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RESEARCH ARTICLE

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Prospective memory functions in traumatic brain injury: The role of neuropsychological deficits, metamemory and impaired self-awareness

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Abstract

A large body of evidence suggests that individuals with traumatic brain injury (TBI) have significant difficulties with prospective memory (PM), the memory for future intentions. However, the processes underlying this cognitive deficit remain unclear. This study aimed to gather further evidence regarding PM functions in TBI and clarify the role of neuropsychological deficits, metamemory, and mood disorders. We used a laboratory-based clinical measure, the Virtual Week, to examine PM function in 18 patients with TBI and 18 healthy control subjects. Measures of attention, processing speed, executive functions, episodic memory, and self-report questionnaires were also administered. In line with prior literature, our findings indicate that individuals with TBI had a consistent deficit compared to controls across all PM tasks. In previous studies, TBI patients had more severe impairment on time-based tasks; nevertheless, our results show that across all participants event-based tasks were easier to perform compared to time-based only when the retrospective memory demand was high. The patients were not only impaired on the prospective component of PM but also failed to recognise the content of their task (the retrospective component). Interestingly, the TBI group did not report higher levels of everyday memory problems, anxiety and depression compared to the control group. These measures also failed to correlate with PM and recognition memory performance. This study found that besides the neuropsychological deficits, a global impairment in PM

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functioning is present in individuals with TBI across various task types, tasks low and high in retrospective demands, and event versus time-based.

KEYWORDS
intention maintenance, prospective memory, self-awareness, traumatic brain injury, virtual week

INTRODUCTION

Remembering to buy bread on the way home, delivering a message to a colleague when we meet them, or going to a dentist appointment at 4p.m. are examples of everyday tasks that are essential both in our private and professional lives and considered prospective remembering. Prospective memory (PM) is a complex neurocognitive ability that allows us to encode, maintain and retrieve future-oriented intentions at the appropriate time and context (Einstein & McDaniel, 1996). The execution of future intentions is prompted by cues based on which we distinguish between event-based and time-based PM tasks. In the case of event-based PM, the intended action is performed when a specific event occurs, while in time-based PM tasks, the intention is carried out at a particular time or after a certain amount of time has passed (Einstein & McDaniel, 1996). Time-based tasks are considered more challenging to perform because they require self-initiated strategic monitoring of time, as opposed to event-based tasks, where an external cue supports the automatic retrieval of the intended action (Henry, 2021).

All PM tasks contain a prospective and a retrospective component. The prospective component allows us to remember the intention to carry out an action at the appropriate moment, while the retrospective component allows recalling the specific contents and remembering that it has already been performed (Einstein & McDaniel, 1990). Poor PM function may be explained by an impairment of these components together or separately.

Neuroimaging and lesion studies have confirmed the critical role of the anterior prefrontal area and the frontoparietal networks in PM functioning (Cona et al., 2015), and several studies indicate that the medial temporal lobe (e.g., Nurdal et al., 2020) and the thalamus (e.g., Cona et al., 2019) are also involved in the retention and execution of intended actions. Not surprisingly, research on PM has become the focus of interest in neurological disorders in which these structures and their connections are affected (for a review, see Kliegel et al., 2012). The assessment of PM is fundamental after brain injuries due to its relevance to clinical decision-making. As Henry (2021) argues: "PM failures are powerful predictors of functional outcomes: they cause more deficits in activities of daily living and caregiver burden than retrospective memory failures, with direct implications for patient management and rehabilitation" (p. 1).

A considerable number of empirical studies and reviews have addressed the general problem of PM dysfunction after traumatic brain injury (Wong Gonzalez & Buchanan, 2019). Traumatic brain injury (TBI) is considered one of the most heterogeneous neurological disorders: there are significant individual differences in the injury characteristics (e.g., the site and severity of injury) as well as the physical and cognitive symptoms (Covington & Duff, 2021). The most common causes of TBI are road traffic accidents, falls, assault/violence, and sport-related injuries (Tagliaferri et al., 2006), resulting in diffuse or focal damage, most commonly to the frontal and temporal lobes (Dikmen et al., 2009). Since successful PM performance relies on the functional integrity of the aforementioned neural systems, PM dysfunction in TBI is not surprising. It has been suggested that individuals with even mild but more commonly with moderate-to-severe TBI have frequent PM deficits (for a review, see Raskin et al., 2018), and this impairment is prevalent in the acute phase (e.g., Kinsella et al., 2009) and the chronic phase (e.g., Knight et al., 2005) of TBI. A recent meta-analysis showed that TBI patients' PM performance is approximately one standard deviation below healthy individuals', and that time-based, non-salient cues and complex ongoing tasks contribute to a greater difference in PM between patients and healthy

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controls (Wong Gonzalez & Buchanan, 2019). A much-debated question is whether prospective and retrospective components are impaired to the same extent after TBI. In some studies, a global PM deficit was found in both components (e.g., Palermo et al., 2020), while in other studies, the patients showed a reduced performance only in the prospective component (e.g., Henry et al., 2007).

The successful execution of an intended action may rely on numerous cognitive functions that are affected after head trauma. Around 65% of patients with moderate-to-severe injuries experience long-term cognitive deficits: the most affected domains are attention, working memory, processing speed, episodic memory, language, visuospatial processing, and executive functions (EFs) (Dikmen et al., 2009). The cognitive outcome may be influenced by the heterogeneity of TBI pathology and patient characteristics (Rabinowitz & Levin, 2014), which, in part, explains why previously published studies on the effect of cognitive deficits underlying PM performance after TBI are inconsistent. Most of these empirical studies focused on executive dysfunction and disturbances in retrospective episodic memory as a result of frontal or medial temporal lobe injuries. Importantly, both processes can lead to reduced PM, and the pattern of performance can be predicted based on the underlying cognitive deficit and the phases of prospective remembering (Henry, 2021).

With respect to the contribution of retrospective memory and EFs to PM functions, previous research has found contradictory results. In some cases, there was a clear association between retrospective memory and PM (e.g., Potvin et al., 2011) and EFs and PM (e.g., Palermo et al., 2020) in the TBI group, while other studies failed to detect a significant relationship (e.g., Mathias & Mansfield, 2005). In the case of EFs, the contradictory results may be explained by task characteristics, as EFs contribute to PM to a greater extent when resource-demanding, self-initiated retrieval is needed, e.g., in the case of time-based tasks (Fish et al., 2007).

The assessment of metamemory is a crucial element in neuropsychological rehabilitation after TBI because compensatory strategies are based on the self-awareness of one's own memory deficits (O'Brien & Kennedy, 2018). A growing body of literature suggests that patients have impaired awareness of their cognitive deficits, which can be explained by the injury characteristics as well as a psychological defence mechanism (Roche et al., 2002). However, results regarding prospective metamemory in this population are contradictory. When performance-based and self-report PM are compared, TBI patients' metamemory poorly correlates with their performance on different PM tasks (Fleming et al., 2008). When compared to a healthy control group on self-report measures, Roche et al. (2002) found that TBI patients tend to underestimate the frequency of their everyday PM difficulties. However, some studies reported more prospective and retrospective memory problems in individuals with TBI in comparison to controls (Pavawalla et al., 2012).

Despite extensive research on the nature of PM deficit following TBI, there are still many unanswered questions. We aimed to objectively clarify the impairment of the prospective and retrospective components of PM and additionally, explore the role of neuropsychological deficits and metamemory in the PM functioning of patients with TBI using experimental measures and questionnaires. We assessed PM with a clinically oriented computerised measure, the Virtual Week (Rendell & Henry, 2009), in a case–control study. It has been demonstrated that Virtual Week is sensitive to PM impairment in this clinical group: compared to healthy controls, TBI patients' PM performance was less accurate on all types of tasks. The cue had a significant effect on the patients' PM performance: they had more pronounced impairment on time-based tasks than event-based tasks. Interestingly, the patients' PM performance did not differ between regular and irregular tasks when no strategy was used (Mioni et al., 2013). However, when future event simulation was applied in the encoding phase, the TBI group performed better on regular tasks compared to irregular tasks (Mioni et al., 2017). The latter research has also shown that the recognition of the PM task content (the retrospective component) may be intact to some extent in this clinical population: their results indicate that when PM tasks were regular and event-based, TBI patients' recognition performance was comparable to the control group.

Even though the PM performance of this patient group has already been studied with the Virtual Week, in previous studies with this PM task, subjects were tested several years post-injury, in the chronic phase of TBI (the mean time post-injury was 67 months in Mioni et al., 2013; 84 months in Mioni et al., 2015; and

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TABLE 1 Demographic and clinical characteristics of the participants with traumatic brain injury ($N = 18$).

Patient code	Gender	Age	Education (years)	Cause	TPI (months)	Injury site	Initial GCS	FIM on admission/discharge
1	M	41	20	Road accident	3	Parietal, cerebellar	4	115/126
2	F	23	12	Assault	17	Cerebellar, basal ganglia	15	126/126
3	M	18	12	Road accident	1.5	Temporal	5	92/119
4	F	28	13	Road accident	10	Diffuse	5	104/122
5	F	25	13	Road accident	3	Diffuse	3	81/119
6	F	37	12	Road accident	4.5	Diffuse	10	96/119
7	M	39	12	Road accident	7.5	Diffuse	3	87/117
8	M	34	8	Road accident	3	Temporal, parieto-occipital	6	53/112
9	M	21	14	Road accident	1.5	Frontotemporal	9	98/117
10	M	45	16	Road accident	4	Frontal	4	22/114
11	M	44	12	Assault	3	Frontoparietal	15	95/124
12	M	48	16	Road accident	5	Diffuse	7	35/126
13	M	40	10	Road accident	11	Diffuse	3	110/126
14	M	43	11	Fall	3	Diffuse	15	83/123
15	M	27	19	Road accident	2	Frontotemporal	3	48/126
16	M	43	12	Road accident	1.5	Temporal	8	95/118
17	M	62	15	Fall	3	Frontal	6	34/110
18	M	31	8	Road accident	4	Parietal	3	18/56

Abbreviations: F, female; FIM, functional independence measure; GCS, Glasgow Coma Scale; M, male; NA, no data available; TPI, time post-injury.

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60 months in Mioni et al., 2017). While impairment on the Virtual Week in chronic TBI is well-documented, no single study exists that has examined this question in persons with recent TBI. Since neuropsychological rehabilitation in TBI begins right after patients emerge from post-traumatic amnesia (PTA), the assessment and management of PM dysfunction in this early, acute phase of TBI is of fundamental importance. If a decreased memory for future intentions is detected in this early stage, cognitive interventions targeting PM functions can be started even before patients leave the rehabilitation unit.

The present research, therefore, was designed to gather further evidence regarding PM in TBI. Unlike previous research with the Virtual Week, the novelty of our study is that participants in the TBI group were tested in the acute phase, soon after their injury, while they were still inpatient in a rehabilitation unit. In addition to the prospective component of PM, our study also focused on the retrospective component, as previous research with the Virtual Week investigated the recognition accuracy only when different encoding strategies were embedded in this task (Mioni et al., 2017). Since there is no empirical data regarding the processes underlying the retrospective component on the Virtual Week in TBI, the present research explores, for the first time, the possible relationship between recognition accuracy and factors such as neuropsychological deficits and metamemory. Furthermore, little attention has been paid to the role of clinical and neuropsychological correlates of PM performance in TBI with this measure. Mioni et al. (2013) revealed a significant correlation between PM accuracy, the level of cognitive functioning and recovery after trauma, and they also found a relationship between time-based PM and semantic fluency. However, further research assessing the possible influence of decreased attentional resources, retrospective memory, and other aspects of EFs on PM performance would provide a deeper insight into PM dysfunction in this patient group.

It was predicted that compared to healthy controls, the overall PM performance of the TBI group would be significantly lower, with more severe impairment on time-based tasks. Individuals with TBI were also expected to perform below the control group on the recognition of the task content in the case of irregular and time-based tasks. Regarding the neuropsychological background tests, we expected that patients with TBI would show significant deficits on the tests of attention, processing speed, episodic memory and EFs.

MATERIALS AND METHODS

Participants

Eighteen patients with TBI and 18 healthy control participants were included in the study. Criteria for inclusion in the patient group were (1) a diagnosis of TBI, (2) after PTA, (3) age between 18 and 65 years, (4) literate in Hungarian. We excluded patients from the experimental sample if they had a history of any other neurological disease, psychiatric condition, or severe language, motor, or attentional deficits that render them unable to attend the experimental sessions. Participants in the TBI group were inpatients in a rehabilitation centre and they were selected by the departmental neuropsychologist and the chief physician, who screened their medical records about injury characteristics. Table 1 shows the demographic and clinical features of the patient sample.

Participants in the healthy control group were matched to the patients in age, gender, and education. The patient group and the control group did not differ with regard to age (TBI $M = 36.10$, SD = 11.19; healthy controls $M = 36.11$, SD = 10.27; $t(34) = .02$, $p = .988$, $d < .01$), years of education (TBI $M = 13.03$, SD = 3.17; healthy controls $M = 13.72$, SD = 2.47; $t(34) = .73$, $p = .469$, $d = .24$) and the proportion of males and females (both groups consisted of 14 males and four females). All participants provided informed written consent before the experiment.

Procedure

Virtual Week (Rendell & Henry, 2009) is a computer-based naturalistic PM measure that simulates daily activities in a board game format. The modified version of the Virtual Week used in this study operates with three virtual days and a trial day.[1] Each virtual day consists of 8 PM tasks: two regular event-based, two regular time-based, two irregular event-based and two irregular time-based tasks. Regular PM tasks simulate routine tasks, and they involve performing the same task on each virtual day. The participants read about these tasks and learn them to a criterion before starting the first virtual day and are not reminded of them before the second and third days. Irregular tasks simulate occasional tasks that are specific to each virtual day. As several previous papers on Virtual Week have noted, this regular-irregular distinction does not necessarily capture the distinction between habitual and occasional tasks, as regular tasks are not repeated enough to become a real habit (Foster et al., 2013). The key distinction between these tasks is rather that they require low and high demands on the retrospective component of the PM task. The retrospective memory demand is reduced for regular compared to irregular tasks (for a more detailed explanation of this distinction, see Mioni et al., 2013).

The latest version of Virtual Week allows for examining the recognition of the PM task content. Following each virtual day, participants are presented with a list of different activities, and they have to match the content of their intention with its cue. In this Task Check part, all 8 PM tasks of that day and four distractor tasks appear, and they have to be matched with eight targets (events and times) or a label saying 'Not required'.

The original version of Virtual Week is characterised by strong psychometric properties; and has proven to be a reliable and sensitive measure of PM deficit in different clinical populations (Henry, 2021). A major advantage of Virtual Week is its complexity: it operates with multiple task parameters (time-based, event-based, regular, irregular), and it provides detailed data on errors. It has been widely used and translated into different languages (e.g., Niedźwieńska et al., 2016). To our knowledge, our study is the first to use this task with a Hungarian sample.

In the Hungarian version of the Virtual Week, the structure and logic of the task remained the same as in the original. During the translation process, we maintained the same length of sentences for the instructions, the Event Cards and the Task Cards. Some minor changes were made in the content to eliminate cultural differences between the Australian and the Hungarian populations. We replaced the first names of the characters that appear in the Australian game (e.g., Kate, David) with their Hungarian equivalents (e.g., Kata, Dávid). In the original version, Event Cards describing meals proposed some response options such as "peanut butter," "stir-fried noodles", and "banana split." As these dishes are not typical for Hungarians, they were changed by more familiar food options such as liver pâté, macaroni Milanaise and cottage cheese cheesecake respectively. The content of some Event Cards and PM tasks and the photos illustrating them have been changed accordingly. For example, Figure 1 represents a PM task in the original Virtual Week (Put the casserole in the oven at 5:00 p.m.) and its equivalent in the Hungarian version (instead of casserole, a typical Hungarian dish, 'rakott krumpli' has to be put in the oven.). An overview of all the changes made in the Hungarian version of the Virtual Week can be found in the Supplementary Material.

Before administering the Virtual Week in the current study, we ran a pilot experiment with 16 undergraduate students to check the Hungarian translation. Their PM performance was around 90% on all tasks of the Virtual Week, which is in line with previous research conducted with young adults (e.g., Niedźwieńska et al., 2016).

After the Virtual Week, participants completed standard neuropsychological tests and questionnaires. The neuropsychological tests were selected to cover all cognitive areas that are commonly affected after TBI and that are shown to affect PM dysfunction. Results of the neuropsychological tests and questionnaires are presented in Table 2.

[1]For a more detailed description of the modified Virtual Week task, see Mioni et al. (2013).

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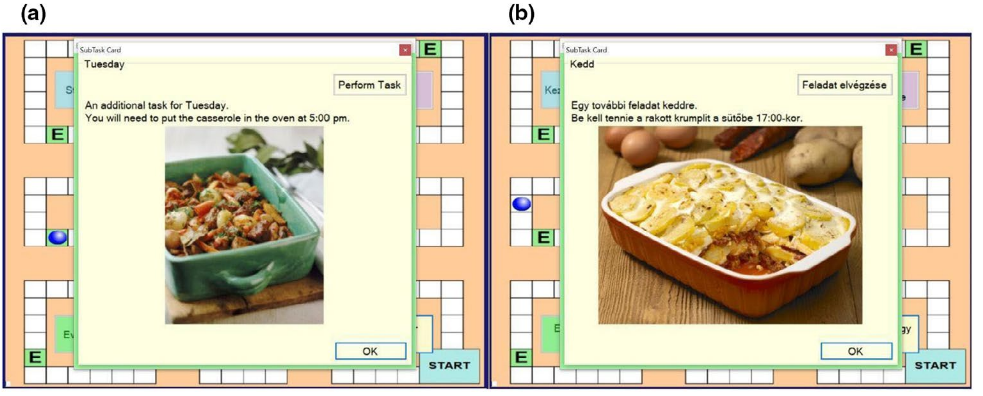

FIGURE 1 The English version (a) and the Hungarian version (b) of a Task Card in the Virtual Week. This is an example of a time-based irregular prospective memory task.

RESULTS

PM performance: The proportion of correct responses

Overall, participants had to complete 24 PM tasks in the Virtual Week: six regular event-based, six regular time-based, six irregular event-based, and six irregular time-based tasks. The proportion of correct responses was analysed in a 2 × 2 × 2 mixed analysis of variance (ANOVA) with the between variable of group (TBI patients, controls), and the within-group variables of task regularity (regular, irregular) and PM cue (event-based, time-based). All tests were two-tailed, and all effects are reported as significant at $p < .05$.

There was a significant main effect of *group*, $F(1, 34) = 32.49$, $p < .001$, $\eta_p^2 = .489$, indicating that patients with TBI had a decreased overall PM performance compared to healthy controls (TBI patients $M = .43$, SD = .30; healthy controls $M = .86$, SD = .11). There was also a significant main effect of *task regularity*, $F(1, 34) = 8.76$, $p = .006$, $\eta_p^2 = .205$, and the main effect of *PM cue* showed a strong tendency to significance, $F(1, 34) = 3.95$, $p = .055$, $\eta_p^2 = .104$. A significant two-way interaction emerged between *task regularity* and *PM cue*, $F(1, 34) = 10.23$, $p = .003$, $\eta_p^2 = .231$. Tests of simple effects showed that all participants did not differ in accuracy on event-based and time-based for regular tasks [$F(1, 34) = .45$, $p = .508$, $\eta_p^2 = .010$; event-based $M = .68$, SD = .32; time-based $M = .70$, SD = .37], but they were more accurate on event than time-based tasks for irregular PM tasks [$F(1, 34) = 9.02$, $p = .005$, $\eta_p^2 = .210$; event-based $M = .68$, SD = .36; time-based $M = .52$, SD = .35].

Further tests of simple effects revealed that on event-based tasks, PM performance did not differ between regular and irregular PM tasks [$F(1, 34) = .02$, $p = .893$, $\eta_p^2 < .010$, regular $M = .68$, SD = .32; irregular $M = .68$, SD = .36], but on time-based tasks participants performed more poorly on irregular than regular PM tasks [$F(1, 34) = 13.84$, $p = .001$, $\eta_p^2 = .280$, regular $M = .70$, SD = .37; irregular $M = .52$, SD = .35]. The task regularity × group interaction, the PM cue × group interaction and the three-way group × task regularity × PM cue interaction were not significant (all *p*s > .05).

The correct recognition of the PM task content

Performance on the retrospective component was measured through the recognition tests at the end of each virtual day on the Virtual Week. The proportion of correctly matched task content-cue pairs was analysed with a 2 × 2 × 2 mixed ANOVA to explore possible within-group and between-group differences with regard to the retrospective component.

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TABLE 2 Performance on the neuropsychological tests and questionnaires in the traumatic brain injury ($N=18$) and the healthy control ($N=18$) group.

Variable	TBI mean (SD)	Control mean (SD)	Group difference (*p*-Value)
Executive functions			
BADS zoo map time (s)	299.31 (194.15)	106.11 (58.27)	.000*
Letter fluency	9.11 (3.11)	17.33 (4.07)	.000*
Category fluency	14.35 (3.00)	23.76 (5.91)	.000*
TMT part B – TMT part A (s)	84.19 (42.53)	38.56 (18.06)	.000*
Digit span backwards	3.94 (.85)	5.00 (1.28)	.003*
Stroop inhibition index	2.56 (7.65)	.28 (1.18)	.111
Attention and processing speed			
Toulouse-Piéron Precision Index	.94 (.06)	.98 (.03)	.013*
Digit span forward	5.19 (.66)	6.61 (1.33)	.001*
TMT Part A (s)	63.19 (27.67)	28.61 (8.33)	.000*
Verbal episodic memory			
RAVLT total recall (Trials I-V)	41.31 (9.76)	55.56 (10.30)	.000*
Metamemory			
PRMQ Prospective Memory Scale	15.44 (4.08)	20.11 (4.14)	.001*
PRMQ Retrospective Memory Scale	14.31 (3.34)	16.67 (4.41)	.049
Depression and anxiety			
BDI-II	7.25 (5.32)	8.11 (7.76)	.938
STAI state anxiety	32.81 (7.49)	32.22 (10.37)	.521
STAI trait anxiety	35.06 (10.66)	42.39 (12.41)	.037

Note: All scores are raw scores. Between-group comparisons were analysed with independent groups *t*-tests. When the assumption of normality was violated, the comparisons between the two groups were conducted with Mann–Whitney *U* tests. The column 'Group difference (*p*-value)' represents raw *p*-values (all two-tailed). Asterisks indicate statistical significance after calculating critical *p*-values using the Benjamini-Hochberg procedure with an FDR rate of .05 (Benjamini & Hochberg, 1995).

Abbreviations: BADS, Behavioural Assessment of the Dysexecutive Syndrome; BDI-II, Beck Depression Inventory; PRMQ, Prospective and Retrospective Memory Questionnaire; RAVLT, Rey Auditory Verbal Learning Test; STAI, State–Trait Anxiety Inventory; TBI, traumatic brain injury; TMT, Trail Making Test.

Similarly to the prospective component, there was a significant main effect of *group*, $F(1, 34) = 13.85$, $p = .001$, $\eta_p^2 = .289$, indicating that patients with TBI had a decreased overall recognition performance compared to healthy controls (TBI patients $M = .72$, $SD = .25$; healthy controls $M = .95$, $SD = .06$). There was also a significant main effect of *task regularity*, $F(1, 34) = 9.61$, $p = .004$; $\eta_p^2 = .220$; showing that all participants had better recognition memory performance when tasks were regular ($M = .89$, $SD = .23$) compared to irregular ($M = .79$, $SD = .23$). The main effect of PM cue, and all the interactions were non-significant (all $ps > .05$). Figure 2 illustrates the proportion of correct responses on the prospective and retrospective components of the Virtual Week, arranged by task type.

Reliability of the Hungarian version of the Virtual Week

Although validation of the Hungarian version of the Virtual Week was not the main purpose of this study, we evaluated the internal consistency and the split-half reliability of this version. Reliability, as indexed by Cronbach's alpha for all PM tasks, was .93 for TBI patients and .62 for healthy control

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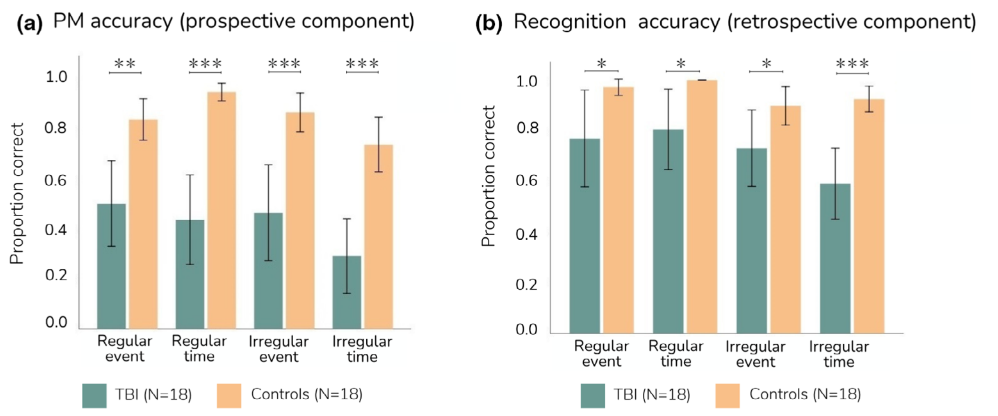

PM task	TBI patients	Controls	Group difference
Regular event	.51 (.35)	.85 (.17)	p = .001
Regular time	.44 (.37)	.96 (.07)	p < .001
Irregular event	.47 (.39)	.88 (.16)	p < .001
Irregular time	.30 (.31)	.75 (.22)	p < .001

PM task	TBI patients	Controls	Group difference
Regular event	.77 (.38)	.97 (.07)	p = .040
Regular time	.81 (.32)	1.00 (00)	p = .019
Irregular event	.73 (.30)	.90 (.15)	p = .047
Irregular time	.59 (.28)	.93 (.10)	p < .001

FIGURE 2 (a) PM accuracy (prospective component) on the Virtual Week task: Mean proportion of correct responses (*M* and SD) and group differences (*p*) by task type. (b) Recognition accuracy (retrospective component) on the Virtual Week task: Mean proportion of correct responses (*M* and SD) and group differences (*p*) by task type. Error bars represent 95% confidence intervals. Asterisks indicate statistical significance, *p < .05. **p < .01. ***p < .001. Abbreviations: PM, prospective memory; TBI, traumatic brain injury.

participants. The Spearman-Brown split-half reliability coefficients for all PM tasks were .85 for TBI patients and .42 for healthy controls.

Exploratory analyses: Correlates of prospective memory performance in the TBI group

We conducted exploratory correlational analyses in the TBI group to examine possible relationships between performance on the Virtual Week (prospective component: PM accuracy for all tasks, and retrospective component: recognition accuracy for all tasks) and clinical, neuropsychological, and meta-memory measures. Spearman rank order correlations were used.

The recognition accuracy on the Virtual Week showed a strong positive correlation with the Functional Independence Measure (FIM) at admission ($r_s = .56$, $p = .016$), the digit span backwards ($r_s = .49$, $p = .038$), the Prospective Memory Scale of PRMQ ($r_s = .52$, $p = .032$) and the Retrospective Memory Scale of the PRMQ ($r_s = .56$, $p = .019$).

In the case of PM accuracy, all correlations were nonsignificant (all ps > .05). However, aside from significance levels, which are affected by sample size, Cohen (1992) corresponds to a correlation of .3 with a medium effect and .5 with a large effect size. When these effect sizes were considered, we discovered several medium-level relationships between neuropsychological measures and performance on the Virtual Week. For example, time to solve Trail Making Test (TMT) Part A showed a negative correlation with PM accuracy ($r_s = -.46$) and recognition accuracy ($r_s = -.42$), and the time difference between TMT Part B and A also negatively correlated with these variables ($r_s = -.44$ and $-.42$ respectively). Total Recall on the Rey Auditory Verbal Learning Test (RAVLT) had a positive relationship with both the prospective ($r_s = .40$) and the retrospective ($r_s = .47$) components. Apart from p-values, similarly to the recognition accuracy, PM accuracy also showed positive relationships with digit span backwards ($r_s = .33$) and the PRMQ (with the Prospective Memory Scale: $r_s = .45$ and with the Retrospective Memory Scale: $r_s = .31$).

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DISCUSSION

This study aimed to investigate PM functions after recent TBI using a computer-based naturalistic task, the Virtual Week (Rendell & Henry, 2009), and explore the role of neuropsychological deficits and metamemory in PM functioning in this patient group. Consistent with a large body of research, our findings indicate that patients with TBI have fundamental difficulties with remembering to carry out future intentions. More specifically, we found that compared to healthy controls, the TBI group had a consistent and substantial PM deficit across all tasks of the Virtual Week, and this pattern of deficit corroborates earlier findings with this measure (for similar results, see Elliott et al., 2021 on the impact of alcohol). Our results support the notion that reducing the retrospective memory demands (regular vs irregular PM tasks) did not reduce the magnitude of TBI impairment which is in line with Mioni et al. (2013). However, our results show that for all participants, event-based tasks were easier to perform compared to time-based only when PM tasks were irregular, while the aforementioned study found that patients with TBI had more severe impairment on time-based tasks regardless of the retrospective memory demand. This contradictory result can be explained by a small but significant methodological difference between the two studies. Mioni et al. (2013) used a modified version of the Virtual Week. To further refine the manipulation of the retrospective memory demand, they embedded regular PM tasks within the practice day, and reminder messages for regular tasks were provided before starting each virtual day. Our study did not follow this modification: as in the original version, regular PM tasks were introduced after the practice day, before starting the first virtual day, and the participants were not reminded of them during the game. Therefore, in the current version of the Virtual Week, regular PM tasks were more difficult to remember, which may have resulted in that event-based and time-based tasks were equally challenging for the participants. Another possible explanation for these results is a challenge of the time-based tasks in the Virtual Week: in this PM measure, time-based tasks are not fully time-based, as generally conceptualised and assessed in other laboratory or real-life PM tasks. In other words, completing these tasks does not require monitoring the passage of actual time, but instead monitoring for a time-themed "event" of the clock cue.[2] This specific feature of the time-based tasks may have resulted in the relative comparability of event- and time-based PM performance in the case of regular tasks. Although it is important to note that even though in the case of irregular tasks, TBI patients' PM performance was better for event-based tasks, compared to healthy controls, the magnitude of the impairment was consistent on all tasks, including tasks with low and high demands on retrospective memory.

On the question of the recognition task accuracy, this study found evidence that TBI patients are not only impaired on the prospective component of PM but also on the retrospective component. This result is in line with previous research that investigated the recognition accuracy on the Virtual Week in patients with TBI (Mioni et al., 2015). However, previous studies found that the patients' performance was comparable to the control group when tasks were regular and event-based (Mioni et al., 2017). In contrast to these findings, the patients in this study showed a more general impairment on the recognition task, as no significant interaction was found between the variables of group and task regularity or PM cue. Although the recognition of regular tasks was more preserved compared to irregular tasks, the recognition performance of the patients with TBI was still lower than the control group, even in the case of regular tasks. This inconsistency may be due to methodological issues. First, the aforementioned studies used different strategies to improve PM performance in TBI, hence it is hard to compare the results with this study that used no encoding strategy. Second, as mentioned before, in these studies, regular PM tasks were presented before each virtual day, while in our study, they were introduced only once before the first virtual day. Our results, therefore, suggest that when differences in the retrospective

[2]In the original version of the Virtual Week, time-check tasks are embedded in the game. These PM tasks are considered 'real' time-based tasks as they require the participant to 'break set' from the board game activity and monitor real time on the stop-clock that is displayed prominently (Rendell & Henry, 2009). To reduce overall task requirements, we excluded these time-check tasks from our study (this is a common practice in studies that use the Virtual Week with different patient groups, e.g., Mioni et al., 2013).

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memory demand between regular and irregular PM tasks are low, then regular tasks do not enhance TBI patients' recognition memory performance.

Another possible explanation for the discrepancy in both the prospective and the retrospective component results may arise from TBI-related characteristics. In the study of Mioni et al. (2013) all patients had suffered a severe head injury and had damage in the frontal areas, while TBI patients included in this study varied in their severity and the site of injury. Moreover, the time post-injury may also explain the different results. In previous studies with the Virtual Week, subjects were tested several years post-injury, in the chronic phase of TBI, while most of our sample was tested in a more acute phase, between 1 and 5 months post-injury. It is not unprecedented that patients with TBI are tested soon after their head trauma: using PM measures other than the Virtual Week, several studies found impaired PM in patients from 1 to 5 months post-injury (e.g., Kinsella et al., 2009). Although there are considerable individual differences in memory recovery curves within the first years of injury (Ruff et al., 1991), successful neuropsychological rehabilitation and spontaneous recovery may have caused intact recognition accuracy in the case of regular and event-based tasks in previous studies.

The patients in this study showed a clear impairment on various tests of EFs, attention, processing speed and verbal episodic memory, which is consistent with previous neuropsychological data (Dikmen et al., 2009). In her review of PM impairment in neurological disorders, Henry (2021) discusses a theoretical framework based on which the pattern of PM impairment and the underlying cognitive deficits can be associated. According to this model, the performance of patients with TBI in this study may be explained by the following: (1) with regard to retrospective memory deficit, impaired encoding of the PM tasks may explain difficulties in the intention formation phase, which results in impaired recognition of PM task content and the advantage of regular tasks over irregular; (2) with regard to executive dysfunctions, impaired strategic monitoring or cue detection may underlie the impairment in the intention retention and initiation phase, which results in more pronounced impairment of time-based PM compared to event-based. These suggestions are partly confirmed by the neuropsychological background measures showing that TBI participants had difficulties with verbal episodic memory encoding (impairment on RAVLT Total Recall). Although a deficit in EFs was apparent, our neuropsychological assessment did not include a measure explicitly targeting monitoring functions. Therefore, future studies should consider using monitoring tasks, such as the keep track task (Miyake et al., 2000), to detect possible associations between EFs and PM performance of TBI patients.

As for the exploratory analyses, our study, for the first time, investigated the correlates of the recognition accuracy (the retrospective component) on the Virtual Week and revealed a strong positive correlation with the digit span backwards, indicating that TBI patients who had longer working memory span were more successful in matching the content of their future intentions to their cues. Other correlations between PM accuracy and recognition accuracy on the Virtual Week and neuropsychological tests were nonsignificant, which may be attributed to the small sample size, the large number of analyses, and the unified variables used (PM accuracy and recognition accuracy were calculated for all tasks). Setting aside p-values, which are affected by sample size, we found several medium-level relationships between PM accuracy and recognition accuracy, and some neuropsychological tests. Our results suggest that individuals with TBI who had difficulties with speed of processing (TMT Part A), executive functions (TMT Part B), and verbal episodic memory (immediate recall on RAVLT) also exhibited greater PM and recognition difficulties on the Virtual Week. These findings on the correlates of PM in patients with TBI are in line with the results of previous studies that revealed the role of executive functions, speed of processing and verbal declarative memory in PM (e.g., Palermo et al., 2020).

The Virtual Week and neuropsychological test results showed that patients with TBI had decreased prospective and retrospective memory performance. In contrast to these findings, they reported fewer everyday memory failures on the Prospective Memory Scale of the PRMQ, and their perceived retrospective memory failures were comparable to the control group. These results support the finding that brain-injured patients have difficulties judging their PM functioning by underestimating the frequency of their forgetting in everyday situations (e.g., O'Brien & Kennedy, 2018). The poor insight into disturbances in cognition in the current study may be explained by the association between injury severity

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and time post-injury. Most of our sample consisted of individuals soon after severe head trauma. It has been suggested that individuals with severe TBI experience impaired self-awareness which results in the overestimation of their abilities in the early stages of injury, but over time they may develop enhanced awareness and even underestimate their level of abilities (Fleming et al., 2022).

Another interesting finding of our research is that the results of the PRMQ – both the Prospective and the Retrospective Subscales – showed a strong positive relationship with the recognition accuracy on the Virtual Week. This result indicates that those patients who had better recognition performance were those who reported more frequent everyday memory problems regarding their prospective and retrospective memory. However, the question of the validity of the PRMQ in the current study arises, as this questionnaire contains items related to daily tasks that occur primarily in real-world situations. As our sample solely consisted of patients with acute TBI who were still inpatient, their ability to test their PM functioning in daily life was likely limited. It is possible that they were drawing upon their previous daily life experience prior to TBI. Therefore, the discrepancies between self-reported and performance-based PM in this study could also be due to the limitations of the instrument. In conclusion, the role of metamemory in PM is likely to be more complex than it could be detected in such a small sample. Our findings suggest that due to impaired self-awareness, the use of self-report questionnaires after brain injury should be considered with care.

The current study was the first to use the Hungarian version of the Virtual Week. Our results indicate that the 3-day Hungarian version is a reliable measure of PM in TBI. For the patient group, reliability indices were comparable to those obtained in previous studies with TBI samples (e.g., Mioni et al., 2013) and the subsequent adaptation studies (e.g., Niedźwieńska et al., 2016). In addition to the existing translations, it provides further evidence that the Virtual Week is a universal measure of PM and may be used in non-English speaking European samples. For the healthy control participants, the reliability of the Virtual Week was also in line with previous research (e.g., Cronbach's alpha for young adults in Niedźwieńska et al., 2016, for healthy controls in Mioni et al., 2013), although questionable. This may be due to their near ceiling performance and, in some cases, the zero variance in their scores (4 PM tasks were excluded from the reliability analysis due to zero variance, i.e. 100% correct responses). This finding suggests that the Hungarian version of the Virtual Week is more suitable for clinical practice rather than revealing individual differences in PM performance in the healthy population. In a future version, increasing the difficulty of the PM tasks (e.g., hiding the virtual clock from the screen, using non-focal tasks, or tasks with more retrospective memory demand) could improve its reliability among healthy adults.

A limitation of our study is its generalisability: caution must be applied, as these findings might not be extrapolated to all individuals with TBI. Our small sample size did not allow us to cluster patients into different subgroups, e.g., based on the neuropsychological profile or injury characteristics. Our patient group was heterogeneous with respect to the severity, cause and site of injury, and time post-injury, although previous studies investigating PM functioning also recruited patients with different injury characteristics (e.g., Henry et al., 2007). Whereas PM functioning is primarily linked to the prefrontal lobe, previous research has shown that deficits in PM occur not only after frontal but also after posterior cortex or thalamic lesions (e.g., Cona et al., 2019). Therefore, the involvement of patients with injuries other than frontal is reasonable.

Our results also need to be interpreted with caution, as statistical corrections were not taken for the exploratory analyses, and p-values were set aside when describing the correlations. The authors acknowledge that these findings are preliminary and require further replication before strong conclusions can be drawn. Although the sample is small, we believe that these analyses have a place in the manuscript, as they may extend our understanding of PM following TBI and inspire further research.

Prospective memory is frequently targeted by cognitive rehabilitation in neurological disorders since the management of daily goals is crucial for successful daily functioning (Henry, 2021). Several neuropsychological rehabilitation programmes have used the Virtual Week to restore PM functions (e.g., Kardiasmenos et al., 2008). This task has various advantages that make it suitable for use in rehabilitation: (1) it quantifies different aspects of PM task performance (time-based, event-based, regular,

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irregular and time-check tasks); (2) it separates the performance on the prospective and retrospective components; and (3) it provides a detailed overview of the type of errors (missed, little early, early, little late, and late responses); thus it enables the thorough analysis of PM functions. The computerised version is less demanding to administer and convenient for home use. Concerning the content of the PM task, it is flexible as it allows for modification of the task for specific populations (Blondelle et al., 2022). Previous research found that cognitive training with the Virtual Week enhanced PM performance in different clinical groups. Several studies suggest that different task modifications and interventions are effective (implementation intentions, Kardiasmenos et al., 2008; combined with rehearsal strategies, Foster et al., 2017; combined with visualisation, Henry et al., 2020; reminders, Henry et al., 2012; future event simulation strategy, Mioni et al., 2017; spaced retrieval, Ozgis et al., 2009). Importantly, in a training study conducted with healthy older adults, PM improvement was associated with a reduction of an event-related potential component associated with processing PM cues, suggesting training-induced neural plasticity (Rose et al., 2015).

Considering that PM is a crucial neurocognitive function needed for independent living and the fulfilment of prescribed health behaviours (e.g., taking medications and keeping therapy appointments), the rehabilitation of PM impairment after TBI is essential (Foster et al., 2017). Previous research has focused on this question in the chronic phase of TBI and administered Virtual Week to patients several years after their head trauma (e.g., Mioni et al., 2017). The present study was novel in that most patients were tested in the acute phase, only some months post-injury, and our findings suggest that Virtual Week is suitable for detecting and monitoring disturbances in PM functioning in such early stages of TBI. It may be an important reference point for clinical practitioners, as cognitive interventions targeting PM functions can be started even before patients leave the rehabilitation unit. However, from the clinician's perspective, the planning of a PM training may be aggravated by the inherent heterogeneity of TBI. Findings from case–control studies with small sample sizes must be interpreted cautiously, as translating group-level results to individuals would average out meaningful inter-individual differences (Covington & Duff, 2021). Cognitive rehabilitation targeting PM should be tailored to individual patients, and the underlying cognitive symptoms must be considered, as different treatment strategies are needed for patients with attention deficits or those with primary EFs deficits (Raskin et al., 2018). In the opinion of the authors, Virtual Week may be suitable for individualised PM training, as (1) the content of the PM tasks can be adapted to the individual's own goals and daily activities, (2) it can be programmed to systematically increase the difficulty as the participant improves, (3) it provides feedback, and (4) the number of the virtual days can be extended for sustained practice (Henry et al., 2021). As for the patients with TBI, further research should be undertaken to investigate the long-term effects of the training, the appropriate strategy, and the transfer to the patients' real-world PM tasks.

AUTHOR CONTRIBUTIONS

Anita Lencsés: Conceptualization; data curation; formal analysis; investigation; methodology; project administration; resources; visualization; writing – original draft; writing – review and editing. **Bernadett Mikula:** Conceptualization; methodology; writing – review and editing. **Giovanna Mioni:** Conceptualization; methodology; writing – review and editing. **Peter G. Rendell:** Data curation; methodology; resources; supervision; writing – review and editing. **Zoltán Dénes:** Resources; writing – review and editing. **Gyula Demeter:** Conceptualization; data curation; funding acquisition; investigation; methodology; project administration; resources; supervision; writing – review and editing.

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CONFLICT OF INTEREST STATEMENT

No potential conflict of interest was reported by the authors.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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REFERENCES

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: A practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society: Series B: Methodological*, *57*(1), 289–300.

Blondelle, G., Sugden, N., & Hainselin, M. (2022). Prospective memory assessment: Scientific advances and future directions. *Frontiers in Psychology*, *13*, 958458. https://doi.org/10.3389/fpsyg.2022.958458

Cohen, J. (1992). A power primer. *Psychology Bulletin*, *112*(1), 155–159.

Cona, G., Laera, G., Edelstyn, N., & Bisiacchi, P. S. (2019). Deficits in prospective memory following damage to the medial subdivision of the mediodorsal thalamic nucleus. *Journal of Neuropsychology*, *13*(3), 398–416. https://doi.org/10.1111/jnp.12154

Cona, G., Scarpazza, C., Sartori, G., Moscovitch, M., & Bisiacchi, P. S. (2015). Neural bases of prospective memory: A meta-analysis and the "attention to delayed intention" (AtoDI) model. *Neuroscience & Biobehavioral Reviews*, *52*, 21–37. https://doi.org/10.1016/j.neubiorev.2015.02.007

Covington, N. V., & Duff, M. C. (2021). Heterogeneity is a hallmark of traumatic brain injury, not a limitation: A new perspective on study design in rehabilitation research. *American Journal of Speech-Language Pathology*, *30*(2S), 974–985. https://doi.org/10.1044/2020_AJSLP-20-00081

Dikmen, S. S., Corrigan, J. D., Levin, H. S., Machamer, J., Stiers, W., & Weisskopf, M. G. (2009). Cognitive outcome following traumatic brain injury. *The Journal of Head Trauma Rehabilitation*, *24*(6), 430–438. https://doi.org/10.1097/HTR.0b013e3181c133e9

Einstein, G., & McDaniel, M. (1990). Normal aging and prospective memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *16*, 717–726. https://doi.org/10.1037//0278-7393.16.4.717

Einstein, G. O., & McDaniel, M. A. (1996). Retrieval processes in prospective memory: Theoretical approaches and some new empirical findings. In *Prospective memory: Theory and applications* (pp. 115–141). Lawrence Erlbaum Associates Publishers.

Elliott, M., Terrett, G., Curran, H. V., De Bono, N., Rendell, P. G., & Henry, J. D. (2021). Prospective memory deficits following acute alcohol consumption. *Journal of Psychopharmacology*, *35*(11), 1386–1397. https://doi.org/10.1177/02698811211056195

Fish, J., Evans, J. J., Nimmo, M., Martin, E., Kersel, D., Bateman, A., Wilson, B. A., & Manly, T. (2007). Rehabilitation of executive dysfunction following brain injury: "Content-free" cueing improves everyday prospective memory performance. *Neuropsychologia*, *45*(6), 1318–1330. https://doi.org/10.1016/j.neuropsychologia.2006.09.015

Fleming, J., Ownsworth, T., Doig, E., Swan, S., Prescott, S., Hamilton, C., & Shum, D. H. K. (2022). Improving self-awareness of prospective memory function after TBI using experiential feedback on a board game activity: An observational study. *Neuropsychological Rehabilitation*, *1–24*, 1989–2012. https://doi.org/10.1080/09602011.2022.2044863

Fleming, J., Riley, L., Gill, H., Gullo, M. J., Strong, J., & Shum, D. (2008). Predictors of prospective memory in adults with traumatic brain injury. *Journal of the International Neuropsychological Society*, *14*(5), 823–831. https://doi.org/10.1017/S1355617708080971

Foster, E. R., McDaniel, M. A., & Rendell, P. G. (2017). Improving prospective memory in persons with Parkinson disease: A randomized controlled trial. *Neurorehabilitation and Neural Repair*, *31*(5), 451–461. https://doi.org/10.1177/1545968317690832

Foster, E. R., Rose, N. S., McDaniel, M. A., & Rendell, P. G. (2013). Prospective memory in Parkinson disease during a virtual week: Effects of both prospective and retrospective demands. *Neuropsychology*, *27*(2), 170–181. https://doi.org/10.1037/a0031946

Henry, J. D. (2021). Prospective memory impairment in neurological disorders: Implications and management. *Nature Reviews. Neurology*, *17*, 297–307. https://doi.org/10.1038/s41582-021-00472-1

17486653, 2025, 1, Downloaded from https://bpspsychub.onlinelibrary.wiley.com/doi/10.1111/jnp.12388 by Australian Catholic University, Wiley Online Library on [01/06/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Henry, J. D., Hering, A., Haines, S., Grainger, S. A., Koleits, N., McLennan, S., Pelly, R., Doyle, C., Rose, N. S., Kliegel, M., & Rendell, P. G. (2021). Acting with the future in mind: Testing competing prospective memory interventions. *Psychology and Aging*, *36*(4), 491–503. https://doi.org/10.1037/pag0000593

Henry, J. D., Phillips, L. H., Crawford, J. R., Kliegel, M., Theodorou, G., & Summers, F. (2007). Traumatic brain injury and prospective memory: Influence of task complexity. *Journal of Clinical and Experimental Neuropsychology*, *29*(5), 457–466. https://doi.org/10.1080/13803390600762717

Henry, J. D., Rendell, P. G., Phillips, L. H., Dunlop, L., & Kliegel, M. (2012). Prospective memory reminders: A laboratory investigation of initiation source and age effects. *Quarterly Journal of Experimental Psychology*, *65*(7), 1274–1287. https://doi.org/10.1080/17470218.2011.651091

Henry, J. D., Terrett, G., Grainger, S. A., Rose, N. S., Kliegel, M., Bugge, M., Ryrie, C., & Rendell, P. G. (2020). Implementation intentions and prospective memory function in late adulthood. *Psychology and Aging*, *35*(8), 1105–1114. https://doi.org/10.1037/pag0000563

Kardiasmenos, K. S., Clawson, D. M., Wilken, J. A., & Wallin, M. T. (2008). Prospective memory and the efficacy of a memory strategy in multiple sclerosis. *Neuropsychology*, *22*(6), 746–754. https://doi.org/10.1037/a0013211

Kinsella, G. J., Ong, B., & Tucker, J. (2009). Traumatic brain injury and prospective memory in a virtual shopping trip task: Does it matter who generates the prospective memory target? *Brain Impairment*, *10*(1), 45–51. https://doi.org/10.1375/brim.10.1.45

Kliegel, M., Jager, T., Altgassen, M., & Shum, D. (2012). Clinical neuropsychology of prospective memory. In M. Kliegel, M. A. McDaniel, & G. O. Einstein (Eds.), *Prospective memory: Cognitive, neuroscience, developmental, and applied perspectives*. Psychology Press.

Knight, R. G., Harnett, M., & Titov, N. (2005). The effects of traumatic brain injury on the predicted and actual performance of a test of prospective remembering. *Brain Injury*, *19*(1), 19–27. https://doi.org/10.1080/02699050410001720022

Mathias, J. L., & Mansfield, K. M. (2005). Prospective and declarative memory problems following moderate and severe traumatic brain injury. *Brain Injury*, *19*(4), 271–282. https://doi.org/10.1080/02699050400005028

Mioni, G., Bertucci, E., Rosato, A., Terrett, G., Rendell, P. G., Zamuner, M., & Stablum, F. (2017). Improving prospective memory performance with future event simulation in traumatic brain injury patients. *British Journal of Clinical Psychology*, *56*(2), 130–148. https://doi.org/10.1111/bjc.12126

Mioni, G., Rendell, P. G., Henry, J. D., Cantagallo, A., & Stablum, F. (2013). An investigation of prospective memory functions in people with traumatic brain injury using virtual week. *Journal of Clinical and Experimental Neuropsychology*, *35*(6), 617–630. https://doi.org/10.1080/13803395.2013.804036

Mioni, G., Rendell, P. G., Terrett, G., & Stablum, F. (2015). Prospective memory performance in traumatic brain injury patients: A study of implementation intentions. *Journal of the International Neuropsychological Society*, *21*(4), 305–313. https://doi.org/10.1017/S1355617715000211

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The Unity and Diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology*, *41*(1), 49–100. https://doi.org/10.1006/cogp.1999.0734

Niedźwieńska, A., Rendell, P. G., Barzykowski, K., & Leszczyńska, A. (2016). Virtual week: Validity and psychometric properties of a polish adaptation. *European Review of Applied Psychology*, *66*(2), 79–84. https://doi.org/10.1016/j.erap.2016.02.003

Nurdal, V., Wearn, A., Knight, M., Kauppinen, R., & Coulthard, E. (2020). Prospective memory in prodromal Alzheimer's disease: Real world relevance and correlations with cortical thickness and hippocampal subfield volumes. *NeuroImage: Clinical*, *26*, 102226. https://doi.org/10.1016/j.nicl.2020.102226

O'Brien, K. H., & Kennedy, M. R. T. (2018). Predicting remembering: Judgments of prospective memory after traumatic brain injury. *Journal of Speech, Language, and Hearing Research*, *61*(6), 1393–1408. https://doi.org/10.1044/2018_JSLHR-L-17-0226

Ozgis, S., Rendell, P. G., & Henry, J. D. (2009). Spaced retrieval significantly improves prospective memory performance of cognitively impaired older adults. *Gerontology*, *55*(2), 229–232. https://doi.org/10.1159/000163446

Palermo, L., Cinelli, M. C., Piccardi, L., De Felice, S., Ciurli, P., Incoccia, C., Zompanti, L., & Guariglia, C. (2020). Cognitive functions underlying prospective memory deficits: A study on traumatic brain injury. *Applied Neuropsychology. Adult*, *27*(2), 158–172. https://doi.org/10.1080/23279095.2018.1501374

Pavawalla, S. P., Schmitter-Edgecombe, M., & Smith, R. E. (2012). Prospective memory after moderate-to-severe traumatic brain injury: A multinomial modeling approach. *Neuropsychology*, *26*(1), 91–101. https://doi.org/10.1037/a0025866

Potvin, M.-J., Rouleau, I., Audy, J., Charbonneau, S., & Giguère, J.-F. (2011). Ecological prospective memory assessment in patients with traumatic brain injury. *Brain Injury*, *25*(2), 192–205. https://doi.org/10.3109/02699052.2010.541896

Rabinowitz, A. R., & Levin, H. S. (2014). Cognitive sequelae of traumatic brain injury. *The Psychiatric Clinics of North America*, *37*(1), 1–11. https://doi.org/10.1016/j.psc.2013.11.004

Raskin, S. A., Williams, J., & Aiken, E. M. (2018). A review of prospective memory in individuals with acquired brain injury. *The Clinical Neuropsychologist*, *32*(5), 891–921. https://doi.org/10.1080/13854046.2018.1455898

Rendell, P. G., & Henry, J. D. (2009). A review of virtual week for prospective memory assessment: Clinical implications. *Brain Impairment*, *10*(1), 14–22. https://doi.org/10.1375/brim.10.1.14

17486653, 2025, 1, Downloaded from https://bpspsychub.onlinelibrary.wiley.com/doi/10.1111/jnp.12388 by Australian Catholic University, Wiley Online Library on [01/06/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Roche, N. L., Fleming, J. M., & Shum, D. H. K. (2002). Self-awareness of prospective memory failure in adults with traumatic brain injury. *Brain Injury*, *16*(11), 931–945. https://doi.org/10.1080/02699050210138581

Rose, N. S., Rendell, P. G., Hering, A., Kliegel, M., Bidelman, G. M., & Craik, F. I. M. (2015). Cognitive and neural plasticity in older adults' prospective memory following training with the virtual week computer game. *Frontiers in Human Neuroscience*, *9*, e00592. https://doi.org/10.3389/fnhum.2015.00592

Ruff, R. M., Young, D., Gautille, T., Marshall, L. F., Barth, J., Jane, J. A., Kreutzer, J., Marmarou, A., Levin, H. S., Eisenberg, H. M., & Foulkes, M. A. (1991). Verbal learning deficits following severe head injury: Heterogeneity in recovery over 1 year. *Journal of Neurosurgery*, *75*, S50–S58. https://doi.org/10.3171/sup.1991.75.1s.0s50

Tagliaferri, F., Compagnone, C., Korsic, M., Servadei, F., & Kraus, J. (2006). A systematic review of brain injury epidemiology in Europe. *Acta Neurochirurgica*, *148*(3), 255–268. https://doi.org/10.1007/s00701-005-0651-y

Wong Gonzalez, D., & Buchanan, L. (2019). A meta-analysis of task-related influences in prospective memory in traumatic brain injury. *Neuropsychological Rehabilitation*, *29*(5), 657–671. https://doi.org/10.1080/09602011.2017.1313748

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Appendix S1

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