ORIGINAL ARTICLE

Prediction of Return to Productivity After Severe Traumatic Brain Injury: Investigations of Optimal Neuropsychological Tests and Timing of Assessment

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ABSTRACT. Green RE, Colella B, Hebert DA, Bayley M, Kang HS, Till C, Monette G. Prediction of return to productivity after severe traumatic brain injury: investigations of optimal neuropsychological tests and timing of assessment. Arch Phys Med Rehabil 2008;89(12 Suppl 2):S51-60.

Objectives: (1) To examine predictive validity of global neuropsychological performance, and performance on timed tests (controlling for manual motor function) and untimed tests, including attention, memory, executive function, on return to productivity at 1 year after traumatic brain injury (TBI). (2) To compare predictive validity at 8 weeks versus 5 months postinjury. (3) To examine predictive validity of early degree of recovery (8wk–5mo postinjury) for return to productivity.

Design: Longitudinal, within subjects.

Setting: Inpatient neurorehabilitation and community.

Participants: Patients (N=63) with moderate to severe TBI.

Interventions: Not applicable.

Main Outcome Measures: Primary outcome: return to productivity at 1 year postinjury. Primary predictors: neuropsychological composite scores. Control variables: posttraumatic amnesia, acute care length of stay (LOS), Glasgow Coma Scale score, age, and estimated premorbid intelligence quotient.

Results: Return to productivity was significantly correlated with global neuropsychological performance at 5 months postinjury ($P<.05$) and showed a trend toward significance at 8 weeks. Performance on the untimed composite score, and more specifically executive and memory functions, mirrored this pattern. Logical Memory performance significantly predicted return to productivity, but not other memory tests. Timed tests showed no significance or trend at either time point. Early degree of recovery did not predict return to productivity. Among control variables, only acute care LOS was predictive of return to productivity.

Conclusions: Findings validate utility of early neuropsychological assessment for predicting later return to productivity. They also provide more precise information regarding the optimal timing and test type: results support testing at 5 months postinjury on untimed tests (memory and executive function), but not simple attention or speed of mental processing. Findings are discussed with reference to previous literature.

Key Words: Outcome assessment (health care); Rehabilitation; Brain injuries; Work.

MODERATE AND SEVERE TBI are associated with cognitive, physical, and emotional impairments that can impede one's ability to engage in productive activities, such as work, school, parenting, and leisure pursuits. One of the more urgent early questions of brain-injured persons and their family members is whether return to prior activities will be possible. However, because of the variability across brain injuries and the wide range of factors that influence return to prior activities, our ability to predict accurately such clinical outcomes is limited, despite extensive research to date.

Indeed, the literature examining prediction of functional outcome is vast. The many predictors that have been examined fall largely into 1 of 2 categories: injury-related variables, such as severity of injury,[1-10] mechanism of injury,[10-17] and cognitive impairment,[9,18-33] and demographic/premorbid variables, such as age,[1,3,6,10,34-39] education,[1,3,4,7,34,36-38,40] and preinjury employment.[3,32,40-46] The functional outcomes predicted by these variables are most frequently measured with broad composite scales, such as the FIM[1,2,7,35,39,42,47-50] and the GOS,[1,4,5,6,10,36,51-54] among a variety of others.[1-3,7,13,15-17,35,39,44,50,55-62] Many of these global assessment tools are widely employed clinically, making them good candidates for retrospective studies. Moreover, their frequent use in the literature facilitates cross-study comparison. However, the limited sensitivity of these measures—particularly to the more subtle deficits that persist in the later stages of recovery[55,63,64]—likely explains some of the discrepancies in the literature, where significant associations are found between a given predictor and an outcome (eg, age and the Community Integration Questionnaire) in some studies,[11,21,59,61] but not others.[3,44]

A more specific functional outcome measure—for which outcome prediction becomes more reliable the further from

List of Abbreviations

GCS	Glasgow Coma Scale
GOS	Glasgow Outcome Scale
LOS	length of stay
NAART	North American Adult Reading Test
PTA	posttraumatic amnesia
RAVLT	Rey Auditory Verbal Learning Test
RTW	return to work
RVDLT	Rey Visual Design Learning Test
TBI	traumatic brain injury
WTAR	Wechsler Test of Adult Reading

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injury—is return to work,[3,7,37-39,44,65-68] where the passage of time allows for differences in recovery rates to exert less of an influence on outcome. In addition to the obvious financial benefits, returning to paid employment has been shown to improve motivation to integrate back into society, increase the opportunity for social interaction, enhance self-esteem and perceived status, and even reduce the likelihood of secondary complications such as physical disability and substance abuse.[69,70] An increased interest in RTW in recent years has been noted by Shames et al,[71] who attribute this in part to a change in the World Health Organization's *International Classification of Functioning, Disability and Health*, where RTW was included as a key component of rehabilitation in 2001.[71] One limitation of RTW as a clinical outcome measure, though, is that it does not subsume clinically and personally relevant vocational and avocational activities, such as parenting, leisure pursuits, and school. Ascertaining such premorbid productivity information, against which to compare postinjury return to productivity, is not straightforward because of the need for an available, reliable historian. Nonetheless, a small number of recent studies have been able to examine return to productivity after TBI.[68]

Although RTW and return to productivity are more reliable outcome measures than composite scales such as the FIM and GOS, prediction studies have still shown inconsistencies. For example, many studies employing demographic predictors have shown significantly better outcomes with younger age,[25,29,37,39,45,46,72-77] but a number have not.[12,23,44,65,78,79] Some studies have shown positive correlations with higher income,[23] lower preinjury education level,[12,32,37,46,66,74,80,81] and lower preinjury substance use,[12,16,82] but, again, conflicting findings have been observed.[44] With regard to injury-related predictors, previous studies have demonstrated that, overall, injury severity is an important predictor of RTW and return to productivity[3,7,8,15,19-21,31-33,37-39,48,60,83-84]; however, many studies have found weak or no evidence of an association between RTW/return to productivity and length of coma, depth of coma (as measured by the GCS), or length of PTA,[15,37,44,45,76,80,84] although length of coma and length of PTA are consistently found to be stronger predictors of outcome than GCS.[19-21,29,72,81,84,85]

Inconsistencies across studies may be attributable, in part, to differences in the quality of predictor variable data across studies. For example, length of coma and length of PTA are often unrecorded,[3,44,73,86] resulting in high rates of missing data in studies.[3,73,86] GCS scores may be confounded by intoxication at time of injury,[87,88] which is prevalent but unreliably reported in medical records.[86-88] Moreover, the collection of these variables is not required to be undertaken in a fully standardized fashion by a trained clinician, which can itself affect the reliability of data. Finally, these injury severity scores are only indirectly related to functional outcome; thus, variance accounted for would logically be limited.

There is a growing literature examining the relationship between neuropsychological test performance and RTW or return to productivity.[9,18-33] Cognitive predictors are injury-related, but have the advantage of being more directly related to functioning (eg, school and most jobs require a minimum level of attention and memory). Neuropsychological tests require standardized administration, and many neuropsychological tests require administration by trained examiners under expert supervision. It is therefore not surprising that correlations between cognitive functions and RTW and return to productivity have been observed not only in studies of concurrent correlation,[76,89-93] but also in studies employing clinically valuable predictive designs, where neuropsychological assessment has been conducted at 6 months or earlier.[9,18,20,23,25-28,30-32] Sherer et al,[32] for example, found a significant contribution to return to productivity at 1 year postinjury of neuropsychological testing conducted on resolution of PTA.

The cognitive functions that have been most strongly associated with RTW or return to productivity are speed of processing,[9,12,23,24,26,27,29,33] memory,[12,18,20,22,24,27,31] and intellectual status.[12,19,23,33,79,93,94] However, as with other predictor variables, some inconsistencies have been observed. For example, regarding memory function, Dawson et al[20] found that recovery of memory during acute care (3 words at 24 hours) was the sole predictor of return to productivity at 4 years postinjury.[20] Boake et al[18] found that all 3 memory tests employed in their study (ie, Logical Memory Immediate and Delayed Recall; RAVLT) significantly predicted return to productivity. Cifu et al[31] found that memory (Logical Memory Delayed Recall) was the only domain among several examined that predicted later return to productivity. On the other hand, Rassovsky et al[9] observed no mediating effect of memory performance (at 6 months postinjury) for injury severity and RTW (at 1 year postinjury), and in an earlier study, Fraser[27] showed a relationship between return to productivity and a range of cognitive functions, with the exception of memory (and problem-solving). Critical differences across studies in the number and type of memory tests and subtests, as well as in the injury severity and demographic control variables employed, likely explain some of these discrepancies. Speed of processing also has shown disparate findings, with most studies demonstrating significant predictive validity of early cognitive processing speed for later return to productivity,[9,32] but a small number of studies showing no relationship.[18,31] Lack of control for manual motor impairments across studies (either orthopedic or centrally mediated) may explain observed disparities. Another important methodologic difference across these studies, as well as the wider literature on prediction of return to productivity, concerns sample bias. For example, some studies have employed retrospective designs,[3,19,22,65,66,79,93,95,96] which are more vulnerable to sample bias as well as constraints on choice of predictor and outcome measures. Others studies have employed prospective designs, though it should be noted that even large, multisite prospective studies using database registries have been vulnerable to selective attrition and consequent sample bias, with attrition rates reaching upwards of 75% in some studies.[31,46,76,97,98]

Given the clinical value of predicting return to productivity, the important findings to date, but also the inconsistencies of past research, further research is clearly warranted. In the current study, we attempted to build on the strengths of previous research, to obviate past methodologic limitations, and to address some novel questions. We recruited patients prospectively from a large, urban neurorehabilitation facility where we had the opportunity to follow every patient clinically over the course of the study, providing clinical assessment and feedback at each assessment. Consequently, recruitment and retention were high, which minimized threat to reliability from sample bias. Family involvement in the study was extensive; therefore, access to reliable historians was available, and it was possible to obtain very specific premorbid and current information regarding roles and activities. As well, we had full control over our choice, timing, and collection of predictor and outcome variables.

We examined early neuropsychological performance as a predictor of return to productivity at 1 year postinjury, comparing the predictive validity of neuropsychological performance at 8 weeks postinjury with performance at 5 months postinjury. To our knowledge, no studies have compared more than 1 early subacute neuropsychological assessment within the same study in the prediction of return to productivity, and only 1 study has examined RTW: Spikman et al[99] found that from a battery of attention, speed of processing, and executive function tests, only early performance on the Stroop Color-Word test (a timed test of selective attention) predicted RTW at 2 to 5 years postinjury. However, the variable accounted for only a small amount of variance. A determination of the optimum earliest time point at which to assess cognitive functioning in order to predict return to productivity reliably, along with an understanding of which tests are most predictive, would be of marked clinical and practical utility. Indeed, only a handful of studies have examined early cognitive assessment and later return to work (see Sherer et al[32] for review).

We also examined whether the degree of early subacute recovery (8wk–5mo postinjury) was a better predictor of outcome than performance level at either of the 2 time points. Again, only the study by Spikman[99] has addressed this question, to our knowledge, and specifically for RTW rather than return to productivity. They found a circumscribed and small effect: that early recovery across the first and third occasion of testing (≈1–6mo postinjury) on the Stroop Color-Word test was predictive of 2-year to 5-year RTW. It is clinically intuitive that a rapid early recovery would predict a better productivity outcome than a slow early recovery. However, this question has had only minimal empirical investigation and there is scope for misinforming patients if this intuitively compelling possibility is actually incorrect.

At each time point, we examined global neuropsychological performance on a composite of cognitive tests from a range of cognitive domains that are commonly disrupted in TBI. Although a large cognitive battery offers the advantage of increased reliability, a more parsimonious battery offers greater feasibility. We therefore subdivided the global composite into a timed test aggregate made up of tests of simple and complex speed of processing, and an untimed test aggregate made up of tests of memory, attention, and executive function. We also examined a series of demographic and injury control variables to identify any variables that might account for significant return to productivity outcome variance, and that would be included in analyses.

Previous studies have identified both timed and untimed tests as predictors of RTW and return to productivity. We were interested in distinguishing timed from untimed processing for several reasons. First, speed of processing is arguably the most ubiquitous and persisting complaint after moderate and severe TBI.[100] Second, whether speed of processing should be disruptive to return to productivity is not self-evident. While many activities involve time constraints, speed of processing impairments can be compensated for by allotting extra time to complete activities. Last, previous studies examining speed of processing as a predictor of return to productivity have employed tasks with manual motor demands, without any reported control for central or orthopedic injuries to motor function; in 1 study,[9] 3 of 4 speed of processing tests had manual motor requirements, for example. Consequently, it has not been clear how much outcome variance in these studies might be attributed to persisting peripheral or central motor damage. In the present study, we employed tests of speed of processing without manual motor demands or where the contribution of manual motor function/dysfunction could be parceled out using a subtraction approach (eg, Trail Making Test Part B minus Trail Making Test Part A).

Finally, in addition to multivariate logistic regression models to examine global predictor (timed vs untimed) and control variables, we also conducted nested regression analyses of the smaller cognitive domains, focusing in particular on memory because of the ubiquitous, but also conflicting findings in this domain. Here, we examined the respective contributions of memory for verbal information (organized and unorganized), and memory for visuospatial (unorganized) material.

In summary, we used regression models to identify relevant control variables, and then examined the predictive validity of cognitive performance for return to productivity at 1 year, comparing 2 early, subacute time points and also using early degree of recovery as a predictor. Composite scores of clinically meaningful domains (eg, timed test aggregate, memory test aggregate) were used; these provide greater reliability than individual test performances, but have been little used in previous studies. We re-examined speed of processing—a predictor with somewhat inconsistent previous findings—controlling for motor impairments that may have confounded previous research. In addition, we examined memory using two approaches to analysis (aggregate, individual test contributions) in order to explain previous inconsistencies with this variable.

METHODS

The study protocol was approved by the research ethics board at the Toronto Rehabilitation Institute, and the procedures of the study were in accordance with the standards of the research ethics board.

Participants

The 63 patients with TBI in this study were part of a larger study conducted at the Neurorehabilitation Program of the Toronto Rehabilitation Institute investigating the natural history and mechanisms of cognitive and motor recovery after TBI. The neurorehabilitation program has a province-wide catchment area, is located in an urban center, and sees patients both with and without motor vehicle or private insurance. Therefore, there is a wide range of socioeconomic status and ethnicities represented in the program. Participants in the larger study underwent prospective neuropsychological assessments at 1 to 3 months postinjury, 3.5 to 5.5 months postinjury, and 11 to 13 months postinjury and met the following inclusion criteria: (1) acute care medical diagnosis of TBI, (2) PTA 1 hour or more and/or GCS of 12 or less either at emergency or the scene of accident and/or positive computed tomography or magnetic resonance imaging findings, (3) age between 17 and 80 years, (4) ability to follow simple commands in English based on speech language pathologist intake assessment, and (5) competency to provide informed consent for study or availability of a legal decision-maker.

Exclusion criteria included the following: (1) orthopedic injuries affecting both upper extremities; (2) diseases primarily or frequently affecting the central nervous system, including dementia of Alzheimer type, Parkinson's disease, multiple sclerosis, Huntington's disease, lupus, and stroke; (3) history of psychotic disorder; (4) not emerged from PTA by 6 weeks postinjury, as measured by the Galveston Orientation Amnesia Test[101]; (5) TBI secondary to another neurologic event (eg, a fall caused by stroke); and (6) failure on a symptom validity test (Test of Memory Malingering)[102] at any of the assessments.

Participants were eligible for the current study if they were at least 1 year postinjury. Of a total of 70 eligible participants from the larger study, 5 could not be reached at 1 year postinjury, and 2 declined to participate. The sample therefore included 63 participants, representing a 90% retention rate.

Table 1 shows the demographic and injury characteristics of the study sample. The study sample was severely impaired on average, with a typically high ratio of male to female subjects,

Table 1: Injury and Demographic Characteristics of Sample (N=63)

Variable	Proportion	Range
Age (y)	36.98±14.91	17–79
Education (y)	12.84±2.75	8–21
Premorbid intelligence quotient (n=58)	99.93±12.90	78–124
Sex (% male/female)	82.5/17.5	
Socioeconomic status (%) (based on Hollingshead Classification)		
1 (Major business/professional)	11.1	
2 (Medium business/minor professional, technical)	38.1	
3 (Skilled craftsperson, clerical, sales worker)	19.0	
4 (Machine operator, semiskilled worker)	30.2	
5 (Unskilled laborer, menial service worker)	1.6	
Type of injury (%)		
Motor vehicle collision	58.7	
Fall	30.2	
Assault	7.9	
Sports injury	3.2	
Acute care LOS	37.10±16.45	9–88
GCS (lowest of recorded scores)	6.77±3.43	2–13
Mild (13–15) (%)	11.1	
Moderate (9–12) (%)	15.9	
Severe (≤8) (%)	63.5	
Missing data (%)	9.5	
Length of PTA (%)		
<5min (very mild)	3.2	
1–24h (moderate)	1.6	
1–7d (severe)	21.0	
1–4wk (very severe)	40.3	
>4wk (extremely severe)	11.3	
Missing data	22.6	

NOTE. Values are means ± SDs unless otherwise noted.

and with the most frequent cause of injury being motor vehicle collisions.

Materials

Predictor variables: neuropsychological test aggregates. All of the tests were selected based on a priori clinical and experimental consensus regarding the cognitive domains most affected by TBI,[100] and on their known validity and reliability for TBI. Cognitive domains assessed included executive function (working memory and abstract intellectual functioning)[103-105]; attention span[106]; speed of processing[100,107,108]; verbal and visuospatial learning, recall, and recognition[100,106]; and verbal intellectual function[104,105] (see table 2 for a list of neuropsychological tests and the functions they measure). None of the neuropsychological tests have appreciable floor or ceiling effects for patients with moderate to severe TBI. Tests with alternate forms were administered on repeat testing to minimize practice effects.

Classification of tests into aggregates was based on known clinical classifications and expert knowledge. The main aggregate was a global neuropsychological aggregate, made up of all neuropsychological tests in the battery (see table 2). This aggregate was then subdivided into timed tests and untimed tests, with the former composed of measures of simple and complex speed of processing (ie, parallel processing or speed of decision-making) and the latter composed of untimed tests of attention, executive function, and verbal and visuospatial memory, for both organized and unorganized material.

In order to avoid contamination of findings by orthopedic injury or central motor deficits, all timed tests either did not have manual motor demands or had motor contributions parceled out through a subtraction method (eg, Trail-Making Test Part B minus Trail-Making Test Part A). The battery required 2 to 2.5 hours to administer on average.

Control variables: preinjury demographic characteristics and injury severity variables. Information about age, productivity, and highest level of education attained was collected during a structured interview from patients, and corroborated by caregivers where necessary. Estimated premorbid intelligence quotient was estimated for each participant using the WTAR[109] or the NAART.[110] (Note that for the larger study from which participants were drawn, the NAART was replaced by the WTAR, which has been shown to demonstrate good psychometric properties for this population.[111])

Information about severity of injury (ie, GCS, PTA, acute care LOS) was abstracted from the rehabilitation hospital records wherever possible. Where information related to PTA was not recorded in the medical record, questioning of the patient and caregivers was undertaken during a structured

Table 2: Neuropsychological Assessment Battery

Aggregate	Cognitive Domain and Test
Untimed	SIMPLE ATTENTION: Auditory-verbal and visuospatial span forwards[106]
	EXECUTIVE FUNCTION (WORKING MEMORY): Auditory-verbal and visuospatial span backwards[106]
	EXECUTIVE FUNCTION (VERBAL ABSTRACTION): Similarities Test (Wechsler Adult Intelligence Scale-III and Wechsler Abbreviated Scale of Intelligence)[104,105]
	MEMORY VERBAL (UNORGANIZED): Rey Auditory Verbal Learning Test: total learning, immediate and delayed recall, recognition subtests[100]
	MEMORY NONVERBAL (UNORGANIZED): Rey Visual Design Learning Test: total learning and recognition subtests[100]
	MEMORY VERBAL (ORGANIZED): Logical Memory (Wechsler Memory Scale-III)[106]: immediate and delayed recall
Timed	SPEED OF PROCESSING: SIMPLE: Stroop Test: Speeded word reading and speeded color naming subtests[108]
	SPEED OF PROCESSING: COMPLEX:
	Symbol Digit Modalities Test-Oral[107] (speeded pairing of visual symbols with digits with responses given orally)
	Hayling Sentence Completion Test (modified for computer administration): congruent minus incongruent conditions[103] (speeded oral generation of words, either congruent or incongruent with a series of target words)
	Choice reaction time minus simple reaction time (speeded, psychomotor tests of decision making and simple response to stimulus)
	Trail Making Test Part B[100] minus Trail Making Test Part A[100] (speeded visual scanning and attention and set shifting [B] and speeded visual scanning and attention [A]; both psychomotor tasks)

interview to ascertain length of PTA. PTA was described according to the classification described by Lezak et al.[100] Acute care LOS was calculated from admission and discharge dates from the acute care hospital.

Outcome variable: return to productivity. A dichotomous classification of return to productivity was made for all patients. Activities included paid employment (full or part-time), volunteer employment, school, parenting, home-making, and active retirement (ie, participation in cultural and physical activities). Information on premorbid and current activities was collected from patients and corroborated by caregivers. Two trained clinicians ascertained the match, or lack thereof, between current and previous level of productivity. In all cases, clear consensus was reached, with patients either returning to prior type and level of productivity or not.

Design and Procedures

The study employed a prospective, repeated-measures design. During the neuropsychological assessments at time 1 (8.0±2.7 weeks postinjury) and time 2 (4.8±1.2 months postinjury), a clinical interview of the patient was followed by the neuropsychological assessment, which was followed by a clinical feedback session with the patient and family/professional caregivers. Detailed information concerning premorbid role and activities was collected in the interview and feedback at the time 1 assessment from patients and their caregivers. Return to productivity information was collected in person at 1 year postinjury.

The neuropsychological test battery was divided into 5 blocks of tests, with a fixed order of tests within each block, and with test blocks counterbalanced across subjects (but consistent within subjects across assessments). The battery was designed to minimize interference between tests (eg, the verbal memory tests contained nonverbal tests between learning and delayed-recall phases). Test blocks were matched as much as possible for the number of timed tests and effortful tests. Each block contained a maximum of 1 memory test. Alternate forms, used to minimize practice effects, were counterbalanced across subjects.

Data Analysis

All raw test scores obtained from standardized neuropsychological measures were transformed into normative scores using published normative data for the test. Cognitive test scores were transformed to a common metric and combined into larger aggregates in order to increase reliability and maximize power; there was insufficient sample size to allow for an examination of every test of cognitive functioning. To combine the tests, each test with normative data was converted to a z score using external standardization. (Percentile norms were converted to z scores by using the normative score corresponding to the percentile.) To combine tests without normative data, we used the means and SDs of the tests in the later stages of recovery (ie, 5mo and 1y postinjury) to generate a z score. The z scores for the tests in a common aggregate were then added, and the sum restandardized using an estimated SD derived from the empirical correlations between the tests.

Logistic regression models were then undertaken. To build our models, we took a conservative approach based on our sample size and knowledge of factors that might influence outcome. First, logistic regression models regressing return to productivity on each of the control variables in separate regression models were carried out in order to determine which would be included as control variables in the cognitive models. Based on findings from previous studies, variables examined were acute care LOS, premorbid intelligence quotient, age, years of education, GCS, and length of PTA. Only acute care LOS was significantly related to return to productivity; it was therefore included in the subsequent models. For each aggregate, separate logistic regressions on the time 1 results, on the time 2 results, and, finally, on the improvement (recovery) from time 1 to time 2 were conducted to study whether any of these significantly predicted return to productivity at the end of 1 year postinjury.

Analyses were performed with the R Programming Language version 2.6.2.[a]

RESULTS

Classification of participants into those who did versus did not return to prior level of productivity revealed that 30.2% (or 19 subjects) had returned to their prior level of productivity by 1 year postinjury, whereas 69.8% participants (44 subjects) had not.

Early recovery as a predictor of outcome. Recovery of cognitive function (ie, change in performance from time 1 to time 2) did not significantly predict return to productivity for any of the aggregates nor show a trend toward significance. Therefore, this variable is not discussed further in the Results section.

All cognitive tests. Global neuropsychological performance at time 2 significantly predicted return to productivity at 1 year (β=0.940, z_{51}=2.135, P<.05, estimate of SE=0.44). At time 1, this aggregate did not significantly predict return to productivity; however, a trend toward significance was observed (β=0.53, z_{51}=1.69, P=.09, estimate of SE=0.31).

Timed neuropsychological tests. In contrast to the findings of global neuropsychological testing, no significant effects or effects approaching significance were observed at either time 2 (β=0.47, z_{52}=1.16, P=.25, estimate of SE=0.41) or time 1 (β=0.36, z_{49}=1.04, P=.30, estimate of SE=0.35). In order to ensure that we were not masking an effect of 1 subdomain by another, we examined simple versus complex subaggregates separately. However, again, no significant effect or trend toward significance was observed at either time 1 or time 2 for either of these timed subaggregates.

Untimed neuropsychological tests. Findings from these analyses mirrored those of the global aggregate and suggested that outcome variance for the global aggregate was likely attributable largely to this domain. At time 2, this aggregate significantly predicted return to productivity (β=0.95, z_{51}=2.18, P<.05, estimate of SE=0.43) and showed a trend at time 1 (β=0.53, z_{51}=1.71, P=.09, estimate of SE=0.31).

In order to understand better the source of outcome variance at time 2, the 3 smaller aggregates were examined. Memory performance significantly predicted return to productivity (β=0.98, z_{51}=2.15, P<.05, estimate of SE=0.45). In more fine-grained, separate analyses for each of the 3 memory recall tests: Logical Memory (immediate plus delayed recall) significantly predicted return to productivity (β=0.70, z_{51}=1.97, P<.05, estimate of SE=0.35). RAVLT (total learning plus short delay recall plus long-delay recall) showed a trend toward significance (β=0.49, z_{51}=1.70, P=.09, estimate of SE=0.29). RVDLT (total learning) showed no significant effect or trend toward significance: (β=0.31, z_{51}=1.48, P=.14, estimate of SE=0.21). For discrimination (RAVLT plus RVDLT recognition hits minus false alarms), a trend toward significance was observed (β=0.80, z_{51}=1.87, P=.06, estimate of SE=0.43).

We next examined the contribution of executive function and attention span subaggregates to the prediction of return to productivity. While attention span at time 2 did not show evidence of predictive validity for return to productivity (β=–0.11, z_{52}=–0.38, P=.70, estimated SE=0.30), executive function significantly predicted return to productivity (β=0.89, z_{51}=2.24, P<.05, estimated SE=.040).

DISCUSSION

We examined the predictive validity of early cognitive performance after moderate and severe brain injury for return to prior level of productivity at 1 year postinjury while controlling for severity of injury. We found that prediction of return to productivity was stronger at 5 months postinjury than at 8 weeks postinjury, and that while performance on global neuropsychological functioning significantly predicted return to productivity, untimed tests rather than tests of speed of processing appeared to account for the outcome variance. More specifically, memory function (both as a composite measure) and individually for Logical Memory (but not RAVLT or RVDLT) at 5 months postinjury significantly predicted return to productivity at 1 year, as did executive function, but not attention span. We found no evidence that early degree of recovery was predictive of eventual return to productivity.

Return to productivity, particularly employment, is highly valued by society.[32] Our ability to predict whether or not TBI survivors can return to their prior type and level of productivity is critically important for clinical and economic planning, as well as the process of adjustment to disability for patients and their families. Our findings validate the utility of neuropsychological testing to predict return to prior type and level of productivity, and shed more light on the timing and type of tests that are most and least predictive for return to productivity.

The current results differ slightly from previous studies. As in our study, Rassovsky et al[9] (at 6 months postinjury) found that cognitive deficits significantly influenced return to productivity in a study using structural equation modeling to explore mediators of the relationship between severity of injury and return to productivity at 1 year postinjury. However, they observed that speed of processing, but not memory (using the RAVLT), accounted for significant outcome variance. This discrepancy may be explained by the outcome measures employed. Using a more reliable index of memory comprising multiple tests, memory predicted return to productivity in our study. As well, we found that RAVLT contributed less outcome variance to return to productivity than Logical Memory. Arguably, Logical Memory (a measure of story recall) has greater ecologic validity than RAVLT (a test requiring the recall of a list of 15 words presented in an unorganized fashion). Most verbal information in everyday life is presented in a more meaningful, structured manner (eg, stories, tasks, anecdotes). In addition, in everyday life, there may be greater expectation and less accommodation for persons to learn and retain this type of information: the inability to recall a personal anecdote, a short story, the contents of a movie, or the elements of a structured task might be quite debilitating in many settings and therefore highly predictive of success or failure. On the other hand, in circumstances in which a long list of unorganized information is presented (eg, a task with many unrelated steps), there might be greater tolerance for and accommodation of compensatory aids to be used, like note-taking. Thus, ability to recall this type of information may be less closely tied to success in returning to prior activities. We did not find any evidence for the predictive validity of visual memory. However, nonverbal memory might play a predictive role for the return to some kinds of activities that depend more heavily on memory for visual information.[33] It would be of value for future research to examine larger samples that would enable subgroups analyses; in this way, activities that specifically depend on visual memory (eg, engineering, taxi-driving, architecture, designing) could be separately examined.

With regard to timed tests, a critical difference between the current study and that of Rassovsky[9] among others that found predictive validity of speed of processing[32,99] was that we designed the present study to minimize the contribution of manual motor capacity in order to avert contamination from manual motor dysfunction. The timed tests either had no manual motor demands or allowed for the use of a subtraction technique to parcel out motor contributions. In the Rassovsky[9] study, for example, 3 of 4 tests had manual motor demands, and orthopedic injury, a common occurrence in TBI, was not an exclusion criterion. By 6 months postinjury, the time of assessment in their study, acute effects of orthopedic injury would have resolved; but many patients can have persisting weakness, pain, and slowness associated with orthopedic injury,[112,113] and there was no evidence presented to rule out the persistence of centrally mediated motor impairments at 6 months postinjury. Consequently, the relationship between speed of processing and return to productivity in past studies could be attributable to manual motor factors (either orthopedic or central), rather than speed of mental processing per se. Why might there be a lack of correlation between speed of processing and return to productivity? One possibility is that there are straightforward, self-evident adaptations that can accommodate slower speed of processing, such as planning and allocating more time for tasks/activities. In many jobs, staying late at work or taking work home is possible. For school, studying for longer hours is within the control of the student. Active retirement activities (eg, cultural, gardening) are not obviously impeded by slower speed. Because speed of processing impairment is so prevalent even many years postinjury, a lack of correlation between speed of processing impairments and return to productivity would be a welcome outcome. Further research with a larger sample size, similarly low attrition, and similar controls for manual motor impairment would be clinically valuable.

Our results also differed somewhat from those of Sherer et al,[32] who found that 1-month performance predicted 1-year postinjury vocational outcome. We found only trends toward significance at our early time point. One explanation is that the Sherer[32] study had more power because of its larger sample size. Another explanation is that in the current study, while attrition was only 10%, the attrition rate in the Sherer[32] study, which was a larger, multisite study, was greater than two thirds. Therefore, it is possible that their study was vulnerable to selective attrition, rendering the sample biased. For example, it is possible that those with milder impairments and greater independence and/or those with more severe impairments and poorer outcomes (with greater need of support) were more able or motivated to return for follow-up examination.

Finally, we did not find any evidence that early, subacute recovery from time 1 to time 2 was predictive of return to productivity, in contrast with Spikment et al,[99]who found that early recovery (1–6mo postinjury only) accounted for a small but significant amount of outcome variance for RTW. From a clinical point of view, it is an intuitively appealing possibility that a good early recovery bodes well for the future and that conversely, a slow early recovery bodes poorly. On the basis of these 2 studies, it would appear that degree of early recovery is not a robust prognosticator of RTW/return to productivity. If this interpretation is verified in future research, then it would be important for clinicians to avoid such an assumption.

Study Limitations

The current study was limited in its power because of sample size. Greater power would have allowed for a more nuanced analysis of the contributions to outcome variance of individual tests. It would have also allowed for subgroup analyses of patients returning to different types of activities that might have been differentially affected by cognitive tests. As well, while only acute care LOS predicted return to productivity, it is possible that interactions between control variables may have had an impact on return to productivity. Again, a more powerful model would have included all control variables and possible suppressor variables within the model. Similarly, while it was necessary to conduct separate regression analyses to examine aggregates, greater power would have permitted the examination of all aggregates within the same model. The absence of significance at 8 weeks postinjury may also be explained by a dearth of power, especially because we observed trends toward significance for some variables. Knowing whether earlier performance is predictive of return to productivity would be clinically valuable. In this regard, while we decided that reliable change indices were beyond the scope of this study, future research might include this level of analysis to determine whether variables are predictive at the individual as well as group levels.

An additional limitation of the current study is the differences in task demands of the tests in the timed and untimed aggregates. Thus, factors other than speed of processing may have differed across the aggregates. A better means of investigating the impact of speed of processing on return to productivity would be to have timed versus untimed analogs of the same tasks.

In the present study, we did not find a relationship between degree of early recovery and return to productivity. Because a higher level of initial performance leaves less room for recovery, the absence of an observed relationship may have been partially attributable to this factor if acute care LOS did not fully control for severity of injury. Again, further research with more powerful statistical models would help to minimize this limitation.

In examining the predictive validity of early neuropsychological testing, one cannot escape the alternative interpretation of the findings that differences in findings across tests may be explained by differences in recovery rates of tests. For example, if speed of processing and attention span impairments recover more quickly or more completely than memory and executive function deficits, this would provide an alternative explanation of the lack of correlation between the former domains and return to productivity. This explanation is rendered less likely by the finding that speed of processing recovers more slowly than other cognitive functions, however.[100]

Finally, our results cannot be generalized to patients with the most severe impairments because we employed as an exclusion criterion patients whose PTA had not resolved by 6 weeks postinjury.

CONCLUSIONS

The current study replicates previous research demonstrating that early neuropsychological testing is a useful predictor of return to productivity at 1 year. Our results extend previous findings by indicating that testing at 5 months postinjury is more effective at predicting return to productivity than testing at 8 weeks postinjury. However, further research with a larger sample size would be valuable to confirm or disconfirm this finding and, moreover, to ask the more nuanced question of whether earlier neuropsychological testing might be predictive of later return to productivity for specific subgroups of people with TBI (eg, those with milder injuries). Our results also extend previous research by suggesting that a more parsimonious battery based on untimed tests—rather than a comprehensive neuropsychological battery—may allow for effective prediction of return to productivity. In particular, our findings indicate that an optimal test battery would be made up of (1) either a variety of memory tests or several tests of verbal memory for organized information (such as Logical Memory) and (2) tests of executive function. Also of clinical relevance was the finding that the magnitude of early recovery did not appear to be a useful predictor of return to productivity; if future research confirms this finding, it will be important for clinicians not to speculate on future outcomes based on early recovery. Finally, our results suggest that speed of processing—whether simple or complex—does not play a significant role in return to productivity. If confirmed, the lack of prognostic value of this prevalent and persisting impairment would be a welcome finding.

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Supplier

a. R Development Core Team, http://www.r-project.org.