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BRIEF REPORT

Individual Differences in Working Memory Capacity Predicts Responsiveness to Memory Rehabilitation After Traumatic Brain Injury

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Abstract

Objective: To explore how individual differences affect rehabilitation outcomes by specifically investigating whether working memory capacity (WMC) can be used as a cognitive marker to identify who will and will not improve from memory rehabilitation.

Design: Post hoc analysis of a randomized controlled clinical trial designed to treat learning and memory impairment after traumatic brain injury (TBI): 2 × 2 between-subjects quasiexperimental design (2 [group: treatment vs control] × 2 [WMC: high vs low]).

Setting: Nonprofit medical rehabilitation research center.

Participants: Participants (N=65) with moderate to severe TBI with pre- and posttreatment data.

Interventions: The treatment group completed 10 cognitive rehabilitation sessions in which subjects were taught a memory strategy focusing on learning to use context and imagery to remember information. The placebo control group engaged in active therapy sessions that did not involve learning the memory strategy.

Main Outcome Measure: Long-term memory percent retention change scores for an unorganized list of words from the California Verbal Learning Test-II.

Results: Group and WMC interacted ($P=.008$, $\eta_p^2=.12$). High WMC participants showed a benefit from treatment compared with low WMC participants. Individual differences in WMC accounted for 45% of the variance in whether participants with TBI in the treatment group benefited from applying the compensatory treatment strategy to learn unorganized information.

Conclusions: Individuals with higher WMC showed a significantly greater rehabilitation benefit when applying the compensatory strategy to learn unorganized information. WMC is a useful cognitive marker for identifying participants with TBI who respond to memory rehabilitation with the modified Story Memory Technique.

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Traumatic brain injury (TBI)—related learning and memory impairment negatively affects quality of life, necessitating effective remediation strategies. In a recent randomized clinical trial,[1] participants with TBI were taught a compensatory memory rehabilitation strategy, the modified Story Memory Technique (mSMT), that teaches patients to focus on using context and imagery to remember information. The treatment group completed 10 sessions of the mSMT, and the placebo control group engaged in active therapy sessions that did not involve learning the memory strategy. A treatment benefit was evident when participants learned organized information (remembering a story), but not when participants learned unorganized information (remembering a list of words).[1] Presently, we further explore these data and examine this discrepancy by evaluating how individual differences influence memory rehabilitation treatment efficacy, specifically with respect to

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long-term memory for unorganized information. The main aim is to investigate whether there is a common cognitive profile/marker to identify which participants respond to applying the mSMT memory rehabilitation strategy to learn unorganized information.

Working memory capacity (WMC) is a strong predictor of individual differences in cognition[2] and a strong candidate to be a cognitive marker.[3] Individuals with high WMC (H-WMCs) better integrate and retrieve information into and out of long-term memory than individuals with low WMC (L-WMCs), and H-WMCs use more efficient cognitive processing strategies.[2] Recent research has demonstrated that WMC is related to memory impairment in TBI[4,5] and other neurologic populations.[6,7] The link between WMC and memory impairment suggests that (1) treatments directed at WMC may improve memory in neurologic patients or that (2) individual differences in WMC will be useful in identifying who will and who will not respond to rehabilitation treatments.[3,5] Herein we test this second proposal and hypothesize that H-WMCs are more responsive to treatment than L-WMCs when learning unorganized information.

Methods

Participants

Participants with moderate to severe TBI who had documented impairments in new learning and memory were included. Four of 69 participants reported in the trial did not have posttreatment data, and they were omitted, leaving 65 participants in the present analysis. Recruitment, condition assignment, and demographics are reported elsewhere.[1] Groups differed only in education (controls > treatment; $P<.01$).[1]

Treatment participants completed 10 sessions of the mSMT. Active placebo control participants performed cognitive tasks that did not include the rehabilitation techniques used in the mSMT.[1] Institutional review board approval was obtained.

Long-term memory percent retained

To control for individual variability in initial learning and variation resulting from pre- and posttesting sessions completed on different days, proportion-retained scores were calculated using the ratio of California Verbal Learning Test-II (supplemental appendix S1, available online only at http://www.archives-pmr.org/) long-delay free recall to short-delay free recall raw scores (see Cowan et al[8]). Long-term memory percent retained change scores (LTMPRΔ) were calculated by subtracting the proportion retained at t1 (pretest) from t2 (posttest), providing an estimate of how retention changed:

$$\text{LTMPR}\Delta = \left(\left[\frac{\text{LDFR}_{\text{t2}}}{\text{SDFR}_{\text{t2}}}\right] - \left[\frac{\text{LDFR}_{\text{t1}}}{\text{SDFR}_{\text{t1}}}\right]\right) \times 100 \qquad (1)$$

where LDFR is long-delay free recall and SDFR is short-delay free recall.

List of abbreviations:

H-WMC	**high working memory capacity individual**
LTMPRΔ	**long-term memory percent retained change scores**
L-WMC	**low working memory capacity individual**
mSMT	**modified Story Memory Technique**
TBI	**traumatic brain injury**
WMC	**working memory capacity**

Quantifying memory using this method allowed for the greatest control over individual performance differences. Alternate forms were used at t1 and t2.[1] Three treatment and 3 control participants were excluded from the analysis because of division by zero.

Working memory capacity

Raw scores for Digit Span Total (Digit Span Forward and Backward) and Letter-Number Sequencing from the Wechsler Adult Intelligence Scale-III (see supplemental appendix S1) administered at t1 were positively correlated ($r=.53$, $P<.001$) and achieved good reliability ($\alpha=.68$). Raw scores were reduced into a single latent WMC factor using principal component analysis (principal component analysis =.86). Individuals were classified as H-WMCs (control, n=13; treatment, n=15) or L-WMCs (control, n=16; treatment, n=15) by computing a median split on the principal component analysis scores.

Statistical analysis

Education was included as a covariate in all analyses (see Chiaravalloti et al[1]). A 2 (group: treatment vs placebo control) × 2 (capacity: H-WMC vs L-WMC) analysis of covariance was used to evaluate the effects of WMC and group on LTMPRΔ scores. Partial correlations were computed to examine the relationships between LTMPRΔ and WMC, as well as LTMPRΔ and the following cognitive domains at t1: processing speed, executive functioning, verbal ability, and perceptual ability. Tests making up each cognitive domain are outlined elsewhere.[4] Alpha was set at .05.

Results

Effect of treatment on LTMPRΔ

Similar to the main findings,[1] LTMPRΔ scores (unorganized information) did not differ as a function of group ($P=.45$).

Treatment × capacity on LTMPRΔ

Education was a significant covariate ($P=.05$). Main effects of group and capacity were not significant (P values >.27). The group × WMC interaction was significant ($F_{1,54}=7.60$, $P=.008$, $\eta_p^2=.12$). Simple comparisons revealed that H-WMCs (23.89±37.50) showed a benefit from treatment compared with L-WMCs (−14.07±43.54) ($F_{1,27}=6.81$, $P=.02$, $\eta_p^2=.20$). H-WMCs and L-WMCs did not differ in the placebo control condition ($P=.23$).

Partial correlations between LTMPRΔ, WMC, and other domains

WMC and LTMPRΔ were significantly positively related for the treatment group ($r=.67$, $P<.001$ [$R^2=.45$]) but not for the placebo controls ($P=.22$) (fig 1).

No correlations between LTMPRΔ and the other cognitive domains reached significance (P values >.36), suggesting that WMC alone is a useful cognitive marker for identifying who will and will not respond to memory rehabilitation.

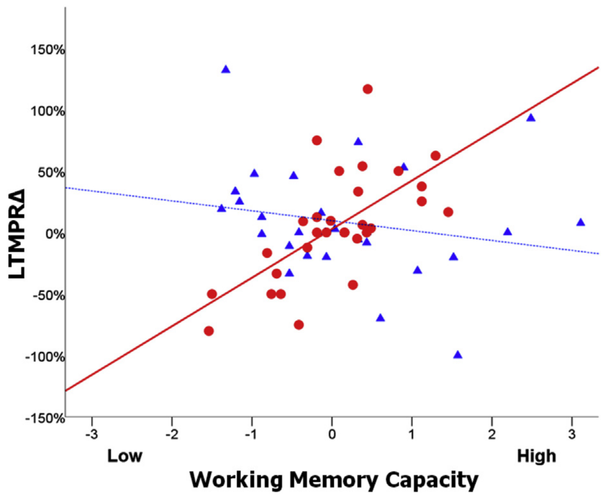

Fig 1 Scatterplot represents correlation between WMC and LTMPRΔ as a function of treatment condition. Red circles and fit line represent treatment group ($R^2 = .45$). Blue triangles and broken fit line represent control group. Individuals in the treatment group with higher WMC responded better to the memory rehabilitaiton treatment. Note: R^2 value based on partial correlation, controlling for education. Principal component analysis on Letter-Number Sequencing and Digit Span Total (only 2 variables of interest) is similar to transforming values into z scores and averaging; thus, the abscissa can be interpreted as relative z scores for the TBI sample.

Discussion

In the main trial,[1] the treatment group benefited from applying the mSMT to learning organized information; however, there was no benefit when learning unorganized information, specifically on the California Verbal Learning Test-II. Based on recent research[4-7] linking WMC and memory impairment in neurologic populations, we analyzed a subset of these data and found evidence that WMC is a useful cognitive marker[3] for identifying who responds to the memory rehabilitation strategy training approach of the mSMT. WMC moderated the effect of treatment, whereby H-WMCs in the treatment group benefited from applying the mSMT to unorganized information while L-WMCs did not.

These differences may be explained, in part, by basic research findings showing that efficiency of strategy selection is related to individual differences in WMC.[2] For example, H-WMCs use more effective retrieval strategies than L-WMCs.[9] It is possible that H-WMCs and L-WMCs both learned the mSMT compensatory strategy; however, only H-WMCs efficiently retrieved and implemented the strategy for the unorganized information. Further, H-WMCs may better integrate the mSMT strategy instructions into their learning processes, while L-WMCs may not efficiently integrate the memory strategy instructions, thus not benefiting the performance of those with L-WMC.[3]

Basic and translational research is necessary in the future to understand how memory-impaired individuals with TBI incorporate and use mnemonic rehabilitation strategies, and whether alternate strategies are more useful for L-WMC participants. Identifying cognitive markers and customizing rehabilitation options will lead to a patient-specific approach that is preferable to a 1-size-fits-all approach.[3] For example, it may be most beneficial to first resolve working memory deficits in L-WMCs followed by teaching patients the learning strategy. This may require treating deficits in 1 cognitive domain, reassessing, and then targeting another cognitive domain.

Study limitations

The analyses were theoretically and empirically motivated; however, they were necessarily post hoc, so conclusions remain preliminary. The correlational and quasiexperimental design requires future empirical work to delineate how capacity differences specifically map onto rehabilitation. Additional research is necessary to clarify whether the benefit observed for H-WMCs in the treatment condition was completely because they applied the mSMT strategy. Future work should also identify what aspect of WMC contributes to successful rehabilitation in TBI.

Conclusions

Individual differences are important for understanding and interpreting cognitive rehabilitation outcomes in heterogeneously impaired neurologic patients.[3] The present study identifies WMC as a cognitive marker that may be useful for identifying which patients will benefit from the mSMT. We encourage additional research that is directed at evaluating the role that WMC plays in memory rehabilitation for individuals with TBI.

Keywords

Brain injuries; Cognition; Memory Disorders; Neurology; Rehabilitation

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Supplemental Appendix S1 List of References of Neuropsychological Measures Used

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