Application of the Spacing Effect to Improve Learning and Memory for Functional Tasks in Traumatic Brain Injury: A Pilot Study

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KEY WORDS
- activities of daily living
- brain injuries
- cognition disorders
- learning
- memory

Research has indicated that many people with traumatic brain injury (TBI) experience learning and memory difficulties because of impairments in the initial acquisition of information. We examined a strategy, the spacing effect, known to enhance new learning in a laboratory setting in healthy control participants (HCs) and in people with TBI. The spacing effect indicates that information is learned better when presentation trials are distributed over time (spaced presentation) rather than consecutively (massed presentation). In this study, we examined the application of the spacing effect in improving functional tasks. We used a within-subject design and included 10 participants with TBI and 15 HCs. In both the TBI and the HC groups, material learned under the spaced learning condition was recalled better than that learned under massed learning conditions. These results provide initial evidence supporting the use of the spacing effect to improve new learning of functional tasks for people with TBI.


Traumatic brain injury (TBI) is one of the leading causes of disability in people <35 years old (Sosin, Sniezek, & Thurman, 1996). Data have indicated that cognitive and psychosocial impairments, rather than physical impairments alone, lead to decreased adaptive and vocational functioning in people with TBI (Anderson, Bigler, & Blatter, 1995; Dikmen, Machamer, Winn, & Temkin, 1995; Olver, Ponsford, & Curran, 1996). Memory impairment is one of the most frequent cognitive symptoms reported by patients, their family members, and clinicians after TBI (Goldstein & Levin, 2001; Rosenthal & Ricker, 2000; van Zomeren & van den Burg, 1985), and it has been shown to be associated with vocational instability (Drake, Gray, Yoder, Pramuka, & Llewelly, 2000). Recent studies have demonstrated that the primary reason for difficulties in new learning and memory in people with TBI is difficulty in the initial acquisition of information rather than the retrieval of information from long-term storage (DeLuca, Schultheis, Madigan, Christodoulou, & Averill, 2000). Specifically, DeLuca et al. (2000) determined that when participants with TBI and healthy control participants (HCs) reached a predetermined learning criterion, those with TBI recalled and recognized the newly learned information at a level comparable to that of healthy adults. However, participants with TBI required significantly more trials to reach this learning criterion. That is, they had difficulty initially learning new information but not in retrieving it from long-term storage. These findings suggest that the primary memory deficit after TBI involves acquiring or learning new information.

Various learning strategies from the cognitive psychology literature have been shown to significantly improve the learning of new information in HC samples.

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However, there has been very little work in applying such strategies to people with TBI, which could potentially result in a significant improvement in cognitive and everyday functioning. One such technique is called the \textit{spacing effect}.

The spacing effect is the observation that information presented using spaced repetitions is better remembered than information presented via massed repetitions (Challis, 1993). A large body of literature has documented that learning trials spaced over time lead to better recall than massed learning (consecutive learning trials), particularly under conditions in which the delay between study and test is long rather than short (Bahrick, Bahrick, & Bahrick, 1993; Bahrick & Phelps, 1987; Cahill & Toppino, 1993; Dempster, 1987, 1988; Glencross, 1976, 1977, 1979; Glencross & Lehmman, 1980; Glover & Corkill, 1987; Hintzman, 1974; Jensen & Freund, 1981; Melton, 1970; Rea & Modigliani, 1985; Shaughnessy, Zimmerman, & Underwood, 1972; Toppino, 1991, 1993; Underwood, 1970; Zeichmeister & Shaughnessy, 1980). Several theoretical explanations for the success of the spacing effect exist, but these are beyond the scope of this article (for further review, see Dempster, 1989).

To date, most of the research on the spacing effect has been conducted with healthy people in laboratory settings (e.g., Challis, 1993; Kahana & Howard, 2005; Janiszewski, Noel, & Sawyer, 2003). Some researchers, however, have examined how the spacing effect might facilitate learning of and memory for different tasks in clinical populations who may exhibit memory deficits, including people with amnesia (Cermak, Verfaillie, Lanzoni, Mather, & Chase, 1996), dementia (Camp & Foss, 1997), multiple sclerosis (Goverrover, Hillary, Chiaravalloti, Arango-Lasprilla, & DeLuca, 2008), and TBI (Hillary et al., 2003). These studies indicated that the spacing effect can effectively facilitate recall of newly learned material in patients with memory impairments. However, most of these studies examining the impact of the spacing effect have been conducted with solely laboratory-based tasks, such as word lists. Thus, the impact of the spacing effect on everyday activities in clinical samples remains unclear. The purpose of this study was to determine whether spaced learning enhances memory of functional tasks in people with TBI.

\textbf{Method}

\textbf{Participants}

Ten participants with TBI and 15 HCs without reported neurological disabilities participated in this study. Participants with TBI were included in the study only if positive computed tomography or MRI neuroimaging results or a documented period of loss of consciousness of ≥24 hr were documented. Participants were excluded from the study if they had a history of neurological illness (aside from TBI), a history of major psychiatric illness, a history of alcohol or drug abuse, or severe visual or motor impairment that might interfere with study procedures. All of the participants with TBI were ≥1 year postinjury (mean years postinjury = 8.2, standard deviation = 6.8). The two groups did not differ significantly with regard to age (TBI = 42.5, HC = 43.3), gender (TBI, 54.5% men; HC, 45.5% men), and premorbid intelligence (as measured by the Wide Range Achievement Test 3 [WRAT–3] Reading Subtest [Wilkinson, 1993]; mean raw score = 51.6 for both groups, the scaled score of indicates above-average reading academic skills for both groups). All recruitment and experimental procedures were approved by the institutional review board (IRB) and Health Insurance Portability and Accountability Act compliance boards. Before study enrollment, all participants indicated willingness to participate in the study by signing a consent form approved by the IRB.

\textbf{Procedure and Materials}

We used a within-subject design in which all participants were required to complete two paragraph-learning tasks (reading a paragraph and being asked to remember it) and two route-learning tasks (after being presented with a route on a map, participants were asked to reproduce it on an identical map). The paragraph-learning task involved two different paragraphs, and the route-learning task included two different black-and-white maps. We chose these two tasks for this experiment to examine verbal (i.e., paragraph) and nonverbal (i.e., map) learning and memory processes on tasks that could be encountered during daily life.

For each task, participants received a total of three learning trials to the task materials. In the massed condition, tasks were presented three consecutive times; in the spaced condition, tasks were presented three times with a 5-min interval between them. The two conditions were presented in counterbalanced order.

\textbf{Paragraph Learning Task}. The paragraph-learning task required participants to read aloud two short paragraphs (one in a massed condition and one in a spaced condition, as described earlier). Both paragraphs were taken from a newspaper and contained 5 sentences, 84 words, and 14 elements of information. After the three learning trials, two recall trials were conducted at immediate recall and then again 30 min after initial presentation. Participants were asked to repeat the paragraph provided to them using “as close to the same words as possible.” The dependent measures for this task were the total number of elements recalled for each of the immediate and delayed free-recall trials, ranging from 0 to 14. The dependent variables were the total score for the immediate and delayed free-recall trials.
Route-Learning Task. The route-learning task was designed to simulate the procedure of learning and recalling a simple set of visual instructions when a new route is learned (e.g., when traveling to a new place). Each of the routes to be learned consisted of 13 different streets and 13 directional turns to be memorized. The three learning trials consisted of the examiner visually presenting the route (including the route streets and turns) using a red laser pointer on a map. During the presentation of the route, the examiner was positioned across a table from the participant. Each presentation lasted 20 s. After three learning trials, a recall trial was obtained by asking the participant to draw the route on another map without further presentation. An identical recall trial was performed after a 30-min delay. For every correct turn and street traced, 1 point was awarded. The range of possible scores ranged from 0 (not remembering anything) to 26 (accurate recollection of the route). The dependent variables were the total score for immediate and delayed free-recall trials.

Neuropsychological Testing

TBI can cause cognitive impairments in the areas of attention (Mathias & Wheaton, 2007), information-processing speed (Madigan, DeLuca, Diamond, Tramontano, & Averill, 2000), learning and memory (Deshpande, Millis, Reeder, Fuerst, & Ricker, 1996), executive functions (Macdonald, Flashman, & Saykin, 2002), and visuospatial abilities. Therefore, the battery of neuropsychological tests administered was geared toward assessing these cognitive functions. This battery consisted of the Digit Span subtest (Wechsler Adult Intelligence Scale–Revised [WAIS–R]; Wechsler, 1981) to assess attention; Symbol Digit Modalities Test (SDMT)—Oral Version (Smith, 1982) to assess processing speed; California Verbal Learning Test (CVLT; Delis, Kramer, Kaplan, & Ober, 1987) to assess learning and memory; and three subtests of the Delis–Kaplan Executive Function System (D–KEFS; Delis, Kaplan, & Kramer, 2000)—the Trail Making Test, Verbal Fluency Test (Letter Fluency), and Color–Word Interference Test (Inhibition–Switching)—to assess executive functions.

Data Collection and Analysis

Participants were recruited by advertisements distributed at local support groups and clinics. On initial phone contact, potential participants were screened for participation on the basis of the inclusion and exclusion criteria discussed earlier. Participants were then scheduled for interview and testing. The testing session lasted approximately 3 hr, in which the neuropsychological battery and the spacing effect protocol were administered by Yael Goverover and Juan Carlos Arango-Lasprilla. All participants were paid for their participation.

To analyze performance on the spacing effect protocol, we analyzed performance on the paragraph and route tasks by means of a 2 (group: TBI vs. HC) × 2 (condition: massed vs. spaced) × 2 (time: immediate vs. 30 min) repeated-measures analysis of variance (ANOVA) with group as the between-groups factor and condition and time as within-group factors.

Results

We analyzed cognitive functioning by using a one-way ANOVA to compare performance between TBI and HC groups. These results are presented in Table 1. The TBI group took significantly longer to perform the D–KEFS Trail Making Test number–letter switching task than did the HC group ($F(1,24) = 13.6, p < .01$). On the CVLT, HC participants recognized significantly more words than did the TBI participants ($F(1,24) = 5.5, p < .05$). Additionally, participants with TBI demonstrated slower speed of processing on the SDMT than did HC participants ($F(1,24) = 4.8, p < .05$).

Performance of Paragraph-Learning Task

Figure 1 illustrates the different scores each participant group received in the different learning conditions for the paragraph-learning task. We observed a significant interaction between time and condition ($F(1,23) = 5.9, p = .02, \eta^2 = .20$). This interaction indicates that information presented in a spaced manner was retained significantly better than information learned in a massed presentation after the 30-min delay and even better than recall immediately after initial learning. This interaction was observed in both the TBI and the HC groups. It is important to note, though, that the

| Table 1. Neuropsychological Test Performance (Means ± Standard Deviations) |
|-----------------------------|-----------------------------|-----------------------------|
| Domain Assessed and Test    | TBI ($n = 10$) | HC ($n = 15$) | $F(1, 24)$ |
| Speed of processing: SDMT   | 42.8 ± 13.9 | 56.3 ± 11.2 | 4.8* |
| Learning and memory         |               |               |          |
| CVLT—Sum of 5 trials        | 50.2 ± 13.8 | 54.8 ± 10.5 | 0.51 |
| CVLT—Discriminability       | 89.8 ± 9.2  | 96.3 ± 3.7  | 5.5* |
| Working memory: Digit Span Total | 18.6 ± 7.6 | 19.3 ± 3.4 | 0.10 |
| Executive functions         |               |               |          |
| D–KEFS Trail Making Test    | 109.8 ± 42.6 | 64.5 ± 14.1 | 13.6** |
| Number–letter switching     |               |               |          |
| D–KEFS Verbal Fluency–Letter Fluency | 34.8 ± 19.3 | 43.2 ± 11.8 | 1.3 |
| D–KEFS Color–Word inhibition and switching | 74.4 ± 18.5 | 58.4 ± 14.8 | 3.8 |

Note. TBI = traumatic brain injury; HC = healthy control participants; SDMT = Symbol Digit Modalities Test; CVLT = California Verbal Learning Test; D–KEFS = Delis–Kaplan Executive Function System.

*p < .05. **p < .01.
main effect of condition was not statistically significant ($F[1, 23] = 3.4, p = .07, \eta^2 = .15$). Thus, tasks of paragraph learning (learned under the spaced condition) were recalled at a slightly higher rate (mean $M = 7.85$) than tasks presented in a massed condition ($M = 7.1$) collapsed across groups and time. However, this difference was not significant, and the effect size was small. Additionally, the relative difference between the spaced versus massed conditions was equivalent across participant groups. The interaction of participant group (HC vs. TBI) and condition (spaced vs. massed) was not significant and demonstrated a small effect size ($F[1, 23] = 0.1, p = .80, \eta^2 = .003$). Thus, both HC and TBI participants showed a similar pattern of learning whereby they benefited from the spaced condition as compared with the massed condition when learning the paragraph.

**Following a Route on a Map**

Performance on the route-learning task is presented in Figure 2. We observed a significant interaction between time and condition ($F[1, 23] = 7.9, p = .01, \eta^2 = .25$). This interaction demonstrates that participants in both the TBI and the HC groups did worse in the immediate recall when they learned the route in a spaced manner. However, after a 30-min delay, routes on the map that were learned in the spaced condition were remembered significantly better than the routes learned in the massed condition. Thus, the pattern of results was reversed at the 30-min recall. There was no significant main effect of conditions (i.e., spaced and massed learning) for the map-learning task across time and groups (space, $M = 16.9$; mass, $M = 16.9$; condition main effect, $F[1, 23] = .00, p = .98, \eta^2 = .01$).

The TBI and HC groups did not differ significantly in the mean number of items recalled. The main effect of group was not significant ($F[1, 23] = 0.34, p = .56, \eta^2 = .009$). Similar to the paragraph tasks, the interaction of participant group and condition (spaced vs. generated) was also not significant ($F[1, 23] = 0.41, p = .52, \eta^2 = .01$), suggesting that the spaced and massed conditions affected memory abilities to an equivalent degree in both participant groups.

**Discussion**

The results of this pilot study are consistent with earlier literature on the spacing effect (Hilary et al., 2003) and suggest that this learning strategy can play a role in rehabilitation even in chronic-stage post-TBI. This study's findings support the idea that treatment focusing on improving acquisition may significantly increase recall of learned information and extend this support to functional tasks.

This study demonstrated two primary findings. First, results showed that the spacing effect can be successfully applied to a functional task such as paragraph and route learning in TBI. Second, when participants acquired skills (reading information from a newspaper or following a route on a map), delayed recall of this information was better when the information was originally learned under spaced conditions. Initial performance was better, however, when the tasks were learned in massed practice compared with spaced practice. These results are consistent with those of previous research. Specifically, Rohrer and Pashler (2007) concluded that the benefits of the spacing effect generally seem to get bigger, not smaller, when one examines longer-term retention.

In terms of long-term retention, the observed benefit of spaced learning trials is of major importance because delayed-recall trials are presumed to be a better reflection of recall of what was learned (transfer test; Hall & Magill, 1995). Spaced practice trials clearly have a significant, long-term positive effect on learning and memory, and this effect is critical to the conduct of clinical rehabilitation. These results have

**Figure 1. Paragraph tasks: Recall scores for spaced vs. massed conditions.**

*Note. HC = healthy control participants; TBI = traumatic brain injury.*

**Figure 2. Map task: Recall scores for spaced vs. massed conditions.**

*Note. HC = healthy control participants; TBI = traumatic brain injury.*
widespread implications for instruction at many levels. Although tradition dictates that therapists present multiple, different sets of instructions or exercises during each therapy session, these findings show that clients might be far better served if material was distributed sporadically across many therapy sessions. The findings of the long-term benefit of learning through spaced learning trials are critical to the rehabilitation of people with TBI who have deficits in acquiring new information because it provides evidence for long-term learning of functional information.

Clinical Implications
This pilot study provides Class II evidence for the use of spaced learning trials in learning and memory interventions (see Cicerone et al., 2000, 2005). Thus, it provides fair evidence to support a recommendation as to whether treatment may be effective. Because of this, the information gained from this pilot study provides the opportunity to proceed to the next step by designing treatment plans that are based on individualized goals but using learning techniques that may improve long-term retention. In sum, spaced learning trials can be viewed both theoretically and practically as a learning strategy that can be applied as a compensatory technique with a variety of tasks with people with TBI.

Limitations of the Study
This study’s results should be interpreted with the following caveats. First, the small sample studied may not be fully representative of the population of people with TBI. Second, severity level was not accounted for, and it is not clear how injury severity may affect the usefulness of spacing effect techniques. Third, this study has demonstrated the usefulness of the encoding strategy in improving two functional activities (route learning and reading a paragraph); however, it is not clear how useful the techniques might be when applied to other daily tasks (e.g., vocational tasks, driving). Fourth, although the spacing effect improved recall immediately and at 30 min after initial presentation, it is not clear whether these gains are maintained over a longer follow-up period.

Future Research
Replication of these results in larger, more diverse populations of people with TBI with differing levels of cognitive impairment is needed to ensure adequate generalization of the findings. Further investigation of the usefulness of this technique on tasks completed in the patient’s natural environment, instead of in a research laboratory setting, would help to determine the spacing effect’s ecological validity. It would also be informative to study the potential benefits of the spacing effect on longer-term recall by including 1-week, 3-month, or 6-month follow-ups, or all of these, in the study design.

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