past events and imagine specific future events.

Our finding that TBI patients show deficits regarding episodic future thinking may have several clinical implications. For example, difficulties with elaborating and maintaining a specific and detailed representations of future rewarding experiences could decrease

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anticipatory pleasure, thus leading to motivational deficits in pursuing personal goals. Also an impaired ability to simulate alternative plans of actions could severely disrupt adequate problem solving thus resulting in more inflexible and stimulus bound actions.

Thus, one possible consequence of the observed impairment of episodic memory and episodic future thinking in TBI patients may be diminished temporally extended self-awareness. The ability to become aware of past and possible future states of oneself is thought to ensure continuity and a sense of self through time. Disorders of episodic memory and episodic future thinking might at least in part explain the impaired awareness of deficits, which is a frequent consequence of TBI (McGlynn & Schacter, 1989) and which represents one of the biggest challenges in the rehabilitation process (Prigatano, 1999, 2005).

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Table 1

Demographic Data and Mean Summary Data for the Traumatic Brain Injury and Control Groups

	TBI (n=9)			Control (n=9)			Normative data	
Test variable	M	SD	Range	M	SD	Range	M	SD
Demographics								
Age	38.4	17.3	17-69	30.7	12.3	20-52		
Schooling(in years)	10.11	0.93	9-12	12.00	0.00	12-12		
Estimated premobid IQ DART[a]	22.63	8.96	13-36	26.56	5.03	21-35	24.96	7.12
Attention/speeded processing								
Digit span forward[a]	9.78	1.92					10.91	2.02
Digit span backward[a]	6.44	1.67					8.43	2.22
Trail Making A[b]	39.44*	10.55					28.54	10.09
Verbal memory								
WMS-III VPA I[c]	7.67	3.39					10	3
WMS-III VPA II[c]	8.33	3.57					10	3
Executive functioning								
Trail Making B[b]	96.33*	27.18					58.46	16.41
Semantic fluency[a]	20.78*	3.60					26.71	4.98
Phonemic fluency[a]	9.56*	4.90					16.31	5.58
Stroop (inhibition)[d]	55.67	7.30					50	10
mWCST (category)[e]	5.67	1.32					5.54	1.17
mWCST (perseveration)[e]	2.11*	2.58					0.5	0.86
Zoo Map Test[f]	1.78	1.64					2.8	1.08

Note. Mean scores are raw scores. Normative data from [a] Danish standard material S-94 (Mortensen, Nielsen & Rune, 1994), [b] Tombaugh (2004), [c] Wechsler (1997), [d] Golden & Freshwater (1998), [e] Gade & Mortensen (unpublished) and [f] Wilson et al. (1996).

*TBI patient group performance below the normal range according to normative data

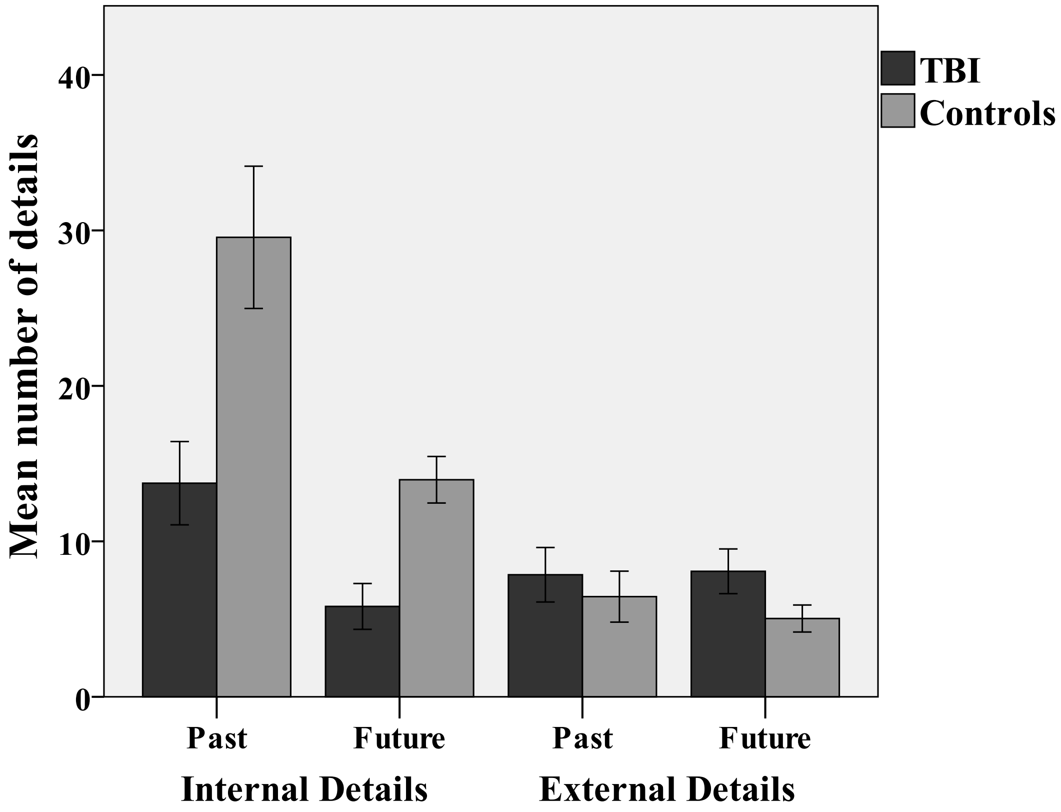

Figure 1. Mean number of internal and external details per event generated for past and future events by TBI patients and controls. Error bars are standard errors of the mean.

This is the accepted version of the following article: Rasmussen, K. W. & Berntsen, D. (2014), Autobiographical memory and episodic future thinking after moderate to severe traumatic brain injury, Journal of Neuropsychology, 8, 34-52, DOI: 10.1111/jnp.12003, which has been published in final form at https://dx.doi.org/10.1111/jnp.12003.

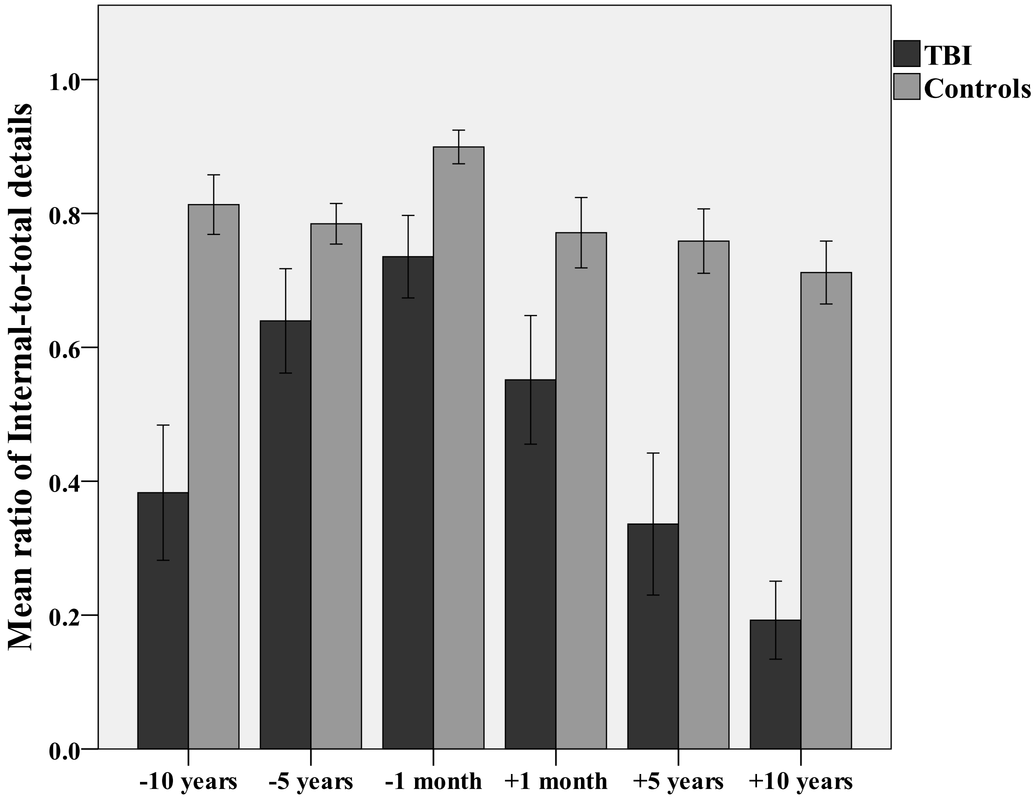

Figure 2. Mean ratio of internal-to-total details per event generated for past and future events by TBI patients and controls. Error bars are standard errors of the mean.