Published in final edited form as:

Arch Phys Med Rehabil. 2008 May ; 89(5): 896–903. doi:10.1016/j.apmr.2007.12.030.

Impact of Age on Long-term Recovery From Traumatic Brain Injury

Carlos Marquez de la Plata, PhD, Tessa Hart, PhD, Flora M. Hammond, MD, Alan Frol, PhD, Anne Hudak, MD, Caryn R. Harper, MS, Therese O'Neil-Pirozzi, ScD, John Whyte, MD, PhD, Mary Carlile, MD, and Ramon Diaz-Arrastia, MD, PhD

Departments of Neurology (Marquez de la Plata, Harper, Diaz-Arrastia), Psychiatry (Frol, Carlile), and Physical Medicine and Rehabilitation (Hudak), University of Texas Southwestern Medical Center, Dallas, TX; Moss Rehabilitation Research Institute and Department of Rehabilitation Medicine, Jefferson Medical College, Philadelphia, PA (Hart, Whyte); Carolinas Rehabilitation, Charlotte, NC (Hammond); Department of Physical Medicine and Rehabilitation, Spaulding Rehabilitation Hospital, Harvard Medical School, Boston, MA (O'Neil-Pirozzi); and Department of Speech-Language Pathology and Audiology, Northeastern University, Boston, MA (O'Neil-Pirozzi)

Abstract

Objective—To determine whether older persons are at increased risk for progressive functional decline after traumatic brain injury (TBI).

Design—Longitudinal cohort study.

Setting—Traumatic Brain Injury Model Systems (TBIMS) rehabilitation centers.

Participants—Subjects enrolled in the TBIMS national dataset.

Interventions—Not applicable.

Main Outcome Measures—Disability Rating Scale (DRS), FIM instrument cognitive items, and the Glasgow Outcome Scale–Extended.

Results—Participants were separated into 3 age tertiles: youngest (16–26y), intermediate (27–39y), and oldest (≥ 40 y). DRS scores were comparable across age groups at admission to a rehabilitation center. The oldest group was slightly more disabled at discharge from rehabilitation despite having less severe acute injury severity than the younger groups. While DRS scores for the 2 younger groups improved significantly from year 1 to year 5, the greatest magnitude of improvement in disability was seen among the youngest group. Additionally, after dividing patients into groups according to whether their DRS scores improved (13%), declined (10%), or remained stable (77%) over time, the likelihood of decline was found to be greater for the 2 older groups than for the youngest group. A multiple regression model demonstrated that age has a significant negative influence on DRS score 5 years post-TBI after accounting for the effects of covariates.

Conclusions—This study supported our primary hypothesis that older patients show greater decline over the first 5 years after TBI than younger patients. Additionally, the greatest amount of improvement in disability was observed among the youngest group of survivors. These results suggest TBI survivors, especially older patients, may be candidates for neuroprotective therapies after TBI.

Reprint requests to Ramon Diaz-Arrastia, MD, PhD, 5323 Harry Hines Blvd, Dallas, TX 75390-9036, e-mail: ramon.diaz-arrastia@utsouthwestern.edu.

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit upon the authors or upon any organization with which the authors are associated.

Keywords

Brain injuries; Disabled persons; Rehabilitation

Traumatic brain injury (TBI) is a significant public health issue, as the incidence in the United States is estimated between 92 and 250 per 100,000 population a year and over 5 million Americans are living with a TBI-related disability.¹⁻⁴ The drain on economic resources stands at about \$9 to \$25 billion dollars.^{5,6} The resulting injuries range from mild disability to long-term disabilities or death.³ It has been observed that particular subpopulations recover differently from similar injuries. One characteristic felt to have an impact on the degree of recovery is age: in general, the older the patient the worse the outcome.⁷⁻¹² Issues of TBI and aging are important to study because of the large and growing number of older people who are affected by TBI, which has a bimodal age distribution peaking in late adolescence/early adulthood and again after age 70.³

TBI may interact negatively with aging in at least 2 ways: (1) recovery after TBI is more limited for older than younger survivors; and (2) older individuals who have suffered a TBI are at higher risk for progressive cognitive decline. First, advanced age at the time of injury may result in less complete recovery compared to younger persons with comparable injuries. While the mechanisms of this phenomenon are not known, it may be due simply to less capacity for compensation or reduced cognitive reserves, with increasing age.¹³ Prospective, longitudinal outcome studies are required to determine whether functional outcomes of TBI improve more slowly, or even decline, among older individuals over time. The Traumatic Brain Injury Model Systems (TBIMS) National Database is a unique resource through which to investigate whether survivors of TBI are at increased risk of late age-associated functional deterioration. The earliest TBIMS studies on this topic were limited by relatively small sample sizes, examined relatively short-term outcomes, and produced conflicting findings. For example, Cifu et al¹⁴ compared patients aged 55 and older at the time of injury with patients below 50 matched for duration and depth of unconsciousness and other severity indicators. Older patients had significantly worse disability scores at both rehabilitation admission and discharge, despite having much longer rehabilitation stays. In contrast, studies have found demographic variables, including age, are minimally associated with long-term outcomes.^{15,16} For instance, Reeder et al¹⁵ found that age was not associated with degree of improvement in FIM instrument and Disability Rating Scale (DRS) scores during inpatient rehabilitation when injury severity and demographic variables other than age were controlled. Prospective outcome studies following patients over longer outcome intervals have found comparable functional outcomes for older and younger survivors of TBI 6 months postinjury, as both groups demonstrate improvement within that time frame; but older patients experience a decline in functional ability 1 year postinjury.^{11,12} Testa et al¹⁷ followed younger (<49y) and older (>50y) cohorts with either TBI or orthopedic injury for 2 years postinjury and concluded that both TBI and older age were associated with less favorable outcomes, particularly in return to work rates.

Second, there is a suggestion that incurring even a mild TBI with loss of consciousness increases the risk of later developing dementia, such as Alzheimer's disease. Some retrospective epidemiologic studies using structured self-report methods have found an increased risk of dementia in patients who reported having sustained even a mild TBI.¹⁸⁻²² The retrospective methodology of such studies carries interpretive limitations. Nonetheless, at least 2 meta-analyses incorporating a number of different study designs have provided partial support for an association between TBI and acceleration or development of later dementia.^{23,24}

In a longitudinal study, indirect support for this relationship might accrue if older patients with TBI experienced progressive decline after initial recovery compared to younger participants

who may be more likely to be stable or continue to recover. The purpose of this study is to determine whether increasing age at injury is associated with a greater risk of progressive functional decline. To our knowledge, this is the first study to examine long-term trajectories of change as a function of age at injury, as long as 5 years after TBI. We hypothesized that older survivors of TBI would demonstrate a greater rate of worsening on objective measures of disability than younger survivors over a 4 year time span. The purpose of this descriptive exploratory study was to determine whether age at injury is associated with progressive functional decline. This hypothesis has important intervention implications, particularly as the advent of neuroprotective therapies for dementia will make it important to identify people at risk for cognitive decline in late life.

Methods

Participants

The current study includes participants enrolled in the TBIMS project between 1991 and 2001, having met the following criteria: (1) age of 16 years or older at the time of injury, (2) arrival at a TBIMS-affiliated hospital emergency department within 8 hours after injury, (3) receipt of acute and rehabilitation treatment at TBIMS-affiliated hospitals, (4) complete DRS²⁵ scores taken at 1- and 5-year follow-up evaluations, and (5) provision of informed consent directly or by proxy. At the time of this investigation 1127 patients were eligible to receive a 5-year post-TBI DRS evaluation specified in the TBIMS protocol, and 624 (55%) patients had complete DRS data 5 years post-TBI. Four hundred twenty-eight patients had complete DRS outcome data at both year 1 and year 5 (38%), and constituted the cohort analyzed here.

Patient's demographic, injury severity, and early outcome measures were examined among patients with and without follow-up DRS data 5 years postinjury to determine representativeness of the present sample with the larger TBIMS sample (table 1). Patients with complete follow-up data were slightly older at time of injury. As a group, patients with follow-up data were slightly more educated and were comprised of a greater proportion of whites than patients without follow-up data. Additionally, patients with follow-up data had longer acute hospitalizations and higher disability ratings than those without follow-up data. The distribution of demographic variables (except race) is commensurate with published incidence rates of TBI in the United States.²⁶

Measures

Glasgow Coma Scale—Injury severity was assessed using the Glasgow Coma Scale (GCS).²⁷ GCS scores were obtained from the emergency department admission forms, and represent the first GCS obtained after stabilization of cardiopulmonary function. Scores on the GCS range from 3 to 15, with higher scores representing a less severe injury.

Traumatic Coma Data Bank score—The Traumatic Coma Data Bank (TCDB)²⁸ score was used to categorize patient's head injury severity based on their computed tomography scans. TCDB scores range from 1 to 6, with the lowest score representing an injury with no sign of intracranial pathology and higher scores representing increasing degrees of intracranial pathology. Only patients with TCDB score ranging from 1 to 4 were analyzed, as scores of 5 and 6 are not solely based on the severity of the injury, but also consider the surgical decision to evacuate a lesion or not.

Disability Rating Scale—The DRS, a commonly used measure of disability that assigns a single score based on functioning in multiple domains, was used as the primary outcome measure. The DRS assesses the level of cognitive disability from the level of consciousness assessed as on the GCS, to disability in more complex areas such as feeding, toileting,

grooming, independence in the home, and employability. Scores range from 0 (no disability) to 29 (severe or complete disability). Scores on the DRS reflect level of disability with higher scores indicating greater disability. Individual DRS items have been found sensitive to long-term deficit improvement post-TBI.^{29,30} The DRS was assessed at admission to and discharge from rehabilitation as well as during scheduled follow-up assessments.

FIM instrument—The FIM³¹ is commonly used by rehabilitation clinicians to assess level of independence and function in various areas of functioning including self-care, sphincter control, transfers, locomotion, communication, and social cognition. The 18-item measure is used to follow patient's need for assistance in these areas. Each area of functioning is given a score ranging from 1 (total assist, indicating the patient performs <25% of the task in question) to 7 (complete independence). The total score for the FIM ranges from 18 to 126, and was assessed at admission to and discharge from rehabilitation as well as during annual follow-up assessments. Year 1 versus year 5 FIM total score comparisons have been found sensitive to subtle improvements post-TBI.³⁰ The present study used the score for the cognitive domain of the FIM independent of the rest of the scale, as the cognitive domain of the FIM score is less influenced by physical disabilities than the total FIM score. The cognitive domain of the FIM is comprised of 5 items whose scores may range from 5 to 35.

Glasgow Outcome Scale—Extended—Functional outcome was also followed annually using the Glasgow Outcome Scale—Extended (GOS-E),³² a measure that assesses functional abilities in multiple domains following a head injury. A score between 1 and 8 (higher scores indicating better global outcomes) is assigned based on a structured interview that includes questions regarding the patient's ability to follow commands, perform activities of daily living, work, travel, and participate in recreational activities. There are also questions about the presence of emotional disruptions and injury complications. Six month outcome based on GOS-E has been found related to DRS-based outcome post-TBI.³³

Procedure

Follow-up assessment of disability was conducted at rehabilitation admission and prior to discharge, and again by telephone 1y±2mo and 5y±6mo post-TBI. Change scores were created for the DRS, FIM, cognitive domain of the FIM, and GOS-E by subtracting the scores obtained at the year 5 assessment from the scores obtained 1 year post-TBI. Greater change DRS scores indicate improvement in functional ability over time, whereas lower change scores on the FIM, cognitive domain of the FIM, and GOS-E indicate improvement in functioning. Problem substance, a variable with potential influence on outcome, use was defined dichotomously as patients who reported using any illicit substances, or participating in binge or heavy drinking as defined by Corrigan et al.³⁴

To investigate the effect of age on functional abilities 5 years post-TBI, patients were divided into 3 age groups based on age at time of injury (ie, youngest, intermediate, oldest). Tertiles were determined to yield equal sized groups. Change in functional abilities were also categorized into 3 groups by determining the mean DRS change score and denoting patients who were 1 standard deviation (SD) above the mean as improvers, 1 SD below the mean as decliners, and those within a SD of the mean were stable. However, DRS change and change group scores must be interpreted with caution, as DRS scores are ordinal data with unequal intervals such that a change at 1 end of the scale may be more meaningful than a change of the same magnitude at another end of the scale.³⁵

Statistical Analysis

Data were examined prior to analysis to determine whether assumptions were met for the planned analyses. Demographic information including sex, race, and level of education were

examined for differences among age groups using chi-square analyses. Hours of unconsciousness after injury, and length of stay (LOS) in acute and rehabilitation hospital were log-transformed, and subsequent analyses utilized the normalized data. Univariate analyses of variance (ANOVA) with planned comparisons (using Scheffé corrections) were run to determine differences among age groups on injury severity measures (ie, hours unconscious, days in post-traumatic amnesia [PTA], length of acute and rehabilitation hospitalizations, and TCDB scores), problem alcohol and substance abuse, DRS scores at admission to and discharge from rehabilitation, DRS score at 1 year postinjury, and the primary outcome measure (ie, DRS score 5y postinjury). Data used in the aforementioned analyses were also analyzed using a nonparametric approach (ie, Mann-Whitney tests) to confirm results are similar when treating the data as ordinal or interval. Given the results of these analyses were similar across approaches, these data are appropriate for inclusion in multivariate regression models.

Multivariate regression analysis was employed to determine whether age (as a continuous variable) significantly influences disability scores 5 years post-TBI. A first regression model fit all covariates found to be significant on univariate analyses using the forward entry method. A second model was fit by removing age at time of injury from the initial model. The difference in the F test statistic was inspected to determine whether removing age from the model changes the level of significance associated with the predictors.

Paired sample *t* tests were used to determine whether there was significant change in outcomes from year 1 to year 5 within each age group. An ANOVA with planned Scheffé comparisons were conducted to determine whether the magnitude of change in outcome measures seen over time is different across age groups. A separate ANOVA was performed to examine differences in demographic and injury-related data across DRS change groups, and a relative risk ratio was used to determine the likelihood of decline or improvement as a function of age.

Results

Patient Characteristics

The statistical analysis will focus on patients who had follow-up data 5 years post-TBI (table 2). There were no differences among groups for sex or race. In terms of injury severity, the 2 oldest groups demonstrated shorter periods of unconsciousness than the youngest group, and the oldest group suffered less severe injuries than the younger groups as rated by the GCS. The youngest group showed a greater rate of problem alcohol and/or substance abuse than the oldest group. There were no differences among groups on duration of PTA and LOS in acute or rehabilitation hospitals. TCDB data shows the 3 age groups were proportional in terms of ratings 1 through 4.

Primary Analysis

Disability ratings—DRS scores showed all 3 age groups had similar DRS scores at admission to a rehabilitation hospital. The oldest group was significantly more impaired than the intermediate group at discharge from rehabilitation. No other differences among the age groups were found on DRS scores at rehabilitation discharge. No differences in DRS were found across age groups at 1 year post-TBI (table 3). Disability scores 5 years postinjury showed the oldest group showed greater disability than the 2 younger groups.

Figure 1 demonstrates all 3 age groups improve between admission and rehabilitation through year 5, and the magnitude, or slope, of improvement among the 3 age groups is similar through the first year postinjury. Paired sample *t* tests show significant improvement in functioning as measured by the 4 outcome measures (ie, DRS, FIM, cognitive domain of the FIM, GOS-E) over time among the youngest group. Additionally, the intermediate group shows significant

improvement on the DRS, and the oldest group does not demonstrate significant improvement on any of the outcome measures (table 4). Change scores for the outcome measures were examined as a marker of the magnitude of improvement between year 1 and year 5. The 2 younger groups demonstrated greater change in DRS than the oldest group, and there were no differences in magnitude of change among the other outcome measures (see table 3).

Multiple regression analysis—A multiple regression model was derived using DRS score at year 5 as the dependent variable and using age at time of injury and other significant univariate variables as independent predictors (ie, hours of unconsciousness, admission GCS, problematic alcohol and/or substance use, and DRS score at discharge from rehabilitation). This model explained only a fraction of the variance ($R^2=.167$) but was associated with a significant F statistic ($F_{5,306}=12.227, P<.001$) suggesting there are regressors in the model that significantly predict the dependent variable. Furthermore, age and DRS at discharge from rehabilitation were the only significant regressors in this model (table 5). The B coefficient for age was statistically significant even after holding the variance from other regressors constant suggesting that for every year increase in age there is an associated increase in DRS score at year 5 follow-up of approximately .031 points. A subsequent model was fit removing the effects of age and it was a worse fit with the data ($R^2=.124$), and was associated with a decrease in the F statistic, as the F test change statistic between the full model and the model without age as a predictor was ($F_{1,308}=15.812, P<.001$) (see table 5). The difference in variance accounted for between the models was $-.043$ suggesting age independently accounted for 4% of the variance in DRS scores at year 5. DRS at discharge from rehabilitation remained significant in the model.

Change group analyses—Improvers (patients who demonstrated an improvement on the DRS ≥ 1 SD than the mean for the entire sample) did not demonstrate a significant difference in age as compared with patients whose scores declined or did not change; however, a trend was noted, as those who declined tended to be older than improvers and patients whose disability scores were relatively equivalent over time. There were fewer decliners among the youngest age group, such that the likelihood of decline for a person younger than 26 years of age is lower than for individuals 26 years or older at time of injury (relative risk [RR]=.321, $P=.001$) (fig 2). Patients who declined after 5 years were more likely to be high school graduates than the 2 other change groups. Furthermore, patients who improved over time had the lowest rate of high school graduates. There were no differences among change groups with respect to GCS, hours unconscious, or length of hospitalizations (table 6) DRS scores at admission to and discharge from rehabilitation were relatively equivalent between decliners and patients whose DRS score did not change significantly. Improvers were significantly more disabled at admission to and discharge from rehabilitation than decliners and patients whose DRS did not change over time. Additionally, improvers were less likely to endorse problem alcohol/substance use than nonimprovers in general (RR=.883, $P=.027$) and patients whose DRS scores neither improved nor declined over time (RR=.87, $P=.026$).

DRS change groups also differed with respect to FIM and cognitive domain of the FIM change scores, as improvers were less disabled on both of these measures than decliners or patients whose scores did not change significantly. Additionally, decliners demonstrated the least improvement of all change groups on FIM and cognitive domain of the FIM change scores.

Discussion

The present study supported our primary hypothesis that older survivors of TBI show greater functional decline than younger survivors. Results from this study demonstrated younger survivors of TBI showed significant improvement in disability ratings between the first and fifth year postinjury, whereas older counterparts did not show significant improvement in

outcome measures over the same time period. Furthermore, the results suggest older survivors have a higher risk of functional decline than younger survivors, as patients 26 years or younger showed a lower rate of decline over a 4 year span than older patients. These results are consistent with findings of a much smaller TBIMS database study of 182 TBI survivors that found age is an independent predictor of cognitive decline 5 years postinjury,³⁶ and extend the influence of age to functional decline. The present study also revealed lack of statistically significant differences in change scores for FIM, cognitive domain of the FIM, and GOS-E across the age groups. These data are consistent with prior TBIMS database investigations by Hammond et al^{37,38} finding age was not useful for predicting improvement or worsening in DRS level of functioning, DRS employability, FIM social interaction, and FIM memory and problem solving. However, Hammond³⁸ did find age to be predictive of improvement in FIM comprehension and expression but not of decline in this FIM item. The discrepancy between this study and Hammond's studies may be attributed to differences in the measures used, as Hammond evaluated the effects of age on certain items of the FIM and DRS, whereas, the present study utilized composite scores for these tests. Furthermore, in contrast to prior studies finding the DRS, FIM, and GOS-E are relatively sensitive to functional change years after TBI^{39,40} the lack of change in FIM and GOS-E scores over time among the older groups in our study suggests age influences long-term functional recovery.

The results of the present study concur with prior investigations finding older patients demonstrate early improvements in functioning similar to those seen in young patients; however, young patients are more likely to demonstrate continued improvement and older patients are more likely to decline.^{11,12} These findings lend credibility to previous retrospective and shorter-term longitudinal studies suggesting a risk for dementia and continued functional decline (some of it perhaps, due to dementing illness) among older individuals, as longitudinal data were utilized for this investigation.^{11,12,18-20}

Interestingly, TBI survivors who improved over time were slightly younger (though not significantly), and had worse disability ratings at admission to and discharge from rehabilitation services than patients who did not improve, and therefore had more room for improvement. While this may explain the potential for greater improvement among the young as compared to older patients, actual improvement over time reflected by the DRS is less understood. The results also show the oldest groups improved to a lesser degree than the youngest group, and the rate of decline was higher among the 2 older groups than the youngest group, while the rate of improvers was similar across age groups. This suggests that older survivors of TBI experience progressive decline over time, whereas younger patients do not. The mechanism of this progressive decline cannot be fully explained with our data, as there are a number of biologic and environmental changes associated with age including decreasing synaptic plasticity and cortical volume with increasing age.⁴¹⁻⁴³

A greater degree of disability 5 years postinjury among older patients may be explained by an increased number of actual and perceived health problems as compared to younger patients. A recent investigation noted patients older than 55 years of age report more problems with headaches, body temperature changes, communication difficulties, sleeping problems, and back and neck pains than age matched controls.⁴⁴ While the ages for the oldest group ranges from 40 to 85, half of the oldest group were over 50 years of age and 25% were over 60 years of age; therefore, it is possible these individuals have more physical complaints than younger TBI survivors. Degree of actual and/or perceived physical burdens were not measured in this investigation, but should be measured in future prospective studies of age and functional recovery from TBI, as it may covary with age and confound the effect of age on disability. While our analysis showed age influences change in functional outcomes over the first 5 years post-TBI, the magnitude of this influence is small. Only a small proportion of the variance in DRS change scores is explained by age as demonstrated by the multivariate regression analysis.

Along a similar vein, patients in this study whose function improved over time were less likely to have abused alcohol or drugs. This is consistent with literature finding patients who abuse alcohol or drugs are at greater risk for unemployment, suicide, and negative health consequences including seizures, and cerebrovascular disease.⁴⁵⁻⁵⁰ However, despite influencing outcome in univariate analysis, substance or alcohol abuse did not significantly influence change in disability scores over the 4-year period in multivariate analyses. These results suggest that age and alcohol and/or illicit substance abuse play only a modest role in change in disability scores over time, and that there are other covarying factors not measured in this investigation that have greater influence on disability post-TBI. Future studies of age and functional recovery from TBI should consider other factors that may impact long term functional outcomes, such as preinjury level of function, preinjury comorbidities, and nature of injury.^{51,52}

Results from the present study suggest TBI survivors, especially older survivors should be studied as candidates for investigational neuroprotective agents for months or years following their injury. Future studies may find it beneficial to examine the DRS to determine if pharmacologic treatment or neurorehabilitative therapies can increase the amount of functional recovery and/or decrease the rate of decline among TBI survivors in a longitudinal fashion.

Study Limitations

One limitation of the study was the potential for systematic bias created by subjects lost to follow-up. Corrigan et al.^{45,53} concluded that in their longitudinal cohort of consecutive admissions to an acute brain injury rehabilitation unit, certain types of outcomes, but particularly employment, could be overestimated because of the loss of subjects with prior histories of substance abuse. Most longitudinal studies of persons with TBI have substantial lost to follow-up rates^{45,53} including the TBIMS dataset. The presence of systematic bias only occurs when a characteristic associated with being lost is also associated with the dependent variable of interest. In the current sample, those eligible for 5-year follow-up who could not be found were determined to be younger and less educated than those who were included in the analyses. It is thought that those who are lost to follow up may be more independent, and thus, not allow follow-up with the rehabilitation hospital. If that is the case, then the findings would be underestimated. However, this is only conjecture as the disability level of those lost to follow-up is not known. Additionally, follow-up data were more difficult to obtain for minority patients than for whites, suggesting limited generalizability among minority patients. Along a similar line, another important consideration regarding the generalizability of our finding is that this study only included those who received inpatient rehabilitation. This is particularly relevant in light of studies finding minorities receive post-TBI rehabilitation services at lower rates than whites.⁵⁴

Another limitation of the present investigation is that it is difficult to determine whether the decline in disability rating over time experienced by the oldest group is attributed to disabling effects of brain injury or simply decline associated with normal aging, as was hypothesized in Cifu et al.¹⁴ However, this is unlikely given that the DRS is not sensitive enough to detect subtle decline associated with normative aging, especially among persons as young as 45 years of age. Future studies may need to incorporate an orthopedic control group separated into age groups to compare rates of DRS change scores with patients with TBI, as was done by Testa et al.¹⁷

Additionally, the determination of the age groups was rather arbitrary, as it was based on dividing the age distribution into 3 equal groups. There is no anatomic, neurologic, or developmental support suggesting people older than 26 years of age differ from younger people. Clinical interpretation of these results should be tempered with that caveat. Additionally, the DRS poses a challenge from an analysis standpoint due to its ordinal nature.

The DRS has been analyzed using Rasch techniques, and has shown to have unequal intervals throughout the scale.³⁵ Therefore, change scores should be interpreted cautiously, as a change of 1 point at 1 end of the scale could be more or less meaningful than a 1-point change at another point of the scale. Finally, the large number of statistical tests utilized to analyze the data increases the risk of a type I error.

Conclusions

The present results are commensurate with prior retrospective studies suggesting increased risk of cognitive and functional decline among older survivors of TBI. Furthermore, while there are many reasons why individual's disability may improve or worsen over time, those who improve are more likely to be younger and less likely to abuse alcohol or use illicit substances. These results may have clinical, and eventually pharmacologic, implications for the long-term management of older survivors of TBI, as they could possibly benefit from neuroprotective therapies.

Acknowledgements

Supported by the National Institute of Health, U.S. Department of Education (grant nos. H133 A020526, R01 HD48179, U01 HD42652).

References

1. Bruns J, Hauser WA. The epidemiology of traumatic brain injury: a review. *Epilepsia* 2003;44:2–10. [PubMed: 14511388]
2. Jager TE, Weiss HB, Cogen JH, Pepe PE. Traumatic brain injuries evaluated in U.S. emergency departments, 1992–1994. *Acad Emerg Med* 2000;7:134–40. [PubMed: 10691071]
3. Thurman DJ, Alverson C, Dunn KA, Guerrero J, Sniezek JE. Traumatic brain injury in the United States: a public health perspective. *J Head Trauma Rehabil* 1999;14:602–15. [PubMed: 10671706]
4. Smith DH, Meaney DF, Shull WH. Diffuse axonal injury in head trauma. *J Head Trauma Rehabil* 2003;18:307–6. [PubMed: 16222127]
5. Meythaler JM, Peduzzi JD, Eleftheriou E, Novack TA. Current concepts: diffuse axonal injury-associated traumatic brain injury. *Arch Phys Med Rehabil* 2001;82:1461–71. [PubMed: 11588754]
6. Rehabilitation of persons with traumatic brain injury. NIH Consensus Development Panel on Rehabilitation of Persons With Traumatic Brain Injury. *JAMA*; Consensus conference; 1999. p. 974–83.
7. Flanagan SR, Hibbard MR, Gordon WA. The impact of age on traumatic brain injury. *Phys Med Rehabil Clin N Am* 2005;16:163–77. [PubMed: 15561549]
8. Katz D, Alexander MP. Predicting course of recovery and outcome for patients admitted to rehabilitation. *Arch Neurol* 1994;51:661–70. [PubMed: 8018038]
9. Stuss DT, Binns MA, Carruth FG, et al. Prediction of recovery of continuous memory after traumatic brain injury. *Neurology* 2000;54:1337–44. [PubMed: 10746607]
10. Kirkness CJ, Burr RL, Mitchell PH, Newell DW. Is there a sex difference in the course following traumatic brain injury? *Biol Res Nurs* 2004;5:299–310. [PubMed: 15068659]
11. Mosenthal AC, Livingston DH, Lavery RF, et al. The effect of age on functional outcome in mild traumatic brain injury: 6-month report of a prospective multi-center trial. *J Trauma* 2004;56:1042–8. [PubMed: 15179244]
12. Livingston DH, Lavery RF, Mosenthal AC, et al. Recovery at one year following isolated traumatic brain injury: a Western Trauma Association prospective multicenter trial. *J Trauma* 2005;59:1298–304. [PubMed: 16394900]
13. Lye CL, Shores EA. Traumatic brain injury as a risk factor for Alzheimer's Disease: a review. *Neuropsychology Rev* 2000;10:115–29.

14. Cifu DX, Kreutzer JS, Marwitz JH, Rosenthal M, Englander J, High W. Functional outcomes of older adults with traumatic brain injury: a prospective, multicenter analysis. *Arch Phys Med Rehabil* 1996;77:883–8. [PubMed: 8822678]
15. Reeder KP, Rosenthal M, Lichtenberg P, Wood D. Impact of age on functional outcome following traumatic brain injury. *J Head Trauma Rehabil* 1996;11(3):22–31.
16. Wood RL, Rutterford NA. Demographic and cognitive predictors of long-term psychosocial outcome following traumatic brain injury. *J Int Neuropsychol Soc* 2006;12:350–8. [PubMed: 16903127]
17. Testa JA, Malec JF, Moessner AM, Brown AW. Outcome after traumatic brain injury: effects of aging on recovery. *Arch Phys Med Rehabil* 2005;86:1815–23. [PubMed: 16181948]
18. Rasmussen DX, Brandt J, Martin DB, Folstein MF. Head injury as a risk factor in Alzheimer's disease. *Brain Inj* 1995;9:213–9. [PubMed: 7606235]
19. Mayeux R, Ottman R, Tang MX, et al. Genetic susceptibility and head injury as risk factors for Alzheimer's disease among community-dwelling elderly persons and their first degree relatives. *Ann Neurol* 1993;33:494–501. [PubMed: 8498827]
20. Corrada MM, Costa PT, Kawas CH. Head injury and the risk of developing Alzheimer's disease [abstract]. *Neurology* 1997;48:A301.
21. Zabar, Y.; Kawas, CH. Epidemiology and clinical genetics of Alzheimer's disease. In: Clark, CM.; Trojanowski, JQ., editors. *Neurodegenerative dementias*. New York: McGraw Hill; 2000. p. 79-94.
22. Mayeux R, Ottman R, Maestre G, et al. Synergistic effects of traumatic head injury and apolipoprotein-epsilon 4 in patients with Alzheimer's disease. *Neurology* 1995;45:555–7. [PubMed: 7898715]
23. Mortimer JA, van Duijn CM, Chandra V, et al. Head trauma as a risk factor for Alzheimer's disease: a collaborative re-analysis of case-control studies. EURODEM Risk Factors Research Group. *Int J Epidemiol* 1991;20:S28–35. [PubMed: 1833351]
24. Fleminger S, Oliver DL, Lovestone S, Rabe-Hesketh S, Giora A. Head injury as a risk factor for Alzheimer's disease: the evidence 10 years on; a partial replication. *J Neurol Neurosurg Psychiatry* 2003;74:857–62. [PubMed: 12810767]
25. Rappaport M, Hall KM, Hopkins K, Belleza T, Cope DN. Disability Rating Scale for severe head trauma patients: coma to community. *Arch Phys Med Rehabil* 1982;63:118–23. [PubMed: 7073452]
26. Bruns J, Hauser WA. The epidemiology of traumatic brain injury: a review. *Epilepsia* 2003;44:2–10. [PubMed: 14511388]
27. Teasdale GM, Jennett B. Assessment of coma and impaired consciousness. A practical scale. *Lancet* 1974;2:81–4. [PubMed: 4136544]
28. Marshall LF, Bowers-Marshall S, Klauber MR, et al. A new classification of head injury based on computerized tomography. *J Neurosurg* 1991;75:S14–20.
29. Hall KM, Bushnik T, Lakisic-Kazacic B, Wright J, Cantagallo A. Assessment and comparison of traumatic brain injury outcome measures for long term follow-up of community based individuals. *Arch Phys Med Rehabil* 2001;82:367–74. [PubMed: 11245760]
30. Hammond FM, Grattan KD, Sasser H, Corrigan JD, Bushnik T, Zafonte RD. Long-term recovery course after traumatic brain injury: a comparison of the functional independence measure and disability rating scale. *J Head Trauma Rehabil* 2001;16:318–29. [PubMed: 11461655]
31. Keith RA, Granger CV, Hamilton BB, Sherwin FS. The functional independence measure: a new tool for rehabilitation. *Adv Clin Rehabil* 1987;1:6–18. [PubMed: 3503663]
32. Wilson JT, Pettigrew LE, Teasdale GM. Structured interviews for the Glasgow Outcome Scale and the extended Glasgow Outcome Scale. *J Neurotrauma* 1998;15:573–85. [PubMed: 9726257]
33. Wilson JT, Pettigrew LE, Teasdale GM. Emotional and cognitive consequences of head injury in relation to the Glasgow outcome scale. *J Neurol Neurosurg Psychiatry* 2000;69:204–9. [PubMed: 10896694]
34. Corrigan, J.; Bogner, J.; Lamb-Hart, G.; Sivak-Sears, N. Technical report on problematic substance use variables. San Jose: Center for Outcome Measurement in Brain Injury; 2003.
35. Hall KM, Hamilton DD, Gordon WA, Zasler ND. Characteristics and comparisons of functional assessment indices: Disability Rating Scale, Functional Independence Measure and Functional Assessment Measure. *J Head Trauma Rehabil* 1993;8(2):60–74.

36. Millis SR, Rosenthal M, Novack TA, et al. Long-term neuropsychological outcome after traumatic brain injury. *J Head Trauma Rehabil* 2001;16:343–55. [PubMed: 11461657]
37. Hammond FM, Grattan KD, Sasser H, et al. Five years after TBI: a study of individual outcomes and predictors of change in function. *Neurorehabilitation* 2004;19:25–36. [PubMed: 14988585]
38. Hammond FM, Hart T, Bushnik T, Corrigan JD, Sasser H. Change and predictors of change in communication, cognition, and social function between 1 and 5 years after traumatic brain injury. *J Head Trauma Rehabil* 2004;19:314–28. [PubMed: 15263859]
39. van Baalen B, Odding E, van Woensel MP, Roebroek ME. Reliability and sensitivity to change of measurement instruments used in a traumatic brain injury population. *Clin Rehabil* 2006;20:686–700. [PubMed: 16944826]
40. Whitnall L, McMillan TM, Murray GD, Teasdale GM. Disability in young people and adults after head injury: 5-7 year follow up of a prospective cohort study. *J Neurol Neurosurg Psychiatry* 2006;77:640–5. [PubMed: 16614025]
41. Kempermann G, Gast D, Gage FH. Neuroplasticity in old age: sustained five-fold induction of hippocampal neurogenesis by long-term environmental enrichment. *Ann Neurol* 2002;52:135–43. [PubMed: 12210782]
42. Sapoznik S, Ivshitz M, Segal M. Age-dependent glutamate induction of synaptic plasticity in cultured hippocampal neurons. *Learn Mem* 2006;13:719–27. [PubMed: 17101873]
43. Ge Y, Grossman R, Babb JS, Rabin ML, Mannon LJ, Kolson DL. Age-related total gray matter and white matter changes in normal adult brain. Part I: volumetric MR imaging analysis. *Am J Neuro Radiol* 2002;23:1327–33.
44. Breed ST, Flanagan SR, Watson KR. The relationship between age and the self-report of health symptoms in persons with traumatic brain injury. *Arch Phys Med Rehabil* 2004;85:S61–7. [PubMed: 15083423]
45. Corrigan JD, Bogner JA, Mysiw WJ, Clinchot D, Fugate L. Systematic bias in outcome studies of persons with traumatic brain injury. *Arch Phys Med Rehabil* 1997;78:132–7. [PubMed: 9041892]
46. Sherer M, Bergloff P, High W, Nick TG. Contribution of functional ratings to prediction of longterm employment outcome after traumatic brain injury. *Brain Inj* 1999;13:973–87. [PubMed: 10628502]
47. Teasdale TW, Engberg A. Suicide after traumatic brain injury: a population study. *J Neurol Neurosurg Psychiatry* 2001;71:436–40. [PubMed: 11561024]
48. Verma NP, Policherla H, Buber BA. Prior head injury accounts for the heterogeneity of the alcohol-epilepsy relationship. *Clin Electroencephalogr* 1992;23:147–51. [PubMed: 1628408]
49. Walbran BB, Nelson JS, Taylor JR. Association of cerebral infarction and chronic alcoholism: an autopsy study. *Alcohol Clin Exp Res* 1981;5:531–5. [PubMed: 7030109]
50. Hillbom M, Juvela S, Numminen H. Alcohol intake and the risk of stroke. *J Cardiovasc Risk* 1999;6:223–8. [PubMed: 10501273]
51. Munro PT, Smith RD, Parke TR. Effect of patients' age on management of acute intracranial haematoma: prospective national study. *BMJ* 2002;325:1001–5. [PubMed: 12411357]
52. Rakier A, Guilburd JN, Soustiel JF, Zaaroor M, Feinsod M. Head injuries in the elderly. *Ann Neurol* 2002;9:187–93.
53. Corrigan JD, Harrison-Felix C, Bogner J, Dijkers M, Terrill MS, Whiteneck G. Systematic bias in traumatic brain injury outcome studies because of loss to follow-up. *Arch Phys Med Rehabil* 2003;84:153–60. [PubMed: 12601644]
54. Shafi S, Marquez de la Plata C, Diaz-Arrastia R, et al. Ethnic disparities exist in trauma care. *J Trauma* 2007;63:1138–42. [PubMed: 17993963]

Disability Ratings by Age Group

Fig 1.

All groups move in the direction of improvement over five years, and at a similar magnitude/slope through the first year post-injury. The two older groups show a similar magnitude of improvement between years 1 and 5; whereas, the youngest group improves most significantly. Adm = admission from rehabilitation hospital. Dis = discharge from rehabilitation hospital.

Change in DRS From Year 1 to Year 5 Across Age Groups

Fig 2.

The youngest group (referent) has a lower proportion of patients who show functional decline after five years than the two other age groups. * Denotes significant difference $P < .01$.

Table 1
Patients With and Without DRS Data for Years 1 and 5

Variables	Complete FU (n=428)	No Year 5 DRS (n=504)	P
Mean age $\pm$ SD (y)	36.45 $\pm$ 15.92	33.73 $\pm$ 14.60	.007*
Sex (% male)	74.5	78.8	.119
Education (% with 12y)	37.9	27.8	<.001*
Race (% white)	57.7	47.6	.003*
GCS score	8.91 $\pm$ 4.11	8.87 $\pm$ 4.00	.934
Unconscious (h)	10.86 $\pm$ 24.93	8.33 $\pm$ 14.03	.482
PTA (d)	32.63 $\pm$ 24.98	29.54 $\pm$ 26.92	.125
LOS acute hospitalization	22.95 $\pm$ 19.14	19.77 $\pm$ 15.54	.037*
LOS rehabilitation	34.82 $\pm$ 25.64	33.91 $\pm$ 28.49	.214
Mean DRS admission $\pm$ SD	13.40 $\pm$ 5.24	12.45 $\pm$ 5.37	.007*
Mean DRS discharge $\pm$ SD	5.72 $\pm$ 3.23	5.62 $\pm$ 3.61	.660

NOTE. Demographic, injury severity, and early outcome variables for patients with and without DRS data for years 1 and 5.

Abbreviations: FU, follow-up.

* Significant probability values.

Table 2
Demographic and Injury-Related Variables by Age

	Age Groups		
	Youngest	Intermediate	Oldest
Mean age $\pm$ SD (y)	20.7 $\pm$ 2.9	33.8 $\pm$ 4.1	54.7 $\pm$ 12.2
Age range (y)	16–26	27–39	40–85
n	141	144	143
Education (% with 12y)	33	45	36
Sex (% male)	69	79	76
Race (% white)	61	54	58
GCS score	7.8 $\pm$ 3.6	8.4 $\pm$ 4.1 [†]	10.3 $\pm$ 4.2 [*]
Unconscious (h)	16.2 $\pm$ 38.9	8.5 $\pm$ 13.0 [*]	8.1 $\pm$ 13.2 [*]
PTA (d)	32.3 $\pm$ 25.0	32.6 $\pm$ 23.6	33.0 $\pm$ 26.7
LOS acute hospitalization	24.6 $\pm$ 22.4	21.7 $\pm$ 18.0	22.6 $\pm$ 16.7
LOS rehabilitation	36.8 $\pm$ 26.1	33.2 $\pm$ 25.0	34.6 $\pm$ 25.8
ETOH/substance abuse, n (%)	22 (18)	14 (11)	9 (7%) [*]
Mean DRS admission $\pm$ SD	14.1 $\pm$ 5.6	13.1 $\pm$ 4.9	13.1 $\pm$ 5.2
Mean DRS discharge $\pm$ SD	5.8 $\pm$ 3.3	5.2 $\pm$ 2.7 [†]	6.2 $\pm$ 3.5
TCDB score, n (%)			
1	59 (66)	63 (69)	61 (59)
2	7 (8)	8 (9)	13 (13)
3	15 (17)	12 (13)	15 (15)
4	8 (9)	9 (10)	14 (14)

NOTE. Comparison of demographic and injury-related variables by age groups.

Abbreviations: ETOH, alcohol.

* Significant difference using the youngest group as a referent ($P < .05$ for all comparisons).

[†] Significant difference using the oldest group as a referent for comparison to intermediate ($P < .05$ for all comparisons).

Table 3
Magnitude of Change for Outcome Measures by Age

Variables	Age		
	16–26y (n=141)	27–39y (n=144)	40–85y (n=143)
DRS year 1	2.72±3.34	2.39±2.35	3.08±2.61
DRS year 5	1.63±2.80	2.03±2.04 [†]	2.87±2.85 [*]
ΔDRS	1.09±1.99	0.35±1.99 [*]	0.22±2.14 [*]
ΔFIM	−3.08±10.73	−0.91±8.81	−0.23±12.35
ΔFIM cognitive	−1.24±4.39	−0.49±4.30	−0.70±5.07
ΔGOS-E	0.42±0.58	0.13±1.59	0.25±1.22

NOTE. All age groups move in the direction of improved disability over time; however, as a group, the youngest patients improve most.

Abbreviation: Δ, change between year 1 and 5.

^{*} Significant difference using the youngest group as a referent ($P<.05$ for all comparisons).

[†] Significant difference using the oldest group as a referent for comparison to intermediate group ($P<.05$ for all comparisons).

Table 4Paired *t* Test Results by Age

Variables	Age		
	Youngest	Intermediate	Oldest
	16–26y (n=141)	27–39y (n=144)	40–85y (n=143)
DRS (y1–5)	<.001*	.035*	.227
FIM (y1–5)	.014*	.326	.874
FIM cognitive (y1–5)	.002*	.177	.122
GOS-E (y1–5)	.002*	.757	.328

NOTE. Probability values from paired sample *t* tests for outcome measures across age groups ($P < .05$ for all comparisons).

* Significant within-group outcome differences.

Table 5
Analysis of Covariates on Disability Rating Score 5 Years Postinjury (n=428)

Covariates	Model F Change	P	B	SE	P
Model 1 (includes age)	12.227	<.001			
Age			.031	.008	<.001
GCS admission			-.042	.034	.223
DRS at rehabilitation discharge			.232	.043	<.001
Unconscious (h)			.190	.205	.354
Problem substance/ETOH			.113	.351	.749
Model 2 (excludes age)	10.869	<.001			
GCS admission			-.007	.034	.842
DRS at rehabilitation discharge			.264	.044	<.001
Unconscious (h)			.054	.207	.796
Problem substance/ETOH			-.025	.358	.944

NOTE. Analysis of the contribution of age to DRS 5 years post-TBI by removing the effect of age from an initial model that includes age as a predictor and analyzing the F change statistic. B weights are provided to characterize the direction and amount of influence for each predictor in the model.

Abbreviation: SE, standard error.

Table 6
Demographic and Injury-Related Characteristics for DRS Change Groups

Variables	Change Group		
	Decline	No Change	Improve
	(n=44)	(n=329)	(n=55)
Age (y)	40.93±14.83	36.12±16.17	34.83±14.89
Education (% with 12y)	51.2	38.6 ^{**}	23.6 [*]
Sex (% male)	75	73.9	78.2
Race (% white)	45.5	60.8	49.1
GCS score	9.21±4.45	9.05±4.09	7.87±3.84
Unconscious (h)	9.58±15.83	10.22±26.39	15.94±21.25
PTA (d)	37.13±25.95	31.77±24.12	35.00±30.32
LOS acute hospitalization	22.7±16.95	21.93±17.73	29.27±26.66
LOS rehabilitation	37.73±26.29	33.49±25.24	40.44±26.96
ETOH/substance abuse, n (%)	4 (11)	40 (14) [†]	1 (2) [*]
Mean DRS admission ± SD	12.48±5.14	13.12±5.19 [†]	15.92±5.02 [*]
Mean DRS discharge ± SD	5.55±2.55	5.50±3.06 [†]	7.27±4.24 [*]
TCDB, n (%)			
1	17 (60.7)	149 (66.2)	17 (54.8)
2	4 (14.3)	21 (9.3)	3 (9.7)
3	5 (17.9)	28 (12.4) [†]	9 (29)
4	2 (7.1)	27 (12)	2 (6.5)

* Significant difference using the declined group as a referent for comparing across groups ($P < .05$ for all comparisons).

[†] Significant difference using the improved group as a referent for comparison to the no change group ($P < .05$ for all comparisons).