= 10.2). The Brief Symptom Inventory (BSI; Derogatis, 1993) was administered to screen for psychiatric disorders. Individuals with significant and acute psychiatric symptoms were not included as study participants. The Michigan Alcoholism Screening Test (MAST; Selzer, 1971) was administered as an assessment of recent alcohol use in order to screen out individuals with suspected current alcohol abuse or dependence. No significant current alcohol abuse or dependence was suggested by individual MAST scores for participants in either the TBI or Control groups, nor did average MAST scores for each group suggest significant use (Average MAST score for control group = 0.5, SD = 1, Average MAST score for the TBI group = 0.8, SD = 1.2)

The cognitive domain of interest in this study was assessed using the California Verbal Learning Test - II (CVLT-II; Delis, Kramer, Kaplan & Ober, 2000). In order to ensure that TBI participants had a deficit in episodic memory, persons with TBI were only included in the study if they performed *at least* 1 standard deviation (SD) below normative standards on any index of the CVLT-II. This test is a reliable and valid measure used to examine episodic memory, and has been well studied in the TBI population (e.g., DeJong & Donders, 2009; Jacobs & Donders, 2007, 2008; Wolfe, et al., 2009). To be eligible for participation in this study, healthy controls were required to perform *no lower than* 1 SD below normative standards in all categories. All participants included in the study met the criteria set for their group. Of a total of 21 consented persons with TBI, seven were excused from further participation for having CVLT-II scores in the normal range. Four of 17 consented controls also had to be excluded for scoring outside the normal range. Three other consented participants (2 TBI and 1 control) also had to be excluded for MRI contraindications not disclosed at original screening. Following the neuropsychological measures, a short practice task was run outside the scanner to familiarize participants with the episodic memory task. MRI safety screening was then completed by the technologist and participants then completed the imaging session. Scans were conducted on a 3-Tesla Siemens Allegra head-dedicated scanner.

fMRI Parameters

Structural scans acquired during these sessions included axial T2 weighted images (39 contiguous 3mm slices, TR = 6440 ms, TE = 73 ms, 256 × 256 matrix, FOV = 200mm, flip angle = 150°) and a sagittal 3-D MPRAGE sequence (224 contiguous 0.78 mm slices, TR = 1680ms, TE = 2.48ms, 256×256 matrix, FOV = 200mm, flip angle = 8°). Functional images consisted of sets of 39 contiguous 3mm axial slices (TR = 2000ms, TE = 25ms, 64×64 matrix, FOV = 200mm, flip angle = 79°).

fMRI Analysis

All pre-processing steps and analyses were conducted with SPM8 software (http://www.fil.ion.ucl.ac.uk/spm/). For pre-processing, images were first corrected for subject motion using a 5th degree B-spline algorithm with a 6 parameter rigid body spatial transformation, and then registered to a mean image. Coregistration of the structural to functional images was accomplished with a normalized mutual information function. Images were then segmented, and normalized into a standard space. The final preprocessing step was smoothing with a Gaussian kernel of 10 mm FWHM.

Data analysis was conducted using a voxel-based approach on each individual participant's data, with motion regressed out. An explicit mask (created using the ART program—http://www.nitrc.org/projects/artifact_detect) was used. Individual first-level analyses were entered into a two-sample t-test. The MNI coordinates (Mazziotta, Toga, Evans, Fox, & Lancaster, 1995) of activated areas were converted to Talairach (Talairach & Tornoux, 1998) coordinates with the use of the icbm2tal algorithm described by Lancaster, et al.

(2007). These coordinates were then localized using the Talairach Client (www.talairach.org/client.html Lancaster, et al., 2000; Lancaster, et al., 1997).

Results

Behavioral Data

A 2 × 8 analysis of variance (ANOVA) was run to see the effects of Group (Control, TBI) and Condition (encoding and recognition conditions for each of the four stimulus types) on response times. As indicated by Figure 1, the conditions with picture and word stimuli resulted in the respective recognition conditions being faster than the encoding conditions. Letters and shapes both exhibited the opposite pattern, with the recognition conditions being slower than the encoding conditions. Shape conditions were especially affected, with shape recognition constituting the slowest response times in the experiment. In the 2×8 ANOVA, there was a significant main effect of condition ($F(7, 154) = 14.71$, $p < 0.001$) but no effect of group ($F(1, 22) = .28$, $p = 0.60$), and no interaction ($F(7, 154) = 0.50$, $p = 0.83$). T-tests were run to see if the TBI group performed slower on any individual conditions than controls, but none of these comparisons proved to be significant (all $ps > 0.11$, two-tailed).

A similar analysis was completed on the accuracy data. Because "phenomenons" is subjective, accuracy values are only available for the recognition conditions. A 2 (Group) × 4 (Condition) repeated measures ANOVA was conducted on these data, and a resulting significant main effect of condition was reported ($F(3, 66) = 120.36$, $p < 0.001$), again with no main effect of group ($F(1, 22) = 0.60$, $p = 0.45$) or group by condition interaction ($F(3, 66) = 1.11$, $p = 0.35$). Overall, the patterns observed in the accuracy data and the response time data were similar in that increased accuracy on a task corresponded with faster response times for that task, with pictures being responded to most accurately (88%, by all participants), followed by words (82%), letters (60%), and shapes (45%). T-tests were conducted to see if the control group was more accurate for any given condition, but no significant differences between the groups were found (all ps were greater than 0.20, two-tailed). It should be noted that performance on the shape condition was quite poor, with accuracy scores falling to chance level in both groups, and increased response times associated with these items. While the finding that the shape condition was too difficult is problematic, it could not have been predicted due to the fact that this kind of condition has not previously been examined in the TBI population. In light of these issues, it was thought best that further analysis not be conducted on the shape data, as any results would be uninterpretable.

Imaging Data

Given that some previous imaging studies have shown examples of equivalent behavioral performance between TBI and control groups on episodic memory tasks (Ricker, et al., 2001, recognition; Levine, et al., 2002, cued recall), it was not surprising that our data for the recognition condition also did not differentiate between the two groups. This finding suggests that the TBI and control groups were equally able to perform the tasks at hand, and it now falls to the imaging data to show whether there are differences in the activation record associated with yielding that equivalence of behavioral performance. As discussed in the Introduction, previous research in persons with TBI has provided evidence that they may recruit additional brain areas to accomplish the same task (Ricker, et al., 2001), and in some cases do this despite achieving the same level of behavioral performance as control participants (see discussion of subgroup in Levine, et al., 2002).

To examine differences between controls and persons with TBI on these encoding and recognition tasks, three models were run for each individual, and the individual contrast

maps were then entered into group analyses to compare the activation patterns of the two groups. The three contrasts that were examined included one focused on process (Word Encoding vs. Word Recognition), as well as two directly comparing the processing of the different stimulus types (Word Encoding vs. Picture Encoding and Word Recognition vs. Picture Recognition). In our initial analysis, considerable individual variation was noted even within the two groups (see, e.g., Miller et al. 2009, for a discussion of individual variation in fMRI). As a result, a threshold of $p = 0.01$ uncorrected along with a cluster size of 10 voxels were used for initial description of the data from the three contrasts. We then implemented more restrictive thresholding ($p < 0.001$, uncorrected, cluster size > 10 voxels) and further evaluated the areas which remained.

Word Encoding vs. Word Recognition

As compared to word recognition, word encoding did not elicit much extra activation in either group. For the recognition portion, however, both groups had some additional areas of activation. The activation seen in the TBI group was much more diverse, with three times as many clusters as in the control group. Most of these clusters were located posteriorly, and there were roughly equal numbers of clusters located in the right and left hemispheres. Controls, on the other hand, had fewer clusters, with nearly all located in the right hemisphere, though this pattern of findings is likely due to the direct comparison between both processes. While these data are preliminary, they are suggestive that persons with TBI recruited more areas in service of the same task. As noted in the description of the behavioral data, above, this pattern of activation was associated with equal task performance. When this contrast was subjected to the more conservative threshold, the only activation which remained was for the TBI group in the word recognition condition. Clusters found included bilateral areas in the temporal lobe (BA 21 and 22, extending to 39 on the right), right inferior frontal gyrus (BA 45), and the inferior parietal lobule on the left (BA 40). These areas suggest that the language and memory systems may have been working harder in the TBI group during word recognition.

Word Encoding vs. Picture Encoding

Again for this contrast, there were no voxels for word encoding which survived thresholding for either group. The controls also did not have any extra voxels associated with the picture encoding condition. The TBI group, however, experienced a great deal of activation associated with the picture encoding condition (see Figure 2). These areas of activation were more commonly seen towards the posterior regions of the brain, but were split fairly evenly between left and right hemisphere areas. Again there was evidence for an increase in the areas of activation associated with performing a task (and achieving control-equivalent behavioral performance), as well as for bilateral activation of areas. Many of these areas survived more stringent thresholding (p uncorrected < 0.001, cluster size > 10 voxels), including bilateral areas in the supramarginal gyri (BA 40), the superior frontal gyri (BA 6 and 8 on the left and 8 on the right), and the middle occipital gyri (BA 19). There was also activation in BA 37 bilaterally, though the cluster on the right was in the fusiform gyrus, while the cluster on the left was in the middle temporal gyrus. Additional lateralized areas included right superior temporal gyrus (BA 22), and left cuneiform. These areas could be more involved in the processing of pictures as opposed to words, as well as possible subvocal rehearsal. In any case, there is again clear evidence of bilateral activations as well as more areas of activity for the TBI group.

Word Recognition vs. Picture Recognition

Overall, this comparison generated less activation for each group, but there were some locations that warrant discussion. The controls, for word recognition, activated some additional areas associated with memory and language processing (i.e., anterior cingulate

cortex, inferior frontal gyrus, superior temporal gyrus, and cingulate gyrus, all on the left). While the areas activated by the control group were cortical, those activated by the TBI group were subcortical (i.e., the right pulvinar and caudate). This distinction will be considered in more detail below. No additional areas survived thresholding for the controls in the picture recognition side of the contrast. In comparison, the TBI group had several additional active areas for picture recognition, including areas which may be involved in the demands of processing more visually demanding stimuli (i.e., right fusiform gyrus, right precuneus, middle occipital gyrus, left posterior cingulate, left medial frontal gyrus, right inferior parietal lobule, and right middle temporal gyrus). The only area that remained at the more rigorous threshold (p uncorrected < 0.001, cluster size > 10 voxels) was the right precuneus (BA 7) in the TBI group during picture recognition. As compared to the controls, these results again represent a more distributed pattern of activation, as well as one slightly more skewed towards the posterior of the brain. The previously-discussed pattern of nearly equal right-left hemispheric distribution does not hold for this contrast.

Together these results suggest that, regardless of process or modality, there is a general tendency for the TBI group to activate more areas than controls, and that the active areas tend to be distributed between the two hemispheres and include more posterior clusters.

Discussion

In this study, we obtained several results which are consistent with previous imaging and behavioral findings in TBI, as well as one which may be novel. First of all, our study results indicated equivalent behavioral performance between the healthy control and TBI groups, in terms of reaction times, accuracy, and performance pattern on all task types. Although these have been carefully considered and analyzed, as our sample size was small it is possible that these negative results reflect an issue of inadequate power. Other studies with similar numbers have, however, seen differences between TBI groups and controls. In any case, despite seemingly equivalent performance, differences were found in the patterns of activation seen in the control and TBI groups. This finding is consistent with previous studies reviewed above. In a sense, it is actually ideal to design a memory task in which individuals with TBI and known memory issues are able to perform equivalently to healthy controls. This is preferable because performance differences are now removed as a factor, and we are able to interpret the differences in brain activation as related to injury, and not simply related to divergent level of performance. Secondly, as seen in previous imaging studies of cognition after TBI (e.g., Ricker et al., 2001), results of the current study found conditions under which a more bilateral pattern was seen for the TBI group. Also consistent, in nearly every contrast there was evidence for more areas of activation and a more distributed pattern of activation surviving threshold for the persons with TBI, as compared to the control group.

In the final, and potentially novel, comparison, results of this study indicated a difference between the groups such that the TBI group showed more subcortical involvement while the activation for the control group was more cortical in nature. It is not known whether this finding represents something which will be confirmed by future studies of episodic memory after TBI, or whether it is unique to this experiment and the condition of word recognition. It should be noted, however, that there is evidence that the structures shown to be active in this portion of the experiment are important in language processing (see Crosson & Haaland, 2003, for a review) as well as other cognitive functions. Even if these subcortical structures are not specifically damaged after TBI (as suggested by Primus, et al., 1997), they are highly interconnected through white matter tracts known to be especially susceptible to injury via TBI (e.g., Whyte, Hart, Laborde, & Rosenthal, 2005), and other researchers (e.g., Little, et al., 2010), have found differences in cognitive functioning associated with damage to

thalamic projection fibers. In either case, given the small number of imaging studies of episodic memory after TBI, a resolution of this issue is not yet possible, but it has the potential to be of interest for future study.

There are, however, some factors which likely impacted our findings. First of all, the study design was originally meant to have high-level controls in the Letter and Shape conditions. Unfortunately, behavioral results seem to indicate that participants did not respond to them as control conditions. As a result, Shape and Letter conditions were not useful for comparison in the manner initially intended. The resulting comparisons had to then be made without benefit of a control condition, creating increased likelihood of washout of observable brain activation between the compared conditions. It should be noted, however, that the study finding of little differential group activation during word encoding, (as found in the word encoding vs. word recognition comparison and the word encoding vs. picture encoding comparison) was consistent with the findings of Strangman (2009), despite the fact that controls and analyses were different between studies. Further study will be required to further assess whether this consistency is a true pattern in neural activation during memory encoding.

There was also a great deal of individual variation, both within groups as well as between members of the two groups. Part of this is likely due to factors unique to the individuals who participated. Miller, et al., (2009) investigated individual differences on three tasks employing different kinds of memory (episodic, semantic, and working) and found that activation was more similar within a single participant across the three tasks than it was across participants doing the same task. Hester, Fassbender, & Garavan (2004) have also addressed this problem to a lesser extent but did find individual differences in activation as well. Another issue which may be affecting our results is that our participants were quite diverse in age, ranging from 18 to 54 across a group of only 12 participants. At the lower end of the age range, participants' brains are likely to not be fully myelinated (Sowell, et al., 2003), while at the higher end of the spectrum normal aging processes may already be underway (see, e.g., Rajah & D'Esposito, 2005, for an example of how aging can lead to differences in fMRI activation). The TBI sample was also necessarily rather heterogeneous. Participants in the TBI group were in the same early chronic phase of injury, but there were differences in the time since injury. Variation in severity and pathology could have also contributed to the heterogeneity of the TBI sample. While necessary to ensure adequate recruitment, including participants with any such differences could lead to lower data quality in a group analysis situation. In sum, it is highly likely that both individual differences and a wide age distribution played a role in our limited ability to appreciate changes in brain activation due to our experimental conditions.

An additional issue which has seen more discussion in literatures dealing with populations other than TBI is that of the reasons behind recruitment of "extra" brain regions during task performance. This is seen quite often in the literature on aging. When older participants are found to have more activation for a given task, it is sometimes attributed to greater recruitment due to neural inefficiency (e.g., Daverese, Habbi, & Rugg, 2008). Another possibility is that increased or divergent activation is due to some form of compensation for brain systems that are not working as they did *before* being injured. While the current study is not designed specifically to address this question, the results may suggest an explanation more to functional compensation, given that the "extra" areas of activation seen in the TBI group were outside the typical memory areas. In fact, they seemed to be drawing more heavily on other cognitive systems which support memory. This finding is not surprising, and the influence of cognitive functions like attention or executive control on episodic memory is beginning to come to light (e.g., Cabeza, Ciaramelli, Olson, & Moscovitch, 2008). These functions are known to be commonly affected by TBI, and disconnection of

white matter tracts contributing to these cognitive functions is also of concern in the TBI population. Future studies from our lab are planning to address these issues by using an episodic memory paradigm that directly manipulates cognitive load during encoding and by considering data from DTI and functional connectivity analyses as well as fMRI.

Finally, given the novelty of this area of research, this study represents a step forward in the efforts to characterize the neural substrates of episodic memory after TBI. While Strangman et al. (2008, 2009) chose an ROI approach to the analysis of memory circuits based on those activated by healthy controls, it should be kept in mind that their purpose was to evaluate whether currently available cognitive rehabilitation strategies could be evaluated for usefulness depending on fMRI findings, even though the more general correlates of fMRI activation associated with episodic memory performance after TBI had yet to be established. Our goal in this study was broader, as we felt that, given the paucity of published studies in this area, it was critical to establish information regarding changes to those memory systems after TBI, and to learn more about changes which might occur outside of normal circuitry. As a result, we felt that a voxel-based approach was more readily applicable for this purpose. It is our hope that, as we continue to learn more about episodic memory functioning after TBI, our increased ability to create new and innovative approaches to assessment and treatment which utilize this knowledge will allow for improvements in quality of life for those who have sustained TBI.

Acknowledgments

This study was supported in part by a grant (NIH-NINDS R01NS04178-01) awarded to Dr. Ricker.

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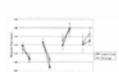

Figure 1.
Response times by group and condition.

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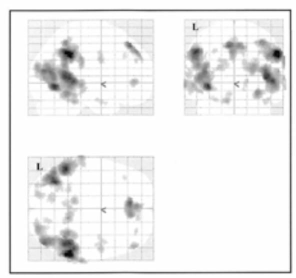

Figure 2.
Activation for Picture Encoding as compared to Word Encoding for the TBI group at $p < 0.005$, uncorrected, excluding clusters with fewer than 10 voxels.

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Table 1

Participant Demographics for the TBI Group

Gender	Age	Yrs. Educ.	InitialGCS	Best GCS/24 hrs.	Yrs. Since injury	Injury Cause
M	35	12	3(T)	7	1.9	MVA
M	18	12	15	15	1.1	Sports
M	31	15	3(T)	7	2.2	MCA
F	21	12	15	15	1.9	MVA
F	29	15	12	15	2.4	Fall
M	23	14	3(TP)	11	2.2	MVA
M	54	16	3(TP)	7	1.1	MCA
M	41	18	7	11	1.1	Falling object
M	30	16	13	15	2.0	MCA
M	47	16	15	15	1.1	Bicycle
F	24	16	4	14	1.1	MVA
M	53	16	14	14	2.6	Fall

GCS = Glasgow Coma Score, T = intubated, P = given paralytic medication, MVA = motor vehicle accident, MCA = motorcycle accident

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Admissibility:

MCL 600.2955

MCL § 600.2955

Michigan Compiled Laws Service > Chapter 600 (Revised Judicature Act of 1961) (§§ 600.101 — 600.1104) > Act 236 of 1961 (Chs. 1 — 58 > Chapter 28(Provisions Concerning Specific Actions (§§ 600.1801 — 600.2971)

§ 600.2955. Scientific or expert opinion or evidence; admissibility.

No. 2003

(1) An action in Michigan is subject to the rule of a minority of jurisdictions, a scientific opinion rendered by a witness qualified expert based scientific evidence unless the trial determines that the opinion is reliable and will assist the trier of fact in making that determination. The court shall determine the relevant and the basis for the opinion, which may include the facts, techniques, methodology, and reasoning upon which by the trier of fact and the character of the following factors:

(a) Whether the opinion and the theory have been subjected to scientific testing and application;

(b) Whether the opinion and the theory have been subjected to peer review publication;

(c) Prevalence and maintenance of generally accepted standards governing the application and interpretation of a methodology or technique and whether the statement is based on consistent with those standards;

(d) The known or potential error rate of the opinion and its basis;

(e) The degree to which the opinion and its basis are generally accepted within the relevant expert authority. As used in this subdivision, "relevant expert community" exemplifies a group or professionals in the field of study and are generally recognized applying the knowledge in distinct manner.

Whether the basis for the opinion conclusion and whether subjects certain that would rely on the basis which is relied the trial efficiency being preferred.

(f) Whether the opinion or conclusion is based upon by experts outside of the context of litigation.

(2) A trial knowledge of court of scientific evidence must be admitted not evidence only if an witnesses qualified that it has achieved generally acceptance among reputed and distinguished experts in that.

(3) In an actionbeing tried not responsible, the provisions of this section shall be applied in criminal actions. But, claims for expert testimony provided in section 2170.

History

Pub. Act 1961, No. 236, Div. 21, § 2955; amended by Pub. Act 1987, No. 184, effective March 29, 1988.

Amendments

Admissibility:

MRE 702

MRE 702

Rules and Proposed Rules current with changes received through August 1, 2023.

Michigan Court Rules > Michigan Rules of Evidence

Rule 702. Testimony by Experts.

If the court determines that scientific, technical, or other specialized knowledge will assist the trier of fact to understand the evidence or to determine a fact in issue, a witness qualified as an expert by knowledge, skill, experience, training, or education may testify thereon in the form of an opinion or otherwise if (1) the testimony is based on sufficient facts or data, (2) the testimony is the product of reliable principles and methods, and (3) the witness has applied the principles and methods reliably to the facts of the case.

History

Rule 702, amended on January 1, 2019.

Amendments.

Notes

Notes

MRE 702 is identical with Fed. R. Evid. 702 as it was amended effective December 1, 2000. The only difference is that the word "if" replaces "the court determines that recognized."

Commentary

Staff Comment:

On June 27, 2018, amendment of MRE 702 effective January 1, 2019 conforms the Michigan rule to the Federal Rules of Evidence as amended effective December 1, 2000, except that the Michigan rule retains the word "The court determines that" after the word "if" at the outset of the rule. The new language requires the judge to act as gatekeeper who must exclude unreliable expert testimony. See Daubert v. Merrell Dow Pharmaceuticals, Inc., 509 U.S. 579, 113 S. Ct. 2786, 125 L.Ed.2d 469 (1993) and Kumho Tire Co., Ltd. v. Carmichael, 526 U.S. 137, 119 S.Ct. 1167, 143 L.Ed.2d 238 (1999). The revised rule emphasizes the centrality of the court's gatekeeping role in excluding unreliable expert theories and methodologies from jury consideration.

Overnight J. - opposed to amendment of MRE 702.

Weaver, J. - would not adopt the amendment MRE 702 at the present time.

Key: J. - Justice.

I would rather be wrong on the law at this time. The amendments, on the foundation non-expert testimony the issue, are inconsistent the Prosecuting Attorneys Association of Michigan and others presenting this

Under Board