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Comorbid Conditions Differentiate Rehabilitation Profiles in Traumatic Versus Nontraumatic Brain Injury: A Retrospective Analysis Using a Medical Database

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Purpose: We examined the relationship between comorbid medical conditions and changes in cognition over the course of rehabilitation following acquired brain injury. In particular, we compared outcomes between traumatic brain injury (TBI) and non-TBI using a retrospective inpatient rehabilitation dataset. We hypothesized that differences by diagnosis would be minimized among subgroups of patients with common comorbid medical conditions. **Materials and Methods:** We used the Functional Independence Measure (FIM)-cognition subscale to index changes in cognition over rehabilitation. A decision tree classifier determined the top 10 comorbid conditions that maximally differentiated TBI and non-TBI. Ten subsets of patients were identified by matching on these conditions, in rank order. Data from these subsets were submitted to repeated-measures logistic regression to establish the minimum degree of commonality in comorbid conditions that would produce similar cognitive rehabilitation, regardless of etiology. **Results:** The TBI group demonstrated a greater increase in ordinal scores over time relative to non-TBI, across all subscales of the FIM-cognition. When both groups were matched on the top 3 symptoms, there were no significant group differences in rehabilitation trajectory in problem-solving and memory domains (Cohen's *d* range: 0.2-0.4). **Conclusion:** Comorbid medical conditions explain differences in cognitive rehabilitation trajectories following acquired brain injury beyond etiology. **Key words:** *comorbid medical conditions*, *FIM-cognition*, *repeated measures*, *traumatic brain injury*

AS MEDICAL FACILITIES increasingly rely on electronic medical records (EMRs), huge data are amassed that may improve our understanding of medical conditions. The parallel development of complex analytical techniques provides an opportunity to test novel hypotheses on large datasets in a low-cost and time-effective manner. This study aimed to take advantage of such advances. We examined the relationship between comorbid medical conditions and changes in cognition over the course of rehabilitation following acquired brain injury.[1] In particular, we compared cognitive outcomes between patients with traumatic brain injury (TBI) and non-TBI. For this purpose, we used a retrospective inpatient rehabilitation dataset from a level I trauma center.

Patients with TBI and non-TBI are placed in the same rehabilitation group in the Uniform Data System for Medical Rehabilitation (UDSMR; Impairment Group Code [IGC] = 2). Although there are considerable differences in etiology between TBI and non-TBI, the disorders are similar in that they both present with primary injuries that may either be focal or diffuse throughout the brain.[2,3] Both patients with TBI and non-TBI demonstrate a heterogeneity of comorbid medical conditions, yet both show comparable clinical courses toward stable function.[4,5] Since improvement in cognitive

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functioning is a primary rehabilitation goal, it is striking that such observations related to "stable function" do not definitively address cognitive outcomes. In general, such studies are limited, and even fewer consider the relationship between cognitive outcomes and the influence of comorbid medical conditions on recovery.

Critically, there is evidence to suggest that comorbid medical conditions (hereafter referred to as "comorbid conditions") directly impacts cognitive functioning in these populations. For example, a recent study showed that comorbid thoracic-dorsal spinal injury impaired cognitive functioning in TBI.[6] Although individual comorbid conditions rarely predict functional outcomes following TBI, taking into account the cumulative effect of comorbid conditions better accounts for functional outcomes in this group.[7] Indeed, the heterogeneity in rehabilitation outcomes may not be solely due to the etiology of the disorder. It may be more accurately defined by the comorbid conditions from which the patient recovers. Therefore, we hypothesized that when patients with TBI and non-TBI had similar comorbid conditions, they would show similar cognitive recovery profiles. Existing cognitive rehabilitation programs do partially account for comorbid conditions, but these are largely restricted to mental health issues.[8–10] Considerably less attention has been paid to comorbid physical health issues interacting with cognitive recovery, which is concerning since both TBI and non-TBI are strongly associated with injuries to physical systems (eg, injury to the circulatory system).[5] Thus, evidence supporting our hypothesis would suggest that cognitive interventions must emphasize a more holistic approach and engage in adequately identifying and treating comorbid health issues—even those separate from neurological issues—to more effectively promote cognitive recovery.

We evaluated cognitive recovery based on the cognitive subscale of the Functional Independence Measure (FIM).[11] This subscale is composed of 5 items: comprehension, expression, social interaction, problem-solving, and memory. These items capture domains of cognitive functioning that have long-term implications for recovery. For instance, individuals with TBI commonly experience pervasive deficits in executive functioning and social interaction; these deficits may be due to secondary injuries in this population.[12,13]

Due to the heterogeneity of comorbid conditions and variability in injury in TBI and non-TBI, it is not feasible to match patients for every condition. A common approach to address this issue is to use proxy comorbidity indices—summary ratings that evaluate whether or not a given set of comorbid symptoms are present in the patient sample (eg, Charlson Comorbidity Index).[14] However, such proxy-based approaches lack specificity to patient groups.[15] Here, we take a data-driven approach to identify comorbid conditions that statistically differentiate TBI and non-TBI groups, and then match individuals on the absence of these conditions to create statistical equivalence between patients.

In this study, we compiled the total number of comorbid conditions recorded in the EMR across both acquired brain injuries. Comorbid conditions that distinguished patients with TBI from non-TBI were determined by a decision tree classifier. This statistical method accounts for complex patterns of medical conditions. It is particularly useful when it is unclear whether a given symptom or condition is a comorbidity, a complication, or an extended definition of a primary diagnosis.[15] Through this process, we identified 10 comorbid conditions that best distinguished the groups. The subgroup of patients who lacked these conditions were determined to have a statistically "common comorbid profile" regardless of etiologic diagnosis. In a repeated-measures logistic regression, we examined differences in recovery by diagnosis in the entire patient sample, as well as in subgroups of patients with a common comorbid profile. We hypothesized that, as a whole, patients with TBI and non-TBI would demonstrate different cognitive rehabilitation trajectories. Further, we postulated that these differences by etiologic diagnosis would be minimized among subgroups of patients with common comorbid profiles. Evidence in favor of our hypothesis would suggest that cognitive outcomes can further be improved by considering the influence of various comorbid medical conditions, beyond just the primary etiology, and thus intentionally developing a more coordinated treatment program.

METHODS

Retrospective data source

This study was approved by the University of Illinois and Carle Hospital Institutional Review Boards. All data were collected from patients at a level I trauma center in the Midwest. The dataset was extracted from the UDSMR (http://www.udsmr.org), which designates admission IGCs to describe the primary reason that patients are being admitted to a rehabilitation program; generally, impairment groups with the same IGC are thought to have similar resource requirements and clinical homogeneity. These impairment groups include stroke, brain dysfunction, orthopedic disorders, and medically complex conditions. Our analysis focuses on the brain dysfunction group.

The brain dysfunction group comprises 2 subgroups—TBI and non-TBI. Patients classified as TBI experience 2 levels of brain insult. The primary insult is the physical brain trauma that occurs due to external mechanical forces at the moment of impact. The secondary insult represents pathological ramifications that emerge as a

consequence of the primary insult, but with delayed clinical presentation.

Brain dysfunctions that are nonvascular and are not the result of direct mechanical impact are grouped under the non-TBI category. These events may be caused by a variety of etiologic agents. They may take the form of cerebral inflammation (leading to encephalitis), inadequate oxygen supply (leading to anoxic brain damage), or degenerative processes (leading to Alzheimer's disease).

Sample description

We obtained data collected at preadmission, admission, and discharge for 4191 inpatient rehabilitation patients. The data were collected from 1994 to 2014 and included a sample of 425 patients with TBI and 325 patients with non-TBI. The patients included in the present analyses were assigned up to 10 comorbid conditions. In the combined TBI and non-TBI dataset, a total of 1317 unique comorbid conditions were reported.

In a follow-up analysis, we evaluated whether common comorbid profiles minimized between-group differences by diagnosis. For this purpose, we refined the dataset to reflect the "typical patient," as defined in the UDSMR. A "typical patient" has a length of stay of more than 3 days, receives a full course of inpatient rehabilitation care, and is discharged to the community. Community settings include all out-of-hospital living accommodations such as home, board and care, and transitional or assisted living. Therefore, we excluded patients who stayed in the inpatient rehabilitation facility for 3 days or less; patients who experienced program interruptions due to death or other reasons; patients whose admission or discharge records did not exist; and patients who were transferred to other hospital settings (including other rehabilitation facilities, acute care, or other care units). To minimize confounding effects, if patients were readmitted to the rehabilitation facility (satisfying the "typical patient" criteria), only information from their first admission and discharge entries were used for analysis purposes. This resulted in a sample of 210 patients with TBI, and 114 patients with non-TBI who were included in the follow-up analysis.

Function assessment

Patient functional status at admission and discharge was assessed using the FIM.[11,16] This instrument has 2 subscales: an FIM-motor subscale of 13 motor items and an FIM-cognition subscale of 5 cognitive items. Across both subscales, tasks are rated on a 7-point ordinal scale to indicate whether the patient can complete the task independently (7 = complete independence, 6 = modified independence), requires modified dependence (5 = supervision or setup, 4 = minimal contact assistance, 3 = moderate assistance), or requires complete dependence (2 = maximal assistance, 1 = total assistance).

The current study tests hypotheses only with the FIM-cognition items. The 5 cognition items are comprehension, expression, social interaction, problem-solving, and memory. The comprehension item assesses understanding of either auditory or visual communications (eg, writing or sign language). The expression item assesses the clear and fluent articulation of information using vocal or nonvocal forms of communication. The social interaction item assesses constructive social communication skills–specifically, engaging with other individuals in a manner that allows dealing with one's own needs as well as the needs of others. The problem-solving item assesses skills associated with problems of daily living. The memory item assesses the ability to store and retrieve information while engaging in everyday routines in community settings.

Statistical analyses

We assessed cognitive rehabilitation trajectories for individuals with TBI and non-TBI. First, we performed a surface-level comparison on mean FIM-cognition scores at admission and discharge from rehabilitation. Next, we employed decision tree classifiers. Decision trees were used to predict TBI versus non-TBI group assignment based on data-driven rules inferred from the aggregate comorbid condition dataset. This analysis was done in Python's Scikit Learn toolbox (sklearn.tree package).

Through this process, we operationalized "distinguishing conditions" as the top 10 comorbid conditions that were *minimally* shared between the 2 groups and ranked these conditions in descending order. Specifically, the topmost was the comorbid condition that maximally distinguished the 2 groups–that is, the condition that would most likely be observed for one group and not the other. We operationalized "common comorbid profiles" as subsets of patients who showed an *absence* of these distinguishing conditions–that is, a set of comorbid conditions that did not differ between diagnosis groups. We hypothesized that individuals with the "common comorbid profile" would show a similar cognitive rehabilitation trajectory, regardless of whether the injury was TBI or non-TBI.

To characterize between-group differences in rehabilitation profile, change in FIM-cognition score over rehabilitation period was estimated in a 2-level (admission and discharge) repeated-measures regression framework. Because FIM scores are interpreted as an ordinal scale, this analysis estimated group differences in a proportional odds logistic regression analysis in the R software repolr package. Furthermore, we used the BootES package in R to generate unstandardized effect size values and corresponding bootstrapped 95%

confidence intervals.[17] For this limited purpose, the FIM scores were treated as a continuous measure, which is an accepted practice for the estimation of effect size with scales including at least 5 levels,[18] as we have here.

To more accurately gauge whether the 2 groups would show similar FIM-cognition scores across all 5 subscales when matched on comorbid conditions, we conducted the repeated-measures model in a hierarchical fashion. First, we ran the repeated-measures model on the total dataset, without matching on common comorbid profiles. In this analysis, we expected to find differences between TBI and non-TBI groups in cognitive rehabilitation trajectories. Second, we tested the hypothesis that patients who were matched on common comorbid profiles would show similar cognitive rehabilitation trajectories across all subscales, regardless of etiology.

To explore the minimum degree of commonality that can equate rehabilitation trajectories, we selected different subsets of patients that were matched on an increasing number of comorbid conditions. Ten subsets of patients were identified by matching on the top 10 comorbid conditions, in rank order. For example, the first subset only shared the topmost-ranked comorbid condition, the second subset shared the top 2-ranked comorbid conditions, and so on. Next, we identified FIM-cognitive trajectories across 10 kinds of "common comorbid profiles." Data from each subset of patients were submitted to repeated-measures logistic regression to test whether there were differences in cognitive rehabilitation trajectory between TBI and non-TBI diagnoses. Significance tests of effects following multiple comparisons were adjusted with a family-discovery-rate (FDR) correction method (q value).[19] By comparing results across subsets, we identified the minimum degree of commonality in comorbid conditions that would produce similar cognitive rehabilitation trajectories, regardless of etiology.

RESULTS

Our initial analysis examining mean scores suggested that patients with non-TBI performed higher than patients with TBI in all FIM-cognitive domains at preintervention (mean range of scores for non-TBI: 3.51-4.41; mean range of scores for TBI: 3.27-4.29; see Figure 1A). This pattern was reversed in the postintervention scores (mean range of scores for non-TBI: 4.64-5.78; mean range of scores for TBI: 4.80-5.85; see Figure 1A). We observed variability in performance also within each diagnosis group at pre- and postintervention (see Figure 1B).

The final optimized decision tree classifier model suggested that, of all comorbid conditions across TBI and non-TBI, intracranial injury best distinguished TBI from non-TBI. In individuals who did not have this comorbid condition (ie, no intracranial injury in TBI and non-TBI), lung contusion was the next strongest predictor to differentiate groups, followed by dorsal vertebra closed fracture, open scalp wound, orbital floor closed fracture, lumbar vertebra fracture, history of TBI, head abrasion, late effect skull fracture, and facial bone fracture (see Figure 2). As this was an exploratory approach, any comorbid condition reported by either group may be identified as predictors that differentiated between them. We observed that all top 10 comorbid conditions that maximally differentiated the 2 groups were common of TBI. Ten subsets of patients were identified by matching on these comorbid conditions and were used in further analysis.

In a repeated-measures ordinal logistic regression model, we evaluated diagnosis-related differences in cognitive rehabilitation trajectory across the FIM subscales, including main effects of group, time (pre- vs postintervention), and the interaction group × time. In this model, coefficients are interpreted as cumulative log odds ratios. Negative coefficients indicate an increase in ordinal score (see Table 1), relative to the TBI group or preintervention average for time effects. We applied an FDR method to the model to determine significance effects.

Across the intervention, patients with TBI demonstrated lower FIM-cognition scores relative to those with non-TBI on all subscales. The cumulative log-odds ratio with respect to the TBI group ranged from 0.23 (memory) to 1.38 (comprehension). However, the magnitude of between-group differences was relatively small (Cohen's $d = -0.02$ to 0.00; see Table 1). Further, there were no diagnosis-related significant differences in the problem-solving and memory domains, once the 2 groups became matched on the top 2 symptoms (FDR-corrected q value < 0.05).

Considering rehabilitation trajectory following intervention, a general comparison of all patients showed that FIM scores on all subscales improved greatly (Cohen's $d = 0.7$-0.9): cumulative log-odds ratio with respect to prerehabilitation ranged from −0.92 (expression) to −1.31 (problem-solving); FDR-corrected $q < 0.05$ for all subscales (see Table 1 and Figure 3). When not matched on comorbid conditions, TBI and non-TBI differed in the magnitude of improvement. The TBI group demonstrated a greater increase in ordinal scores over time relative to the non-TBI group, across all subscales (see Table 1).

When patients were matched on increasingly common comorbid profiles, the diagnosis-related differences were minimized: cumulative log-odds ratio ranged from −0.27 (memory) to −0.80 (comprehension); FDR-corrected $q < 0.05$ for all subscales (except some subset comparisons of the problem-solving and memory subscales; see Table 1). When patients were matched on the top 3 comorbid conditions, there were no significant group differences in rehabilitation trajectory

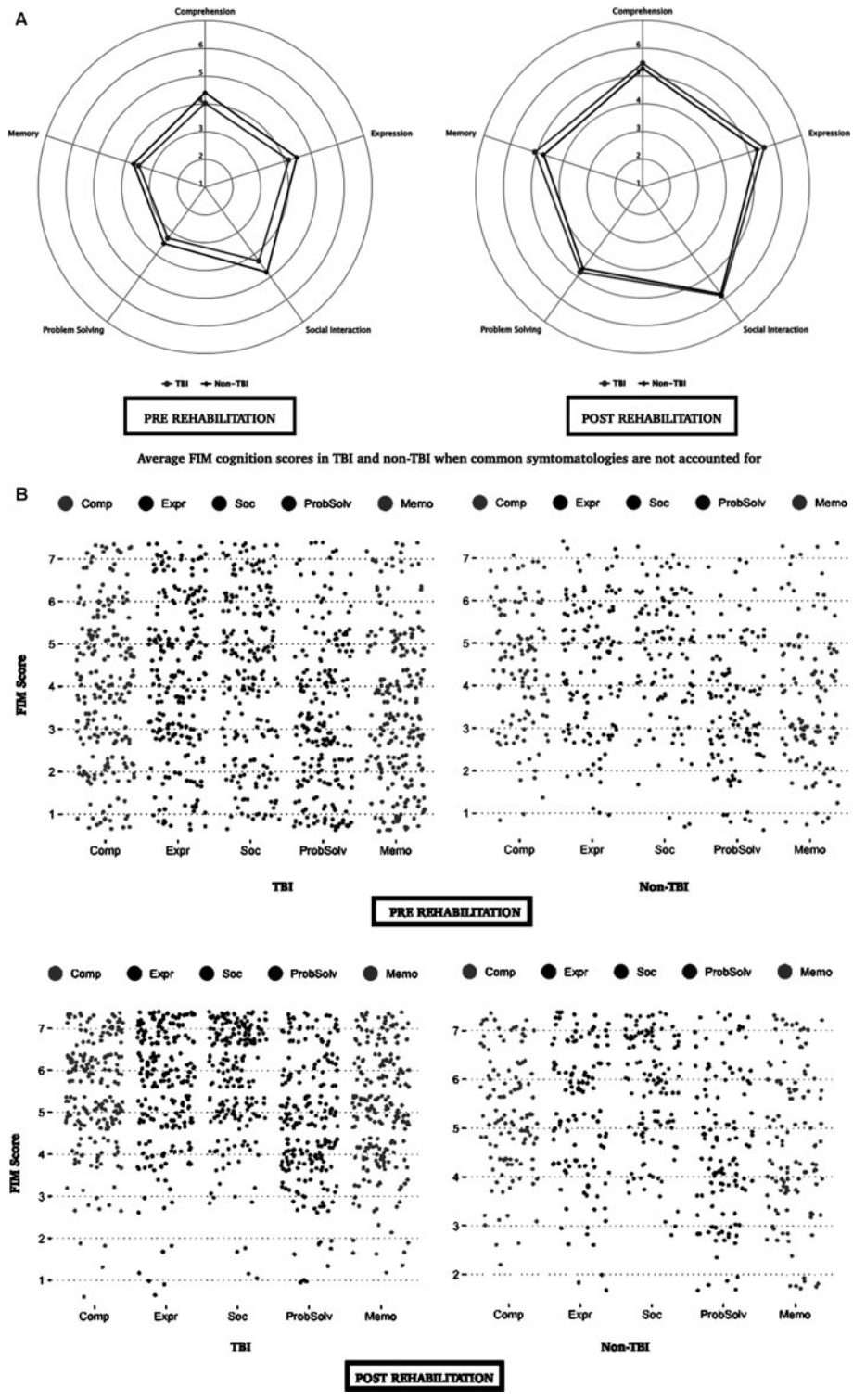

Figure 1. (A) Average FIM-cognition scores by domain in TBI and non-TBI groups at pre- and postrehabilitation. Patients with TBI (blue line) and patients with non-TBI (black), on average, demonstrated improvement in FIM scores across cognitive domains as illustrated by the wider data web at postrehabilitation (STAT). Patients with TBI presented with lower mean FIM scores at prerehabilitation but performed comparably or better than patients with non-TBI patients at postrehabilitation. (B) Distribution of FIM-cognition scores by domain in TBI and non-TBI groups at pre- and postrehabilitation. Each individual point is shown by group (ie, TBI or non-TBI). For a given group, the number of points corresponds to the number of records in a given FIM category (Comp = Comprehension, Expr = expression, Soc = social interaction, ProbSolv = problem-solving, Memo = memory). FIM scores are ranked from 1 to 7. Lower FIM scores indicate more cognitive impairment. FIM indicates Functional Independence Measure; TBI, traumatic brain injury.

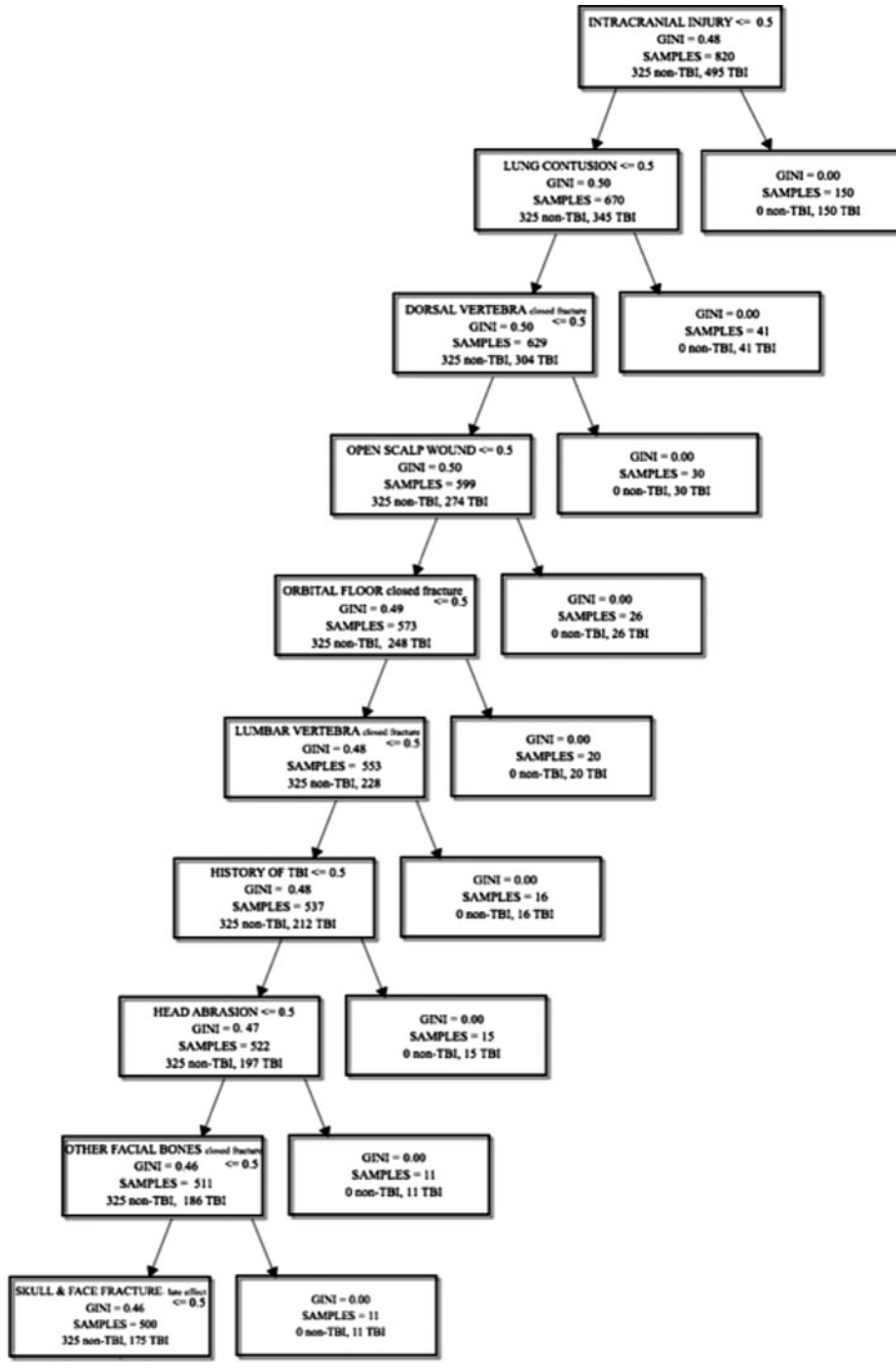

Figure 2. Comorbid condition decision tree classification for TBI ($n = 495$) and non-TBI ($n = 325$). Of all the features (ie, comorbid conditions), intracranial injury is the top predictor that distinguishes between TBI or non-TBI groups. Of the 820 patients considered, all 150 individuals reported to have an intracranial injury were classified as TBI (Gini index = 0). For the remaining individuals (TBI and non-TBI who do not have this comorbid condition), the next best classifier was lung contusion. Of the 41 individuals who had this condition (but did not have intracranial injury), all were observed to have a TBI diagnosis. It is noteworthy that the 10 top-ranked comorbid conditions that best distinguished TBI and non-TBI groups were specific to TBI. FIM indicates Functional Independence Measure; TBI, traumatic brain injury.

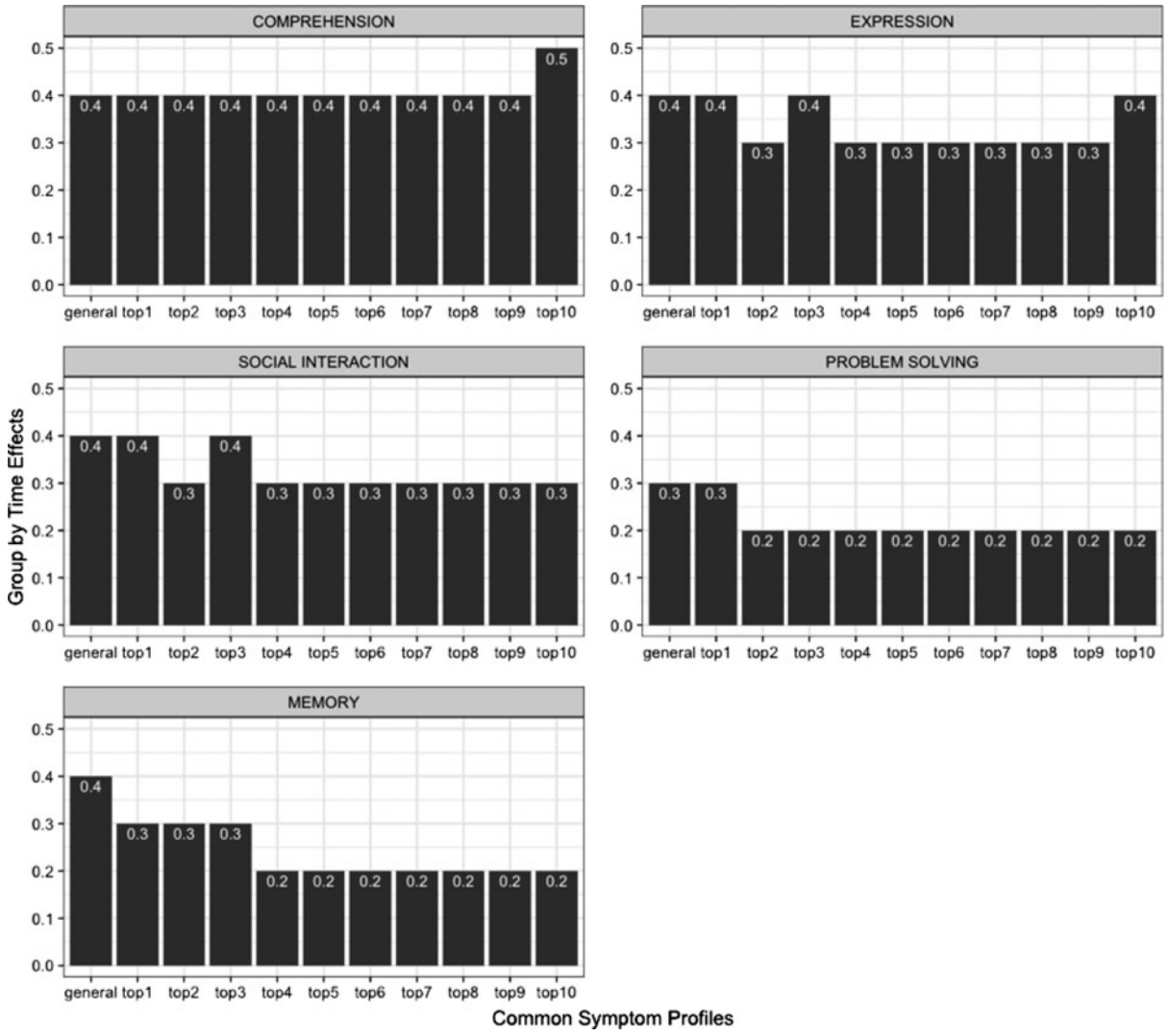

Figure 3. Effect size estimates showing group×time intervention effects for the comprehension, problem-solving, and memory domains of the FIM-cognition. As is seen in the "general" comparison of all patients, there are moderate differences between patients with TBI and non-TBI in the magnitude of functional improvement from pre- to postrehabilitation. Matching patients on common comorbid profiles absent of the top ranked distinguishing comorbid conditions, the difference between patients with TBI and non-TBI in rehabilitation trajectories is reduced in the social interaction, problem-solving, and memory cognitive domains. However, this pattern of effect is inconsistent for performance in the comprehension and expression domains. FIM indicates Functional Independence Measure; TBI, traumatic brain injury.

in problem-solving and memory domains, and the group ×time effect size was reduced (Cohen's *d* range: 0.2 to 0.4; see Table 1). These group differences remained significant for the comprehension, expression, and social interaction domains, with the latter showing a decline in group×time effect size for increasingly common comorbid profiles.

DISCUSSION

Patients with TBI and non-TBI are both placed in the same rehabilitation category (UDSMR) and both etiologic diagnoses present with heterogeneity in outcomes. Variability in rehabilitation outcomes have been linked to comorbid conditions.[5,6] We hypothesized that patients with similar comorbid medical conditions, regardless of diagnosis, may show similar cognitive rehabilitation trajectories. We used a decision tree classifier to identify the top 10 comorbid conditions that best distinguished TBI from non-TBI. Decision tree classifiers are agnostic to the specific label applied to biological sequela and therefore classify symptoms or conditions as TBI or non-TBI without being bound by taxonomical constraints. In this exploratory analysis, intracranial

TABLE 1 *Change in functional scores from pre- to postrehabilitation across FIM cognitive domains and group differences therein*[a]

Term	Subset sample size	Number of similar comorbid conditions	Relative log odds ratio estimate (effect size estimate)				
			COMP	EXPR	SOC	SOLV	MEMO
TBI (relative to non-TBI)	NT = 114, T = 210	General	*1.13 (−0.1)*	*0.94 (0.0)*	*1.09 (−0.1)*	*0.89 (0.0)*	*0.84 (0.0)*
	NT = 114, T = 159	1	*1.10 (−0.1)*	*0.97 (0.0)*	*1.10 (−0.1)*	*0.83 (0.0)*	0.70 (0.1)
	NT = 114, T = 142	2	*0.95 (−0.1)*	*0.79 (0.0)*	*0.89 (−0.1)*	0.64 (0.0)	0.46 (0.1)
	NT = 114, T = 130	3	*0.99 (−0.1)*	*0.85 (0.0)*	*1.03 (−0.1)*	0.76 (0.0)	0.45 (0.1)
	NT = 114, T = 120	4	*0.95 (0.0)*	*0.74 (0.0)*	*0.90 (−0.1)*	0.62 (0.0)	0.23 (0.1)
	NT = 114, T = 113	5	*1.00 (0.0)*	*0.76 (0.0)*	*0.87 (−0.1)*	0.64 (0.0)	0.27 (0.1)
	NT = 114, T = 106	6	*1.12 (−0.1)*	*0.78 (0.0)*	*0.99 (−0.2)*	0.74 (−0.1)	0.36 (0.0)
	NT = 114, T = 103	7	*1.19 (−0.1)*	*0.81 (−0.1)*	*1.08 (−0.2)*	0.75 (−0.1)	0.37 (0.0)
	NT = 114, T = 99	8	*1.22 (−0.1)*	*0.82 (−0.1)*	*1.07 (−0.2)*	0.79 (−0.1)	0.38 (0.0)
	NT = 114, T = 96	9	*1.23 (−0.1)*	*0.85 (−0.1)*	*1.02 (−0.2)*	0.75 (−0.1)	0.34 (0.0)
	NT = 114, T = 93	10	*1.38 (−0.1)*	*0.98 (−0.1)*	*1.10 (−0.2)*	0.90 (−0.1)	0.44 (0.0)
Change in scores at postrehabilitation (relative to prerehabilitation)	NT = 114, T = 210	General	*− 0.99 (0.8)*	*− 0.94 (0.8)*	*− 1.12 (0.9)*	*− 1.25 (0.9)*	*− 1.13 (0.9)*
	NT = 114, T = 159	1	*− 0.97 (0.8)*	*− 0.92 (0.8)*	*− 1.13 (0.9)*	*− 1.22 (0.9)*	*− 1.10 (0.8)*
	NT = 114, T = 142	2	*− 0.99 (0.8)*	*− 0.93 (0.7)*	*− 1.15 (0.8)*	*− 1.25 (0.8)*	*− 1.12 (0.8)*
	NT = 114, T = 130	3	*− 1.00 (0.8)*	*− 0.94 (0.7)*	*− 1.14 (0.8)*	*− 1.26 (0.8)*	*− 1.14 (0.8)*
	NT = 114, T = 120	4	*− 1.01 (0.8)*	*− 0.94 (0.7)*	*− 1.14 (0.8)*	*− 1.26 (0.8)*	*− 1.14 (0.7)*
	NT = 114, T = 113	5	*− 1.02 (0.8)*	*− 0.95 (0.7)*	*− 1.14 (0.8)*	*− 1.26 (0.8)*	*− 1.13 (0.7)*
	NT = 114, T = 106	6	*− 1.03 (0.8)*	*− 0.95 (0.7)*	*− 1.15 (0.8)*	*− 1.28 (0.8)*	*− 1.14 (0.7)*
	NT = 114, T = 103	7	*− 1.03 (0.8)*	*− 0.95 (0.7)*	*− 1.15 (0.8)*	*− 1.28 (0.8)*	*− 1.14 (0.7)*
	NT = 114, T = 99	8	*− 1.03 (0.8)*	*− 0.94 (0.7)*	*− 1.15 (0.8)*	*− 1.28 (0.8)*	*− 1.14 (0.7)*
	NT = 114, T = 96	9	*− 1.03 (0.8)*	*− 0.94 (0.7)*	*− 1.16 (0.8)*	*− 1.29 (0.8)*	*− 1.15 (0.7)*
	NT = 114, T = 93	10	*− 1.04 (0.8)*	*− 0.95 (0.7)*	*− 1.16 (0.8)*	*− 1.31 (0.8)*	*− 1.16 (0.7)*

(*continues*)

TABLE 1 *Change in functional scores from pre- to postrehabilitation across FIM cognitive domains and group differences therein*[a] (Continued)

Term	Subset sample size	Number of similar comorbid conditions	Relative log odds ratio estimate (effect size estimate)				
			COMP	EXPR	SOC	SOLV	MEMO
Group × time (relative to non-TBI and prerehabilitation)	NT = 114, T = 210	General	*− 0.71 (0.4)*	*− 0.64 (0.4)*	*− 0.65 (0.4)*	*− 0.55 (0.3)*	*− 0.60 (0.4)*
	NT = 114, T = 159	1	*− 0.71 (0.4)*	*− 0.67 (0.4)*	*− 0.66 (0.4)*	*− 0.51 (0.3)*	− 0.55 (0.3)
	NT = 114, T = 142	2	*− 0.60 (0.4)*	*− 0.53 (0.3)*	*− 0.52 (0.3)*	− 0.38 (0.2)	− 0.39 (0.3)
	NT = 114, T = 130	3	*− 0.63 (0.4)*	*− 0.56 (0.4)*	*− 0.60 (0.4)*	*− 0.43 (0.2)*	− 0.39 (0.3)
	NT = 114, T = 120	4	*− 0.61 (0.4)*	*− 0.50 (0.3)*	*− 0.55 (0.3)*	− 0.35 (0.2)	− 0.27 (0.2)
	NT = 114, T = 113	5	*− 0.67 (0.4)*	*− 0.51 (0.3)*	*− 0.52 (0.3)*	− 0.37 (0.2)	− 0.28 (0.2)
	NT = 114, T = 106	6	*− 0.69 (0.4)*	*− 0.50 (0.3)*	*− 0.54 (0.3)*	− 0.37 (0.2)	− 0.29 (0.2)
	NT = 114, T = 103	7	*− 0.73 (0.4)*	*− 0.50 (0.3)*	*− 0.58 (0.3)*	− 0.36 (0.2)	− 0.27 (0.2)
	NT = 114, T = 99	8	*0.74 (0.4)*	*− 0.51 (0.3)*	*− 0.56 (0.3)*	− 0.39 (0.2)	− 0.30 (0.2)
	NT = 114, T = 96	9	*− 0.74 (0.4)*	*− 0.52 (0.3)*	*− 0.52 (0.3)*	− 0.37 (0.2)	− 0.28 (0.2)
	NT = 114, T = 93	10	*− 0.80 (0.5)*	*− 0.57 (0.4)*	*− 0.55 (0.3)*	− 0.42 (0.2)	− 0.31 (0.2)

Abbreviations: COMP, comprehension; EXPR, expression; MEMO, memory; NT, nontraumatic brain injury; SOC, social interaction; SOLV, problem-solving; T, traumatic brain injury.

[a]Reported coefficients are cumulative log odds ratios. Negative coefficients indicate an increase in ordinal score. Standardized effect sizes are reported in parentheses. *Italicized* coefficients indicate family-discovery-rate (FDR)-corrected *P* values at $q < 0.05$. Reported coefficients are for the 5 cognitive subscales of the FIM. For number of similar comorbid conditions, "general" is a comparison of all patients without selection for comorbid conditions. Subset 1 compares patients with TBI and non-TBI who have a common comorbid profile that excludes intracranial injury—the topmost comorbid condition that discriminates between diagnosis groups. Subset 2 compares patients with TBI and non-TBI who do not have the 2 top-ranked distinguishing comorbid conditions (ie, intracranial injury and lung contusion) and so on.

injury was identified as the strongest predictor to differentiate TBI and non-TBI, and the remaining top-ranked 9 comorbid conditions were other secondary injuries specific to TBI. Overall, patients with TBI demonstrated significantly greater improvement in FIM-cognition scores over rehabilitation as compared with non-TBI. However, group differences between TBI and non-TBI in rehabilitation trajectories were minimized when patients were matched on similar sets of comorbid conditions.

The effect of comorbid conditions on cognitive rehabilitation was specific to functional domain. Accounting for comorbid conditions eliminated between-group differences in rehabilitation trajectories within problem-solving and memory domains, followed by a reduced (but still significant) between-group difference in social interaction, and no effect within the expression and comprehension domains. We observe the domains that demonstrated reduced between-group differences when controlling for comorbid conditions included executive functions and declarative memory. For example, social interaction emphasized executive function skills related to self-control (eg, controlling temper) and cognitive perspective taking.[20,21] Likewise, the problem-solving component involved skills related to initiation of activities, planning, and self-correction. In contrast, comprehension (associated with language perception) and expression (associated with language production) are considered the 2 basic developmental frameworks of language[22,23] and we found no evidence for altering rehabilitation recovery in these domains.

We note that comprehension and expression are both predominantly represented in the left hemisphere of the brain,[24,25] whereas social interaction, executive functioning, and memory networks are dispersed throughout the brain.[26–28] We posit that because social interaction, memory, and problem-solving are part of large-scale brain networks (in particular, the default

mode network and the central-executive network),[1] the capacity for neural compensation is greater in these cognitive domains than for language abilities. This theorization will likely hold when brain injuries are heterogenous and diffuse and may explain the inconsistent pattern in group×time effects observed for left-hemisphere-dominant functions that are impaired by brain injury (ie, comprehension and expression), relative to social interaction, problem-solving, and memory. Future studies can pair the rich information from EMRs with targeted MRI data to address this hypothesis.

In sum, we determined that comorbid conditions that were specific to TBI partially accounted for differences in cognitive rehabilitation trajectories between groups. It is notable that the comorbid conditions included injuries external to the central nervous system—conditions that may not be readily identified in a clinical setting as impediments to cognitive recovery. It logically follows that when the 2 groups differ in comorbid conditions—as is likely the case—the cognitive rehabilitation trajectories of the 2 groups are likely to be different.

Within this context, our results advance cognitive rehabilitation research on 2 accounts. First, our findings suggest that identifying and evaluating comorbid physical conditions is crucial for monitoring changes in cognitive functioning. For example, lung contusion was the second-ranked comorbid physical condition found by the decision tree classifier analysis. However, this injury is typically unrecognized and neglected from radiological reports until severe complications develop.[29] Second, our findings invite further research on specific mechanisms for comorbid conditions to modify neural and cognitive rehabilitation. For instance, dorsalthoracic spinal injury (the third-ranked symptom in the decision tree analysis) may cause brain inflammation and indirectly impair cognition following TBI[6] and contribute to brain shrinkage that has lasting cognitive consequences.[30]

The current report should be interpreted with consideration of its strengths and limitations. While these interpretations are informative, the nature of our data cannot comment on causal mechanisms of rehabilitation or sources of between-group differences. We speculate that the rehabilitation context is similar between groups; however, the types of therapy administered may differ by diagnosis despite the reimbursement policy and UDSMR code. In general, all patients are presumed to have received equivalent amounts of time for therapy. Moreover, other demographic and individual-specific health factors are expected to contribute to the variance in rehabilitation outcomes, which we could not adequately address here due to limitations of available data in the EMR.

CONCLUSION

There is a dearth of research relating the extent to which cognitive rehabilitation interventions benefit different kinds of brain injuries, particularly those that are thought to have similar clinical courses to functional stabilization. In this context, we examined TBI and non-TBI and found evidence that, when matched on comorbid medical conditions, patients showed similar recovery in problem-solving, memory, and social interaction skills. However, comorbid conditions did not significantly alter between-group differences in recovery of comprehension and expression domains. Our study demonstrated that comorbid conditions appear to explain individual differences in cognitive rehabilitation trajectories following acquired brain injury beyond etiology. This finding is significant since it can inform how rehabilitation interventions are delivered to populations with TBI and non-TBI.

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