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Predicting Levels of Independence With Expressing Needs and Ideas 1 Year After Severe Brain Injury

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Purpose/Objective: Severe brain injury (BI) is a catastrophic event often evolving into a complex chronic and severely disabling condition making activity participation possible only with sustained caregiving. One aspect of building sustainable caregiving is early provision of information about expected outcomes germane to patients and their caregivers. An analysis was conducted to determine whether 2 levels of independence with expressing needs and ideas 1-year after severe BI could be predicted using variables available early after injury. ***Method:*** The authors examined a subsample (n = 79) of participants of an outcome study who received repeated neurobehavioral evaluations with the Disorders of Consciousness Scale (DOCS) and who were assessed 1 year after injury with the Functional Independence Measures (FIM). Explanatory variables included DOCS measures, patient characteristics, coexisting conditions, and interventions. The outcome is measured with the FIM Expression item. Optimal data analysis was used to construct multivariate classification tree models. ***Results:*** The 2nd (p = .004) DOCS visual measure and seizure (p = .004) entered the final model providing 79% accuracy in classifying more or less independence with expressing needs and ideas at 1 year. The model will correctly identify 78% of future severe BI survivors who will have more independence and 82% of persons who will have less independence. ***Conclusions:*** For persons incurring severe BI, it is possible to predict, early after injury,

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continued

more and less independence with expressing needs and ideas 1-year after injury. This evidence is 1 contribution to a larger body of evidence needed to enable early caregiver education about recovery expectations in terms of patient functioning relative to caregiving needs, which in turn will help build sustainable caregiving for this population.

Keywords: prognoses, communication, coma, vegetative state, minimally conscious state

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Impact

- Multiple studies have identified that the most important information for caregivers early after injury is the patient's expected functional recovery, yet this remains the least often met need for severely disabling brain injury (BI).
- This unmet need is likely related to the dearth of knowledge regarding recovery trajectories for specific cognitively mediated tasks.
- This article provides evidence regarding the patient's expected level of independence with expressing basic needs and ideas 1 year after injury.
- Psychologists, speech language pathologists, and social workers can share this evidence, within the appropriate context, with families and potential caregivers early after injury.
- Evidence early after injury, regarding a patient's expected level of independence with expressing needs and ideas, should inform caregiver selection and training to ultimately contribute to the building of sustainable caregiving.

Severe brain injury (BI) is a catastrophic event often evolving into a complex chronic and severely disabling condition. Residual impairments (Lammi, Smith, Tate, & Taylor, 2005; Multi-Society Task Force on PVS, 1994) often make initiation of and participation in daily activities possible only with caregiver support, which is commonly provided by loved ones who transition to a caregiving role (Gan, Gargaro, Brandys, Gerber, & Boschen, 2010; Kolakowsky-Hayner, Miner, & Kreutzer, 2001). Multiple studies have identified that the most important information for caregivers early after injury is the patient's expected functional recovery, yet for severely disabling BI this remains the least often met need (Kolakowsky-Hayner et al., 2001; Kreutzer, Serio, & Berquist, 1994; National Alliance for Caregiving, 2010).

It is possible that early education regarding expected long-term recovery remains an unmet need because existing prognostic models use outcomes describing general recovery categories. The original version of the Glasgow Outcome Scale (GOS; Jennett, & Bond, 1975; Jennett et al., 1979; Levin et al., 1990; Levin, Grossman, Rose, & Teasdale, 1979; Multi-Society Task Force on PVS, 1994; Whyte et al., 2009), for example, uses disability categories to define functional outcomes (e.g., "Moderate Disability" indicates independence in daily life and an ability to work in a sheltered environment). General outcomes such as the original GOS are not sufficiently germane to the daily lives of the patients and their caregivers (Cameron & Gignac, 2008; Gan et al., 2010). For severely disabling BI, a germane outcome is one that informs the caregiver about the context of the patient's daily life such as the amount of assistance the patient will require to engage in cognitively mediated activities (Gan et al., 2010; Kreutzer et al., 2009).

To address the need to develop prognostic evidence using more germane outcomes, we selected an outcome reflecting independence with a specific cognitively mediated task. The level of independence with expressing needs and ideas was selected as the outcome because it is a cognitively mediated ability that, after emergence from the minimally conscious state, is meaningful to the patient and informs caregivers about long-term cognitive changes in relationship to communication abilities (Gan et al., 2010; Kreutzer, Gervasio, & Camplair, 1994). The FIM Expression item (Granger, 1998) was used because it measures a person's level of independence with performing a task relative to the resources needed to enable performance.

The purpose of this article is to report findings from an analysis conducted to determine whether explanatory variables available

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The research would not be possible without the contributions of each participating study site, and these sites include Marianjoy Rehabilitation Hospital, the Minneapolis VA Health Care System, James A Haley VA Health Care System, the Hines VA Hospital, Rehabilitation Institute of Chicago, On With Life and RML Specialty hospital. On a special note, we acknowledge our research participants who have had their lives dramatically and suddenly altered. While our participants are adjusting to a lifetime of rehabilitation, they also agreed to allow us to capture a segment of their lives. They participated for many reasons, but a common driving force is an altruistic desire to help others.

To obtain the Disorders of Consciousness Scale (DOCS), go to http://www.queri.research.va.gov/ptbri/clinicians.cfm

The views expressed in this article are those of the authors and do not necessarily reflect the position or policy of the United States Department of Veterans Affairs or the United States government.

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early after injury can be used to inform prognoses regarding the level of independence with expressing needs and ideas 1 year after severe BI.

Method

The study sample was extracted from a larger observational study, which enrolled consecutive admissions to an acute or subacute rehabilitation unit if they had incurred a severe BI and were (a) admitted to one of four inpatient rehabilitation sites within 180 days of injury, (b) 18 years of age or older at time of study enrollment, and (c) in a state of disordered consciousness for ≥28 days consecutively. Subjects were excluded from the larger study if their BI was due to cancer, tumors, inflammatory, infectious, and/or toxic metabolic encephalopathies. Participants were recruited from two freestanding inpatient rehabilitation facilities, one long-term acute care hospital providing inpatient rehabilitation, and one Department of Veterans Affairs Medical Center providing inpatient rehabilitation. Each research participant was then followed from time of rehabilitation admission through the first year of recovery to monitor time to consciousness. The larger observational study and the study described in this article were each approved by human subject institutional review boards (IRB) at each site or the coordinating IRB, respectively.

Data Collection

For the larger study, data was extracted from each subject's trauma, intensive, and acute care medical records, and cause of injury data was collected from family interviews. During rehabilitation, bedside assessments were conducted and included the Disorders of Consciousness Scale (DOCS), which was administered weekly until recovery of full consciousness or completion of a sixth evaluation. To determine days of unconsciousness, consciousness assessments were conducted one–two times per week during rehabilitation and monthly after discharge up to 1 year. For a subset of participants, the final interview at 1 year also included the Functional Independence Measure (FIM).

Instrumentation: Disorders of Consciousness Scale (DOCS)

The DOCS is a bedside test of neurobehavioral functioning for patients in states of disordered consciousness (Pape, Heinemann, Kelly, Hurder, & Lundgren, 2005; Pape, Senno, Guernon, & Kelly, 2005; Pape et al., 2009), and it is administered by allied health clinicians. Following baseline observations, test items are administered, and the best elicited behavioral responses are rated on a 3-point scale (0 = No response, 1 = Generalized Response, 2 = Localized Response). There are 23 test stimuli for clinical use, and one objective for the larger study was to examine eight experimental test stimuli (see Supplemental Online Table D). DOCS raw scores for all studies were converted to logit measures and rescaled to 0 to 100, where larger numbers indicate higher levels of functioning (see Supplemental Online Tables A & B).

The DOCS has strong reliability, construct validity, and predictive validity (Pape, Heinemann, et al., 2005; Pape, Senno, et al., 2005, 2009). The DOCS interrater reliability between therapists, for example, was examined pairwise across all raters using the facets model (Linacre, 1994). The percentage of observed agreement (54.4%) is greater than the predicted (43.8%), and this ratio is analogous to a kappa of .95. Weekly measures during acute or subacute rehabilitation over 6 weeks were used to examine test–retest reliability and item stability–validity over time. This study (Pape, Heinemann, et al., 2005) found no item bias over time and that the DOCS items retain their meaning over 6 weeks. The absence of item bias and rater bias over 6 weeks (Pape, Heinemann, et al., 2005) makes the DOCS useful for reliably detecting subtle neurobehavioral changes weekly up to 6 weeks (Pape et al., 2009). The DOCS has been shown to be a strong predictor of recovery of full consciousness with accuracy ranging between 87% and 88% (Pape et al., 2009) and the DOCS minimal clinically important difference using an anchor-based approach (i.e., receiver operating characteristic curves and absolute probabilities) for predicting recovery of consciousness is seven to nine units of DOCS change (Copay, Subach, Glassman, Polly, & Schuler, 2007; Pape, Heinemann, et al., 2005; Pape et al., 2009).

Explanatory Variables

Eighty-nine explanatory variables (see Supplemental Online Table C) were examined for utility in predicting more and less independence with expressing basic needs and ideas 1 year after injury. The explanatory variables include neurobehavioral measures derived from the DOCS, patient characteristics, coexisting conditions, and interventions.

DOCS measures examined include total DOCS measures, total DOCS change measures, DOCS Auditory measures, DOCS Visual measures, DOCS Tactile measures, and change in each of these three modality measures. The total and modality DOCS measures include baseline measures, weekly measures, change between baseline and the second DOCS, change between baseline and last DOCS, and average DOCS measures. For all total DOCS measures, we computed the measures using the original 23 items (DOCS 23; Pape, Heinemann, et al., 2005) and the additional items being examined in the larger study (DOCS 31). Because the DOCS test-item administration procedures allow for testing of specific sensory pathways, specific items can be used to create modality measures. The items used to compute the total DOCS measures (DOCS 23 and DOCS 31) and each of the three modality measures (Auditory, Tactile and Visual) are provided in Supplemental Online Table D.

Since duration of disordered consciousness is strongly associated with outcome, (Multi-Society Task Force on PVS, 1994) duration of unconsciousness was also included in analyses as an explanatory variable. Consciousness for the ongoing study requires behavioral demonstrations of external and internal awareness that are consistently manifested and where the behaviors meet at least one of three criteria: (a) functional interactive communication, (b) functional use of an object, or (c) a behavioral manifestation of sense of self in an environment that is documentable (Andrews, 1996; Giacino, 1997; Jennett, 1997; Multi-Society Task Force on PVS, 1994; Pape, Heinemann, et al., 2005; Pape, Senno, et al., 2005; Plum & Posner, 1980; Zasler, 1996).

Outcome: Independence With Expressing Needs and Ideas

The FIM assesses a person's independence with tasks relative to amount of assistance needed, which is measured in terms of direct physical assistance and indirect assistance in terms of supervision (Corrigan, Smith-Knapp, & Granger, 1997; Granger, 1998). A FIM rating of 1 means that the individual requires total assistance, and a 7 means complete independence. In terms of FIM Item 15 (Expression), a 5 indicates that they express basic daily needs and ideas more than 90% of the time, and ratings of 6 and 7 indicate that they express complex or abstract ideas at least 90% of the time (Granger, 1998; Linacre, Heinemann, Wright, Granger, & Hamilton, 1994).

The FIM is used in this study to indicate more and less independence with expressing basic needs and ideas (FIM Item 15). The FIM rating scale was collapsed to a dichotomous outcome where ratings 1 through 3 indicate less independence, and 4 through 7 indicate more independence. Less independence means that the patient's abilities will range from no ability to express needs and ideas to being able to express needs and ideas about 75% of the time if provided assistance for approximately one fourth of all communicative interactions. More independence means that the patient is able to express needs and ideas at least 75% of the time and may need assistance with one fourth or fewer of these communicative interactions but that the patient may be completely independent with expression of needs and ideas where the patient does not require assistance.

Study Sample

The study sample was abstracted form the larger observational database of 191 participants (see Figure 1). This subset (n = 107) was abstracted because their follow-up at 1 year included an interview using the FIM. Inclusion criteria for the study sample also required that participants' DOCS measures be derived by paired raters and that each participant had received at least two DOCS evaluations. The final set of participants meeting eligibility for inclusion is 79 patients who were consecutively admitted to an acute or subacute rehabilitation program.

The study sample of 79 participants included eight cases with missing data. Seven participants were missing visual data from DOCS tests, and one patient was missing seizure data. These eight participants were excluded from the analyses, yielding a final study sample of 71.

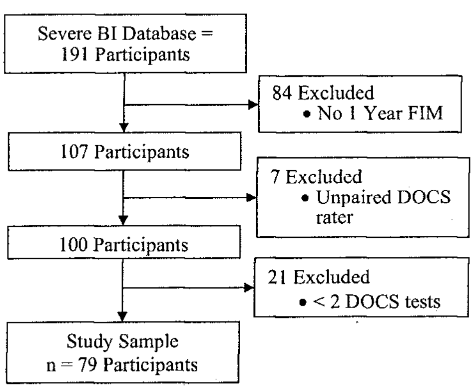

Figure 1. Study Sample by Inclusion Criteria. FIM = Functional Independence Measure; DOCS = Disorders of Consciousness Scale.

Data Analyses

All data were inspected for data entry errors by computing descriptive statistics and inspecting scatterplots. SPSS (Statistics, 2008) was then used for descriptive analyses and post hoc comparisons. All DOCS measures were calibrated, according to rater calibrations, using the FACETS model (Linacre, 1994) to account for patient ability, item difficulty, multiple raters, and repeated DOCS testing. The measures were then rescaled to a 0 to 100 clinical scale (Fisher, 1925; Rasch, 1960; Wright & Masters, 1982). Optimal data analysis (ODA) was used to build the classification model. The statistical tool ODA was used to conduct classification tree analyses (CTA) because this tool includes procedures accounting for a small sample of subjects relative to a large number of explanatory variables (Yarnold & Soltysik, 2010c). That is, ODA sequentially identifies the variable with optimal classification accuracy one covariate at a time rather than dozens at once thereby limiting error.

For all optimal data analyses, Monte Carlo procedures were used to examine significance and leave-one-out (LOO) resampling was used to examine stability of effect strength sensitivity (ESS; Efron & Tbshirani, 1997). ESS is a normed index of the likelihood of correct classification ranging between 0 (*classification accuracy expected by chance*) and 100 (*errorless classification*). ESS is used to examine the classification performance of the final ODA model and ESS values <0.25 are regarded as weak, values between 0.25 and 0.50 are considered moderate, and values >0.50 are strong effects (Yarnold & Soltysik, 2005). ODA uses percentage of accuracy in classification (PAC) to compute ESS as follows:

$$\text{PAC} = 100\% \times (\text{true positives} + \text{true negatives})/N$$

$$\text{Mean PAC} = 100\% \times (\text{Se} + \text{Sp})/C$$

$$\text{ESS} = 100\% \times (\text{Mean PAC} - 50)/50,$$

where C = no. of response categories for the outcome, which for this study is 2;

where Se = [true positives/(true positives + false negatives)] × 100; and

where Sp = [true negatives/(false positives + true negatives)] × 100.

UniODA (Yarnold & Soltysik, 2005) was used for univariate analyses, and automated CTA software was used to construct the model (Feinglass, Yarnold, Martin, & McCarthy, 1998; Yarnold & Soltysik, 2010a, 2010c). Univariate ODA was conducted to identify the first variable–node to be used in the multivariate CTA model. The variable with the greatest ESS was selected as the first node if it was significant ($p < .05$) according to Monte Carlo procedures and if ESS was LOO stable. A variable is LOO stable if ESS does not vary between total sample and LOO analyses on the resampled total sample. LOO stable criterion is used to optimize the cross-sample generalizability of the final model to the target population.

After using univariate results to select the first node, automated CTA was used to identify lower nodes–variables. For multivariate analyses using automated CTA, the remaining 88 explanatory variables at every node of the tree were examined regardless of statistical significance in univariate analyses. Variables were included in the multivariate model according to ESS, significance, and LOO stability criteria.

In LOO, each observation is removed from the sample one at a time, and an ODA model is obtained for the remaining subsample. The ODA decision rule is used to classify the single-removed observation, and the classification accuracy results (PAC) are stored and tabulated iteratively across all observations. We used a conservative LOO stability criteria where the variable must yield a LOO PAC that does not decrease compared with the PAC for the full sample. To prune the model, we also used a sequentially rejective Bonferroni-type multiple comparisons procedure to control for experiment-wise Type I error (Cook & Campbell, 1979; Ryan, 1959; Yarnold & Soltysik, 2010b) and to maximize classification accuracy ($p < .05$; Klockars, Hancock, & McSweeny, 1995).

The stringent pruning procedures described above were used, in part, to maximize the cross-sample generalizability of the final CTA model, which yields patient strata. To further examine cross-sample generalizability, post hoc one-way analyses of variance (ANOVAs) were conducted to compare patient strata defined in the final CTA model.

Results

The majority of the study sample ($n = 71$) are young (average age in years = 33.27 ± 15.8; median = 26.0 years), White (78%), single (64%), males (70%) who were employed outside the home (60%) at time of injury. Twenty-five percent of the subjects are eligible for health care benefits from the U.S. Department of Veterans Affairs (VA), and almost the entire sample (95%) had private insurance.

The majority of the subjects (82%) incurred traumatic BI (i.e., closed contracoup, open, and blast), and 18% incurred nontraumatic BI from anoxic (10%) or vascular (8%) incidents. The average baseline DOCS of 52.1 ± 12.8 (*Mdn* = 51.1) indicates that most subjects demonstrated behaviors indicative of the minimally conscious state (MCS) at study enrollment (Andrews, 1996), with 14% in a comatose state (DOCS range = 0 to 39.52) and 27% in a vegetative state (DOCS range = 40.58 to 49.82).

Univariate Optimal Data Analyses (ODA)

Univariate findings (see Supplemental Online Table C) indicate that the second DOCS Visual measures, derived from 23 and 31 test stimuli (DVIS232 and DVIS312, respectively) have identical optimal cut-points (42.88), and both are LOO stable as well as significant ($p = .0002$). These variables also have the greatest, as well as equivalent, ESS (43%), and each has the same predictive value for more independence of 46% and for less independence of 96%. This suggests that a multivariate model using either of these variables as the first node will optimize prediction of more independence. Because the DOCS Visual measure based on 23 test stimuli requires less time clinically, relative to administering 31 test stimuli, we selected DVIS232 as the first node.

Multivariate Classification Tree Analyses (CTA)

Using DVIS232 as the first node, multivariate CTA indicated that 2 of the 89 variables entered the final model; the 2nd DOCS Visual measure (DVIS232, $p = .004$) and Seizure ($p = .004$). Findings indicate that classification accuracy was most optimal using the cutpoint for the 2nd DOCS Visual measure of 42.88.

Interpreting the final CTA model (see Figure 2) is illustrated through a hypothetical patient having a second DOCS Visual measure of 40.26. Starting with the first node, this patient will follow the left branch. The Type I error rate indicates that 4 in every 1,000 patients ($p = .004$) would be erroneously allocated to the left branch based on use of the DVIS232. This hypothetical patient is next classified, by the CTA model, into the endpoint of less independence at 1 year (Stage I). The CTA model predicted or classified that this patient will have less independence at 1 year. The probability that this patient will actually be less independent is 96%. This probability is based on the findings from our study that 23 of the 24 (23/24) subjects classified by the CTA model as less independent at 1 year were actually observed and rated to be less independent.

One subject in our study was missing seizure data. Therefore, 47 of the 48 subjects were directed by the CTA model to the right branch. If at any time point after injury a patient with a second DOCS visual score >42.88 had a seizure, then the patient was classified by the CTA model into the endpoint of less independence (Stage III). For our study, 18 of these 47 subjects had a documented seizure, and 15 of the 18 were observed and rated to actually be less independent. Thus, the CTA model predicts that a patient with a DOCS Visual score >42.88 who also incurred a postinjury seizure will be less independent at 1 year, and the chances of this patient actually being less independent is 83%. Similarly, the probability that a patient who did not incur a seizure is actually more independent (as predicted by the CTA model) is 62% because 18 of the 29 patients who did not experience a seizure were actually observed and rated to be more independent 1 year after injury.

An alternative representation of multivariate CTA results is a staging table (see Table 1), which provides indices of the likelihood of showing more independence for each model endpoint. Probabilities of more independence reflect chances of model misclassifications for each stage–endpoint illustrated in Figure 2. The probability of more independence, for a patient with a DVIS232 score ≤42.88 (Stage I) is 46%. For every patient at Stage I who actually shows more independence at 1 year, 23 patients show less independence. For a patient with a DVIS232 score >42.88 who incurs a seizure (Stage II), the probability of more independence at 1 year is 61%. That is, for every three patients who actually demonstrate more independence, 15 patients show less independence. A patient classified into the Stage III endpoint has a probability of 62% to actually have more independence at 1 year. In other words, for every 18 patients who show more independence, there will be 11 patients who show less independence.

Model Performance: Discriminant Validity

Indices of CTA model performance are derived from Table 2, where rows indicate the actual levels of independence and columns indicate predicted levels. One technique to assess model performance is to compare the actual and predicted levels of independence by computing sensitivity (Se) and specificity (Sp). Positive and negative predictive values (PPV and NPV, respectively) and overall accuracy or PAC are also provided to examine model precision.

In summary, 41% [(11 + 18)/71 = .41] of the sample is predicted to have more independence 1 year after injury. These

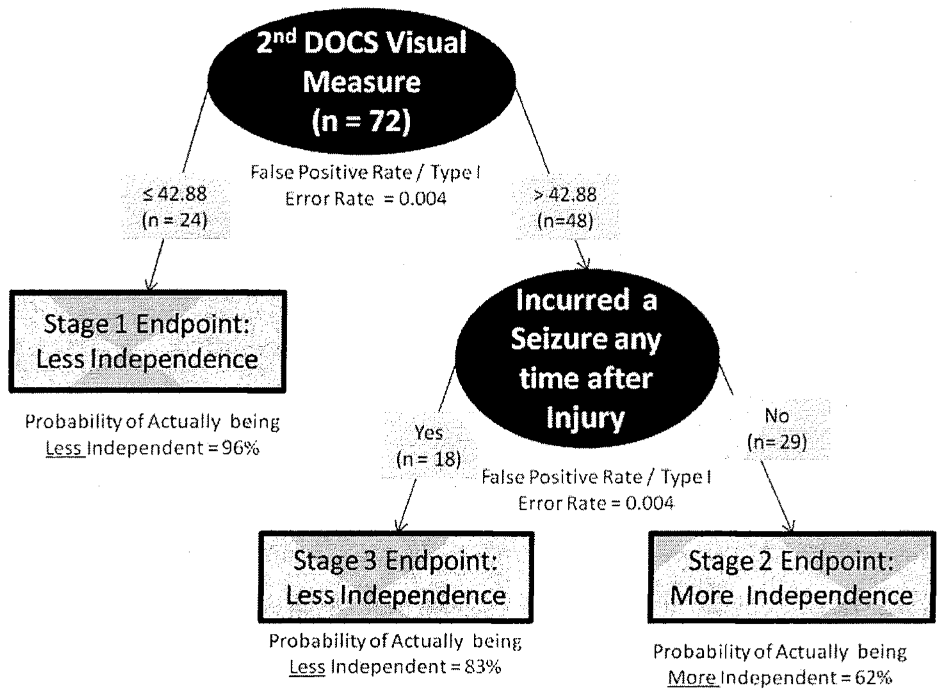

Figure 2. Optimal Multivariate Hierarchical CTA Model. Endpoints (rectangles) represent sample strata identified by the CTA model. Numbers overlying arrows indicate the optimal cut-point value for the 2nd DOCS Visual Score node. Values underneath 2nd DOCS Visual Score and Seizure nodes give the generalized (per-comparison) Type I error rate or false positive rate for each respective node. The probabilities of actually being more–less independent are indicated beneath each endpoint.

predictions are correct 62% (PPV) of the time and correctly identify 78% (Se) of all persons with more independence with expression of needs. Also, 90% (NPV) of model-based predictions of less independence at 1 year are correct and correctly classify 82% (Sp) of all persons with less independence. Overall, the model correctly classified 79% (PAC = 100% × (.82 + .78)/2) of persons in the sample.

Model Performance: Effect Strength Sensitivity

The classification performance of the final model was examined with ESS because the five previously reported indices of discriminant validity are not normed relative to chance and do not have a *p* value (Hennekens, 1987). The overall ESS was computed across classes using mean PAC:

$$\text{Mean PAC} = 100\% \times (0.8182 + 0.7755)/2 = 79.38\%$$

$$\text{ESS} = 100\% \times (79.4 - 50)/50 = 59\%$$

These computations indicate that the final CTA model achieved 59% (ESS) of the improvement in classification accuracy theoretically possible to attain beyond the performance achieved by chance—a strong effect.

Generalizability to Target Population

LOO analyses indicate strong generalizability in that the model will correctly identify 82% (Se) of future severe BI survivors who will have more independence and 78% (Sp) of future survivors who will have less independence with expressing needs 1 year after injury. The model captured 59% of the possible theoretical improvement in classification accuracy—a strong effect.

The CTA model identified three patient strata in the sample, which is reflective of the target population (see Table 3; Cullen,

Table 1
Staging Table

Stage/Endpoint	DOCS Visual 2	Seizure	$N = 72$	$P_{\text{More Independence}}$	Odds
1 = Less independence	≤42.88	—	$n = 24$	0.46	1:23
2 = Less independence	>42.88	Yes	$n = 18$	0.61	3:15
3 = More independence	>42.88	No	$n = 29$	0.62	18:11

Note. DOCS = Disorders of Consciousness Scale; P = probability of more independence.

Table 2
Indices of Discriminant Validity

	CTA model predicted independence			
Actual independence	Less	More	Total	Se/Sp
Less	38 (TN)	11 (FP)	49	82%
More	4 (FN)	18 (TP)	22	78%
Totals	42	29	$N = 71$	
NPV/PPV	90%	62%		

Note. SSe = Sensitivity; Sp = Specificity; NPV = negative predictive value; PPV = positive predictive value; TP = true positive; TN = true negative; FP = false positive; FN = false negative; Se = [TP / (TP + FN)] × 100; Sp = [TN / (FP + TN)] × 100 PPV = [TP / (TP + FP)] × 100]; NPV = [TN / (FN + TN)] × 100].

Park, & Bayley, 2008; Granger et al., 2010; Ottenbacher et al., 2004). The majority of the sample demonstrated more independence with expressing needs and ideas 1 year after injury falling within the Stage II endpoint.

The stratified groups are similar according to age, days between injury and rehabilitation admission, days of rehabilitation, and proportion incurring traumatic BI. Strata 2, the more independent strata, had fewer days of disordered consciousness, and this was significantly shorter relative to Strata 3.

The average 1-year FIM Expression rating of 1.5, for Strata 1, indicates that this subgroup required the most assistance whereas Strata 2 subjects required assistance to express needs and ideas 26% to 50% of the time, and Strata 3 subjects required assistance 51% to 75% of the time. The stratified groups do significantly ($ps < .006$) differ according to FIM total, cognitive and motor scores, but Strata 1 is significantly lower functioning for all for FIM scores when compared to Groups 2 and 3. Similarly, Strata 2 patients have significantly higher functioning when compared with patients in Stages 1 and 3. Thus, each strata is functioning significantly higher or lower motorically and cognitively relative to the other strata. In summary, the optimal multivariate CTA model is applicable to patients who experience disordered consciousness for at least 28 days consecutively and receive more than one DOCS evaluation during rehabilitation.

Power

We conducted a post hoc power analysis for the final pruned hierarchically optimal CTA model. Because hypotheses and corresponding statistical analyses vary across multiple outcome measures and multiple types of measurement scales, we computed statistical power in assessing the overall classification accuracy of the multiattribute tree model ($N = 71$) in predicting classification of more (1) versus less (0) independence with FIM expression. The actual FIM data (i.e., not endpoints predicted by the model) revealed a distributional split of 69.1% ($n = 49$) less independence and 31.0% ($n = 22$) with more independence. For the model's power analysis, we used the 38 positive cases (78% classification accuracy) for the final CTA model in predicting less independence and the 18 positive cases (82% classification accuracy) in predicting more independence. The power estimation of the final two-predictor CTA model used a nondirectional Fisher's exact test with $p < .025$ to reflect Bonferroni criteria for experimentwise statistical significance. This analysis indicates that the sample sizes

Table 3
Description of Study Sample by Final Model Endpoints

Strata									FIM Scores at 1 Year**			
Stage/ Endpoints	DVIS232	Seizure	% Total $N = 71$	Age	% Traumatic BI	Days of unconsciousness*	Days btw injury and rehab admit	Rehab LOS	Express	Total	Cognitive	Motor
Stage 1: Less independent ($n = 24$)	≤42.88	—	34%	39.5 ± 16.6	79%	221.7 ± 139.8	50.9 ± 38.3	76.7 ± 35.5	1.5 ± 0.9	28.0 ± 17.6	8.0 ± 4.4	20.0 ± 14.1
Stage 2: More independent ($n = 29$)	>42.88	No	41%	29.8 ± 16.5	86%	144.8* ± 108.7	112.3 ± 343.3	81.0 ± 71.4	4.0 ± 2.0	64.5 ± 38.0	19.7 ± 9.4	44.3 ± 30.6
Stage 3: Less independent ($n = 18$)	>42.88	Yes	25%	30.6 ± 11.1	78%	249.1* ± 146.4	74.6 ± 38.1	81.0 ± 46.9	2.0 ± 1.7	31.6 ± 24.9	9.8 ± 6.3	21.7 ± 19.3

Note. BI = brian injury; btw = between; DVIS232 = 2nd DOCS Visual score derived from 23 items; LOS = length of stay in days; Rehab = acute rehabilitation hospitalization; *,** Significantly different between stages where all p values are ≤.05 using a one-way analysis of variance (ANOVA) with a Bonferroni test for multiple comparisons; ** Significantly different between stages where p values are all <.006 using a one-way ANOVA with Bonferroni test for multiple comparisons.

provide 100% power to classify participants accurately in the two-attribute CTA model. Given the observed classification accuracy for less independence, the present sample sizes provide adequate (i.e., 80%; Cohen, 1988) power to detect at $p < .025$ classification accuracy for more independence as small as 61.1% (i.e., Cohen's effect size $W = 0.37$, which represents a medium-sized effect).

Conclusion and Discussion

The evidence indicates more and less independence with expressing needs and ideas 1 year after severe BI is predictable with strong precision using variables available early after injury and specifically during acute rehabilitation. Findings indicate that two DOCS evaluations, at rehabilitation admission and 7 days later, provide the maximum predictive accuracy. Because the patient is likely to be in acute rehabilitation for at least 1 week, it is feasible to conduct two evaluations.

Patients with a second DOCS visual score (DVIS232) ≤ 42.88 are likely to require moderate-to-total assistance to express needs and ideas 1 year after injury. Patients with a DVIS232 score >42.88 and who do not incur a seizure at any time point after injury are likely to be more independent requiring at most minimal prompting to enable expression of needs and ideas.

The relationship between improving visual skills during coma recovery and expression of needs 1 year after injury is unclear, whereas seizure activity is clinically intuitive. Clinical observations suggest that the visual pathway is often the testing modality where the most behavioral gains are detected in persons making slow yet incremental gains. Visual tracking and focusing also commonly precede substantive auditory gains. Patients who consistently track and focus may have motoric issues complicating the measurement of auditory comprehension. Therefore, the DOCS test may be capturing recovery at a time when the visual modality is dominating recovery or that detecting behavioral change in visual skills is less complicated relative to other modalities.

The probability of a person experiencing a seizure after a severe traumatic BI is about 10% (Annegers, Hauser, Coan, & Rocca, 1998), and 25% of our sample experienced at least one seizure after injury. Because seizures cause additional neurological damage, our finding that seizure activity negatively influences independence with expressing needs and ideas is not surprising and is consistent with evidence of the impact of myoclonic seizures on functional outcomes (Young, 2009). Variables obtainable during rehabilitation were examined because interdisciplinary acute and subacute rehabilitation clinicians have the expertise necessary to translate findings to families within the context of the patient's lifetime. Reported findings do not mean that recovery of expressive skills stops after 1 year. Persons identified as at risk for less independence may or may not continue to make small incremental functional gains throughout their lifetime.

The final CTA model reveals the groups at risk for less independence with expressing needs, which can be used to design clinical trials. Although the evidence does not indicate that variables predictive of recovery cause recovery, the variables could be used to stratify study cohorts by likelihood of recovery. Because evidence indicates that the recovery trajectory for nontraumatic BI is notably shorter than traumatic BI, (Multi-Society Task Force on PVS, 1994) we expected etiology to be a significant predictor variable in the final CTA model. DOCS measures were estimated by etiology, and this may have contributed to the substantively lower ESS (17%) for etiology. Calibrating DOCS measures by etiology is feasible at bedside because conversion tables by etiology are provided in the DOCS administration manual (Pape, Lundgren, Guernon, Kelly, & Heinemann, 2011).

Given previously published associations between duration of disordered consciousness and outcome (Giacino, Kezmarsky, DeLuca, & Cicerone, 1991) we expected to find a predictive relationship between duration and independence with expressing needs and ideas. Although the three patient strata clearly had differing durations of disordered consciousness, only Strata 2 and 3 were significantly different. This variable was significant in univariate analyses ($p = .006$) and had a univariate ESS of 25% but fell out in the pruning stage of the multivariate CTA indicating that LOO PAC changed relative to PAC for the total sample.

This analysis was the first time DOCS measures derived from 23 and 31 test items were examined simultaneously, and we expected the DOCS measures based on 31 test items to have more predictive accuracy compared to those based on 23 test stimuli. Although the univariate results indicated equally significant and strong ESS for DVIS232 and DVIS312, the pruning process of the multivariate analyses indicated that ESS for DVIS312 did not remain LOO stable. The use of 23, rather than 31 test stimuli, is also clinically less burdensome and yields better accuracy for classifying more and less independence with expressing needs and ideas 1 year after injury.

The duration of unconsciousness and the DVIS312 variables were excluded from the final CTA model because we adopted a stringent pruning method to build a final CTA model that would assess the likelihood of replication in an independent future sample of severe BI survivors. We also used this stringent approach because we sought insights about whether or not clinicians need to administer all 31 DOCS test items to yield evidence to inform prognoses. These findings indicate that clinicians can administer the shorter DOCS test that includes only 23 items and inform prognoses about independence with expressing needs and ideas 1 year after injury.

Although the evidence of discriminant validity for the final CTA model is strong and power is more than adequate, a limitation of the study is that a single dataset was used to identify both the variables and optimal cut-points and to evaluate their predictive ability. Predicting recovery of function 1 year post injury using data as early as 1 month (i.e., fewest days between injury and study enrollment is 33 days) after injury can impact long-range planning decisions made by the caregivers and clinicians. It is prudent, therefore, that the accuracy of the model predictions be examined through replication of this analysis with either an alternate sample or a random selection of participants from a larger sample. This would also enable an examination of the model using differing base rates–proportions of persons with actual levels of more and less independence ultimately providing more evidence regarding model precision.

A larger sample size would also allow for a three categorical FIM outcome. Considering caregiving burden as well as quality of life, there could potentially be a meaningful difference between a group with FIM ratings of 4 and 5 and those with ratings of 6 and

7. Future research should strive to allow for more than two categories related to levels of independence.

In summary, scientific knowledge regarding variables predicting more and less independence with expressing needs and ideas and the accuracy of those predictions is important for caregivers. Persons caring for severe BI survivors need to know what to expect to respond to and cope with the common logistical, financial, personal, and ethical issues associated with a lifetime of severe cognitive and physical impairments (Gan et al., 2010; Kreutzer, Gervasio, & Camplair, 1994; Romano, 1989). Given the reported preliminary evidence combined with advances in neurobehavioral measurement (Seel et al., 2010) and prediction modeling, (Yarnold & Soltysik, 2010a) this line of research merits further investigation.

References

Andrews, K. (1996). International Working Party Report on the vegetative state. *Brain Injury, 10,* 797–806. doi:10.1080/026990596123918

Annegers, J. F., Hauser, W., Coan, S., & Rocca, W. (1998). A population-based study of seizures after traumatic brain injuries. *New England Journal of Medicine, 338,* 20–24. doi:10.1056/NEJM199801013380104

Cameron, J. I., & Gignac, M. (2008). "Timing is Right": A conceptual framework for addressing the support needs of family caregivers to stroke survivors from hospital to the home. *Patient Education and Counseling, 70,* 305–314. doi:10.1016/j.pec.2007.10.020

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Cook, T., & Campbell, D. (1979). *Quasi-experimentation: Design and analysis issues in field settings.* Chicago, IL: Rand McNally.

Copay, A. G., Subach, B., Glassman, S., Polly, D., & Schuler, T. (2007). Understanding the minimum clinically important difference: A review of concepts and methods. *The Spine Journal, 7,* 541–546. doi:10.1016/j.spinee.2007.01.008

Corrigan, J. D., Smith-Knapp, K., & Granger, C. (1997). Validity of the functional independence measure for persons with traumatic brain injury. *Archives of Physical Medicine and Rehabilitation, 78,* 828–834. doi:10.1016/S0003-9993(97)90195-7

Cullen, N. K., Park, Y., & Bayley, M. (2008). Functional recovery following traumatic vs non-traumatic brain injury: A case-controlled study. *Brain Injury, 22,* 1013–1020. doi:10.1080/02699050802530581

Efron, B., & Tbshirani, R. (1997). Improvements on cross-validation: The 632+ bootstrap method. *Journal of the American Statistical Association, 92,* 548–560.

Feinglass J, Y. P., Yarnold, P. R., Martin, G. J., & McCarthy, W. (1998). A classification tree analysis of selection for discretionary treatment. *Medical Care, 36,* 740–747. doi:10.1097/00005650-199805000-00013

Fisher, R. (1925). Theory of statistical estimation. *Proceedings of the Cambridge Philosophical Society, 22,* 700–725. doi:10.1017/S0305004100009580

Gan, C., Gargaro, J., Brandys, C., Gerber, G., & Boschen, K. (2010). Family caregivers' support needs after brain injury: A synthesis of perspectives from caregivers, programs, and researchers. *NeuroRehabilitation, 27,* 5–18.

Giacino, J. T. (1997). Disorders of consciousness: Differential diagnosis and neuropathologic features. *Seminars in Neurology, 17,* 105–111. doi:10.1055/s-2008-1040919

Giacino, J. T., Kezmarsky, M., DeLuca, J., & Cicerone, K. (1991). Monitoring rate of recovery to predict outcome in minimally responsive patients. *Archives of Physical Medicine and Rehabilitation, 72,* 897–901. doi:10.1016/0003-9993(91)90008-7

Granger, C. V. (1998). The emerging science of functional assessment: Our tool for outcomes analysis. *Archives of Physical Medicine and Rehabilitation, 79,* 235–240. doi:10.1016/S0003-9993(98)90000-4

Granger, C. V., Markello, S., Graham, J., Deutsch, A., Reisletter, T., & Ottenbacher, K. (2010). The uniform data system for medical rehabilitation report of patients with traumatic brain injury discharged from rehabilitation programs in 2000–2007. *American Journal of Physical Medicine and Rehabilitation, 89,* 265–278. doi:10.1097/PHM.0b013e3181d3eb20

Hennekens, C. (1987). *Epidemiology in medicine* (1st ed.). Boston, MA: Little, Brown.

Jennett, B. (1997). A quarter century of the vegetative state: An international perspective. *Journal of Head Trauma Rehabilitation, 12,* 1–12. doi:10.1097/00001199-199708000-00003

Jennett, B., & Bond, M. (1975). Assessment of outcome after severe brain damage. *The Lancet, 305,* 480–484. doi:10.1016/S0140-6736(75)92830-5

Jennett, B., Teasdale, G., Braakman, R., Minderhoud, J., Heiden, J., & Kurze, T. (1979). Prognosis of patients with severe head injury. *Neurosurgery, 4,* 283–289. doi:10.1227/00006123-197904000-00001

Klockars, A. J., Hancock, G. R., & McSweeny, M. D. (1995). Power of unweighted and weighted versions of simultaneous and sequential multiple-comparison procedures. *Psychological Bulletin, 118,* 300–307. doi:10.1037/0033-2909.118.2.300

Kolakowsky-Hayner, S. A., Miner, K., & Kreutzer, J. (2001). Long-term life quality and family needs after traumatic brain injury. *Journal of Head Trauma Rehabilitation, 16,* 374–385. doi:10.1097/00001199-200108000-00007

Kreutzer, J. S., Gervasio, A. H., & Camplair, P. S. (1994). Primary caregivers' psychological status and family functioning after traumatic brain injury. *Brain Injury, 8,* 197–210. doi:10.3109/02699059409150973

Kreutzer, J. S., Rapport, L. J., Marwitz, J. H., Harrison-Feliz, C., Hart, T., Glenn, M., & Hammond, F. (2009). Caregivers' well-being after traumatic brain injury: A multicenter prospective investigation. *Archives of Physical Medicine and Rehabilitation, 90,* 939–946. doi:10.1016/j.apmr.2009.01.010

Kreutzer, J. S., Serio, C., & Berquist, S. (1994). Family needs after brain injury. *Journal of Head Trauma Rehabilitation, 9,* 104–115. doi:10.1097/00001199-199409000-00009

Lammi, M. H., Smith, V. H., Tate, R. L., & Taylor, C. M. (2005). The minimally conscious state and recovery potential: A follow-up study 2 to 5 years after traumatic brain injury. *Archives of Physical Medicine and Rehabilitation, 86,* 746–754. doi:10.1016/j.apmr.2004.11.004

Levin, H. S., Gary, H. E., Eisenberg, H. M., Ruff, R. M., Barth, J. T., Kreutzer, J., . . . Marshall, L. F. (1990). Neurobehavioral outcome 1 year after severe head injury. Experience of the Traumatic Coma Data Bank. *Journal of Neurosurgery, 73,* 699–709. doi:10.3171/jns.1990.73.5.0699

Levin, H. S., Grossman, R., Rose, J., & Teasdale, G. (1979). Long-term neuropsychological outcome of closed head injury. *Journal of Neurosurgery, 50,* 412–422. doi:10.3171/jns.1979.50.4.0412

Linacre, J. M. (1994). *Many-facet Rasch Measurement.* Chicago, IL: Mesa Press.

Linacre, J. M., Heinemann, A., Wright, B., Granger, C., & Hamilton, B. (1994). The structure and stability of the Functional Independence Measure. *Archives of Physical Medicine and Rehabilitation, 75,* 127–132.

Multi-Society Task Force on PVS. (1994). Medical aspects of the persistent vegetative state. *New England Journal of Medicine, 330,* 1572–1579.

National Alliance for Caregiving. (2010). *Caregivers of Veterans–Serving on the Homefront: Report of study findings.* Bethesda, MD: Author.

Ottenbacher, K. J., Smith, P., Illig, S., Linn, R., Ostir, G., & Granger, C. (2004). Trends in length of stay, living setting, functional outcome, and mortality following medical rehabilitation. *JAMA: Journal of the American Medical Association, 292,* 1687–1695. doi:10.1001/jama.292.14.1687

Pape, T. L., Heinemann, A., Kelly, J., Hurder, A., & Lundgren, S. (2005). A measure of neurobehavioral functioning after coma. Part I: Theory, reliability and validity of the Disorders of Consciousness Scale. *Journal of Rehabilitation Research and Development, 42,* 1–18. doi:10.1682/JRRD.2004.03.0032

Pape, T., Lundgren, S., Guernon, A., Kelly, J., & Heinemann, A. (2011). *Disorders of Consciousness Scale (DOCS): Administration Manual.* Washington, DC: U.S. Department of Veterans Affairs.

Pape, T. L., Senno, R., Guernon, A., & Kelly, J. (2005). A measure of neurobehavioral functioning after coma. Part II: Clinical and scientific implementation. *Journal of Rehabilitation Research and Development, 42,* 19–28. doi:10.1682/JRRD.2004.03.0033

Pape, T. L., Tang, C., Guernon, A., Lundgren, S., Blahnik, M., Wei, Y., . . . Soneru, I. (2009). Predictive value of the Disorders of Consciousness Scale (DOCS). *PM & R: The Journal of Injury, Function, & Rehabilitation, 1,* 152–161.

Plum, F., & Posner, J. (1980). *The diagnosis of stupor and coma* (3rd ed.). Philadelphia, PA: FA Davis.

Rasch, G. (1960). *Probabilistic models for some intelligence and attainment tests.* Copenhagen, Denmark: Danish Institute for Educational Research. (Expanded edition, 1980. Chicago: University of Chicago Press).

Romano, M. D. (1989). Ethical issues and families of brain injured persons. *Journal of Head Trauma Rehabilitation, 4,* 33–41.

Ryan, T. A. (1959). Multiple comparison in psychological research. *Psychological Bulletin, 56,* 26–47. doi:10.1037/h0042478

Seel, R. T., Sherer, M., Whyte, J., Katz, D., Giacino, J., Rosenbaum, A., . . . Zasler, N. (2010). Assessment scales for disorders of consciousness: Evidence-based recommendations for clinical practice and research. *Archives of Physical Medicine and Rehabilitation, 91,* 1795–1813. doi:10.1016/j.apmr.2010.07.218

Statistics, P. (2008). SPSS (Version 17.0.1). Chicago, IL: SPSS.

Whyte, J., Gosseries, O., Chervoneva, I., DiPasquale, M., Giacino, J., Kalmar, K., . . . Eifert, B. (2009). Predictors of short term outcome in brain-injured patients with disorders of consciousness. *Progress in Brain Research, 177,* 63–72. doi:10.1016/S0079-6123(09)17706-3

Wright, B., & Masters, G. (1982). Rating Scale Analysis. *University of Chicago,* Chicago, IL: MESA Press.

Yarnold, P. R., & Soltysik, R. C. (2005). *Optimal data analysis: A guidebook with software for Windows.* Washington, DC: American Psychological Association.

Yarnold, P. R., & Soltysik, R. C. (2010a). Automated CTA software: Fundamental concepts and control commands. *Optimal Data Analyses, 1,* 144–160.

Yarnold, P. R., & Soltysik, R. C. (2010b). Maximizing accuracy of classification trees by optimal pruning. *Optimal Data Analyses, 1,* 23–29.

Yarnold, P. R., & Soltysik, R. C. (2010c). Optimal data analysis: A general statistical analysis Paradigm. *Optimal Data Analyses, 1,* 10–22.

Young, G. B. (2009). Clinical practice. Neurologic prognosis after cardiac arrest. *New England Journal of Medicine, 361,* 605–611. doi:10.1056/NEJMcp0903466

Zasler, N. (1996). Nomenclature: Evolving trends. *NeuroRehabilitation, 6,* 3–8. doi:10.1016/1053-8135(95)00143-3

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