Journal of the International Neuropsychological Society (2001), **7**, 892–898.

Criterion validity of new WAIS–III subtest scores after traumatic brain injury

JACOBUS DONDERS,[1] DAVID S. TULSKY,[2] AND JIANJUN ZHU[3]

[1]Mary Free Bed Hospital & Rehabilitation Center, Grand Rapids, Michigan
[2]Kessler Medical Rehabilitation Research & Education Corporation, West Orange, New Jersey
[3]The Psychological Corporation, San Antonio, Texas

(Received January 8, 2001; Revised April 16, 2001; Accepted May 21, 2001)

Abstract

The criterion validity of the new subtests from the Wechsler Adult Intelligence Scale–Third Edition (WAIS–III; Wechsler, 1997) was evaluated in a sample of 100 patients with traumatic brain injury (TBI). Letter–Number Sequencing and Symbol Search, but not Matrix Reasoning, yielded statistically significant differences in performance between patients with moderate–severe TBI, patients with mild TBI, and demographically matched controls. Level of education accounted for a statistically significant amount of variance in the performance of patients with TBI, in addition to that explained by injury severity variables. It is concluded that Letter–Number Sequencing and Symbol Search have satisfactory criterion validity, but that they need to be supplemented with other measures in the context of neuropsychological evaluations. Matrix Reasoning, on the other hand, is not sensitive to the sequelae of TBI and more studies are needed to determine how it can be used for neuropsychological assessment purposes. (*JINS*, 2001, *7*, 892–898.)

Keywords: WAIS–III, Traumatic brain injury, Criterion validity

INTRODUCTION

The Wechsler Adult Intelligence Scale–Third Edition (WAIS–III; Wechsler, 1997a, 1997b) is a widely used measure of psychometric intelligence. This instrument has excellent psychometric properties, particularly in terms of its standardization and reliability (Kaufman & Lichtenberger, 1999, p. 164). As part of the revision of its predecessor, the Wechsler Adult Intelligence Scale–Revised (WAIS–R; Wechsler, 1981), three new subtests were added, including Letter–Number Sequencing, Matrix Reasoning, and Symbol Search. The purpose of this investigation was to evaluate the clinical utility of these new subtests in the evaluation of sequelae of traumatic brain injury (TBI).

The addition of the three new subtests resulted in the possibility of computing four factor index scores which may provide a better reflection of an individual's cognitive abilities than the traditional Verbal and Performance IQ scores. These index scores are defined as, respectively, Verbal Comprehension (VC; based on the Vocabulary, Similarities, and Information subtests), Perceptual Organization (PO; Picture Completion, Block Design, and Matrix Reasoning subtests), Working Memory (WM; Arithmetic, Digit Span, and Letter–Number Sequencing subtests), and Processing Speed (PS; Digit Symbol–Coding and Symbol Search subtests). Hawkins (1998) has demonstrated that the PS index is affected by a wide range of dysfunctions. In addition, Martin et al. (2000) have provided evidence for sensitivity of the PS factor to severity of TBI. There are not yet comprehensive research data pertaining to the clinical utility of the other index scores, or the new subtests.

Even though interpretation of factor index scores appears to be preferable to subtest profile interpretation under many circumstances because of the greater reliability of the former scores, this may not be advisable when there are large discrepancies between the subtests comprising a particular factor (Sattler & Ryan, 1999, p. 1220). For example, if an individual obtained scaled scores of 6 on Digit Symbol–Coding and 14 on Symbol Search, the average PS score of 99 would not reflect the fact that performance was clearly below average on one subtest and clearly above average on the other one. It is also possible that some subtests that purportedly load on the same factor differ in their relative sensitivity to acquired cerebral dysfunction. For example, it

Reprint requests to: Jacobus Donders, Psychology Service, Mary Free Bed Hospital & Rehabilitation Center, , 235 Wealthy, S.E., Grand Rapids, MI 49503-5299. E-mail: jdonders@mfbrc.com

https://doi.org/10.1017/S1355617701777132 Published online by Cambridge University Press

is a well-known fact that TBI is often associated with deficits in speed of information processing (Dikmen et al., 1995) and, hence, an untimed task like Matrix Analogies may be affected less than a subtest like Block Design which includes bonus points for fast performance. Another possibility is that differences in the degree of required mental manipulation of information may affect the criterion validity of specific tasks. For example, in light of the fact that backward recitation of digits appears to measure something distinctly more complex than its forward version (Reynolds, 1997), it is possible that the mixed composite of Digit Span may be less sensitive to attentional dysfunction than Letter–Number Sequencing with its consistent requirements of both numerical and alphabetical reorganization. For all of these reasons, an investigation of the criterion validity of the WAIS–III subtests, with particular attention to the newest additions, appeared to be in order.

Patients with TBI were selected for this investigation because deficits in attention, novel reasoning, and speed of performance are among the most commonly reported sequelae (Jones et al., 1996; Williamson et al., 1996). Thus, this population offers ample opportunity to evaluate sensitivity to injury severity of the new WAIS–III subtests. Letter–Number Sequencing presumably has working memory demands, Matrix Reasoning is purported to measure fluid reasoning, and Symbol Search strongly emphasizes fast and accurate performance (Wechsler, 1997b). If these subtests truly have criterion validity, then they should demonstrate meaningful relationships with measures of TBI severity. For these reasons, the first goal of this investigation was to evaluate the sensitivity of the new WAIS–III subtests to variables such as the presence of intracranial lesions (as documented with neuroimaging) and length of coma (the number of days until verbal commands were followed).

Another area of interest was the potential influence of level of education. WAIS–III standard scores are age-based but there are currently no education-adjusted norms for this instrument, although these may be forthcoming (Heaton et al., 2000). There has been considerable debate in recent years with regard to the desirability and validity of correcting cognitive test scores for level of education in clinical samples (Heaton et al., 1996; Moses et al., 1999; Reitan & Wolfson, 1995; Vanderploeg et al., 1997). There is recent evidence that in patients with TBI, level of education explains a significant degree of the variance in various neuropsychological test scores, above and beyond that accounted for by injury severity (Sherrill-Pattison et al., 2000). For these reasons, a second goal of this investigation was to evaluate the influence of level of education on the new WAIS–III subtest scores.

METHODS

Research Participants

Following institutional review board approval, two groups of participants were included in this investigation. The clinical patients were selected from an almost 3-year series of consecutive referrals to a regional Midwestern rehabilitation facility. Data collection continued until 100 participants were available who met all of the inclusion criteria (see below). A control group ($N = 100$) was subsequently obtained from the standardization sample of the WAIS–III. These participants were matched to the clinical patients on the variables gender, ethnicity, age, and education, and none of them had a history of neurological or psychiatric dysfunction. The clinical sample used in this investigation was completely independent of that used previously in a study pertaining to the effects of injury severity and demographic variables on neuropsychological tests (Sherrill-Pattison et al., 2000). About half of the clinical participants had previously been included in another study (Martin et al., 2000) in which WAIS–III factor index scores were compared with the IQ composite score of the General Ability Measure for Adults (GAMA; Naglieri & Bardos, 1997) after TBI.

The following criteria were used to select the clinical patients: (1) diagnosis of TBI through an external force to the head, with alteration of consciousness, (2) age between 16 and 89 years (to allow applicability of the WAIS–III norms), (3) absence of prior neurological, psychiatric, or substance abuse history, (4) absence of disputed financial compensation-seeking related to TBI, or other variables that could reasonably be expected to compromise validity of the assessment results (e.g., non-English language background, orthopedic injury to the dominant hand), and (5) evaluation with the WAIS–III within 1 year after injury. Only first evaluations, not repeat evaluations, were included. Although the nature of the other tests that had been administered to the participants as part of their evaluations differed somewhat, they had all completed at least one forced-choice measure of effort and motivation such as the Recognition Memory Test (RMT; Warrington, 1984) or the Test of Memory Malingering (TOMM; Tombaugh, 1996). None of these participants had test findings within the range of suspected poor effort, such as raw scores below 33/50 on the RMT (Charter, 1994; Millis & Putnam,1997) or raw scores below 45/50 on the second trial of the TOMM (Rees et al., 1998; Tombaugh, 1997).

The patients with TBI were seen for evaluation with the WAIS–III at a median of 65 days post injury (range 15–327). The majority of these participants had sustained injuries in motor vehicle accidents, either as drivers ($n = 48$), passengers ($n = 18$) or pedestrians or cyclists that were struck ($n = 10$). The remaining injury circumstances included falls ($n = 8$), recreational activities ($n = 7$), and other ($n = 9$). Several measures of injury severity were considered. Estimates of post-traumatic amnesia were not consistently reliable due to the need for retrospective estimation in a sizable minority of the cases. There were also a number of cases where the Glasgow Coma Scale (GCS; Teasdale & Jennett, 1974) was quite variable within the first 24 hr after injury. For these reasons, and in order to have sufficient numbers of participants in each subgroup to ensure adequate power for the statistical analyses, the patients with TBI were divided into two injury severity groups on the basis of the following criteria. Patients with *moderate–severe* injury ($n = 59$) had documented CT or MRI scan evidence for a posttraumatic intracranial lesion ($n = 54$), duration of coma of at least 24 hr ($n = 36$), or both. Patients with *mild* injury ($n = 41$) had no evidence for an intracranial lesion on neuroimaging and they did not have prolonged delays until they followed verbal commands.

Procedure

The WAIS–III was administered to clinical patients, as part of neuropsychological evaluations in the context of their rehabilitation, when they were medically stable and could remember recent events from day to day. As part of these evaluations, only the 11 subtests that are needed to compute the factor index scores were routinely administered. Subtest scaled scores ($M = 10$, $SD = 3$) were used for all of the statistical analyses.

RESULTS

The demographic characteristics of the two clinical patient subgroups and the matched controls from the WAIS–III standardization sample are presented in Table 1. There were no statistically significant differences between the two clinical subgroups in terms of gender, ethnicity, age, or education ($p > .05$ on all variables). Formal statistical comparisons with the control group from the standardization sample were not performed on these variables because the latter participants had been selected in order to match them to the clinical patients on the same characteristics. The difference between the two clinical groups in time since injury was also not statistically significant ($p > .10$).

The average scaled scores on the WAIS–III subtests are presented in Figure 1 for the two clinical patient subgroups and the matched control group. The associated factor index scores are presented in Table 2 for illustrative purposes but they were not subjected to additional statistical analyses because those would not be independent of analyses with the subtest scores. A multivariate analysis of variance was first performed with groups ($n = 3$) as the independent variable and the 11 WAIS–III subtest scores as the dependent variables. This yielded a statistically significant main effect of groups [$F(11,188) = 8.17$, $p < .0001$]. With regard to *post-hoc* analyses, it was anticipated that a traditional Bonferroni correction (.05/33) would be overly conservative. In order to balance the relative risks of Type I and Type II errors, and in order to facilitate focusing on the clinically most relevant group differences, it was decided *a priori* that only those findings would be interpreted that met the following criteria: (1) minimum level of statistical significance (α) of .01 for the main effect of groups on any specific subtest, and (2) minimum univariate effect size (η^2) of .05 for any individual group difference.

There were only four subtests (including two of the three new ones) for which the *a priori* established criteria regarding α and η^2 were met, including Picture Completion, Letter–Number Sequencing, Digit Symbol–Coding, and Symbol Search. For none of these subtests, the difference between the mild injury group and the standardization control group met even liberal standards of statistical significance ($p > .10$ on all variables).

Table 1. Demographic characteristics of clinical patients and standardization controls

Variable	Mild TBI ($N = 41$)	Moderate–Severe TBI ($N = 59$)	Control Group[a] ($N = 100$)
Gender (%)			
Man	46.34	62.71	55.00
Woman	53.66	37.29	45.00
Ethnicity (%)			
White	90.24	86.44	89.00
African American	7.32	8.47	8.00
Latino	2.44	5.08	3.00
Age (years)			
M	36.54	31.07	33.65
SD	16.73	13.06	15.46
Education (years)			
M	12.78	12.12	12.43
SD	2.02	1.91	1.94
Injury–testing interval (days)			
M	101.49	84.71	—
SD	66.78	70.56	—

Note. TBI = traumatic brain injury. [a] Standardization data derived from the Wechsler Adult Intelligence Scale–Third Edition (WAIS–III).

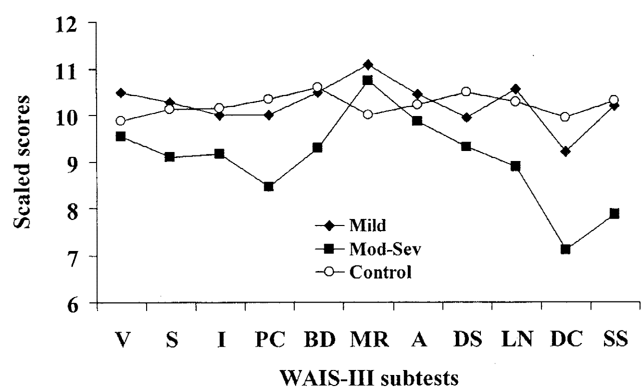

Fig. 1. WAIS–III subtest profiles for mild traumatic brain injury group (Mild), moderate–severe traumatic brain injury group (Mod-Sev), and demographically matched standardization control group (Control). V = Vocabulary; S = Similarities; I = Information; PC = Picture Completion; BD = Block Design; MR = Matrix Reasoning; A = Arithmetic; DS = Digit Span; LN = Letter–Number Sequencing; DC = Digit Symbol–Coding; SS = Symbol Search. Standardization control group data derived from the Wechsler Adult Intelligence Scale–Third Edition (WAIS–III).

https://doi.org/10.1017/S1355617701777132 Published online by Cambridge University Press

Table 2. WAIS–III factor index scores of clinical patients and standardization controls

Variable	Mild TBI ($N = 41$) M (SD)	Moderate–severe TBI ($N = 59$) M (SD)	Control group[a] ($N = 100$) M (SD)
Verbal Comprehension	101.42 (14.45)	98.85 (13.98)	100.07 (12.01)
Perceptual Organization	104.10 (15.89)	96.44 (12.49)	101.36 (13.50)
Working Memory	100.85 (13.96)	95.81 (14.91)	101.64 (14.21)
Processing Speed	98.00 (11.57)	86.90 (12.29)	100.55 (15.37)

Note. TBI = traumatic brain injury. Standard scores ($M = 100$, $SD = 15$) for all variables.
[a]Standardization data derived from the Wechsler Adult Intelligence Scale–Third Edition (WAIS–III).

Differences between the moderate–severe injury group and the standardization sample controls met the combined criteria for statistical significance and univariate effect size for all four subtests: Picture Completion [$F(1,157) = 17.12$, $p < .0001$, $\eta^2 = .10$]; Letter–Number Sequencing [$F(1,157) = 7.93$, $p < .01$, $\eta^2 = .05$]; Digit–Symbol Coding [$F(1,157) = 36.07$, $p < .0001$, $\eta^2 = .19$]; and Symbol Search [$F(1,157) = 27.07$, $p < .0001$, $\eta^2 = .15$]. In each case, the performance of the moderate–severe injury group was worse than that of the standardization control group.

The same criteria were also met for these four subtests regarding differences between the moderate–severe injury group and the mild injury group: Picture Completion [$F(1,98) = 7.80$, $p < .01$, $\eta^2 = .07$]; Letter–Number Sequencing [$F(1,98) = 6.87$, $p < .01$, $\eta^2 = .07$]; Digit–Symbol Coding [$F(1,98) = 16.96$, $p < .0001$, $\eta^2 = .15$]; and Symbol Search [$F(1,98) = 20.99$, $p < .0001$, $\eta^2 = .18$]. In each case, the performance of the moderate–severe injury group was worse than that of the mild injury group. Consistent with the comparisons involving the standardization sample controls, the effect sizes appeared to be relatively greater for the Processing Speed subtests (Digit–Symbol Coding and Symbol Search) than for the other ones.

In order to explore the degree to which any of these four subtests could actually be relied upon to classify individuals as having either a mild TBI or a moderate–severe TBI, a logistic regression analysis was performed, using only the clinical patients. Symbol Search was entered first because it had the greatest effect size in the previous analysis. Adding any of the other three subtest scores did not result in significant improvement ($\leq$ 2% additional correct classification). The best overall classification was obtained with a criterion of scaled scores less than 9 on Symbol Search being considered impaired, which resulted in a 72% correct group assignment [$\chi^2(1) = 19.48$, $p < .0001$]. However, although the specificity (85%) of this criterion was arguably satisfactory, the sensitivity (63%) was fairly disappointing. Moreover, when the same criterion was applied to the standardization control group, it appeared that 28% of these participants without TBI had Symbol Search scaled scores under 9 (consistent with what one would expect in a normal distribution of scores).

The relative influences of injury severity and education on the new WAIS–III subtests (Letter–Number Sequencing, Matrix Reasoning, and Symbol Search) were evaluated next in the complete clinical sample with a series of hierarchical regression analyses. The purpose of this serial procedure, which has clear precedent in the literature (Sherrill-Pattison et al., 2000) was to see if the same or different models of prediction would occur for each of these subtests. The independent variables were the same for each of these three analyses: coma (defined as present or not present for at least 1 day, because of the very skewed distribution as a continuous variable); intracranial lesion (defined as present or absent on neuroimaging); and education (in years). Coma was consistently entered first, followed by intracranial lesion, and finally by education. We wanted to determine whether level of education explained additional variance in the WAIS–III subtest scores, over and above that accounted for by various injury severity parameters. However, it was decided *a priori* that only variables that explained a statistically significant amount of variance ($p < .05$) would be retained in the final regression models for each subtest. As a result, if a particular injury severity variable did not explain a statistically significant degree of the variance in the dependent variable, it was removed from the model before adding other variables.

The best regression models for the three WAIS–III subtests of primary interest are presented in Table 3. Inspection of this table suggests that, although the best regression models varied per subtest, education was the only variable that explained a statistically significant amount of the variance in the scaled scores of each one of them. For Matrix Reasoning, it was actually the only variable that remained in the model, and injury severity parameters were not of statistically significant influence on the level of performance on this subtest. Performance on Letter–Number Sequencing was affected relatively more by education than by injury severity, whereas the reverse pattern emerged for Symbol Search.

Finally, because of the apparent influence of level of education on performance in the clinical sample, it was decided to explore how much of the variance in performance on the same subtests could be explained by this single vari-

https://doi.org/10.1017/S1355617701777132 Published online by Cambridge University Press

Table 3. Regression models for selected WAIS–III subtests in 100 patients with traumatic brain injury

Subtest	Variable	Partial R^2	F	$p <$
Letter–Number Sequencing	Education	.12	13.09	.001
	Intracranial lesion	.04	4.17	.05
Matrix Reasoning	Education	.06	5.82	.05
Symbol Search	Education	.04	5.64	.05
	Coma	.21	25.27	.0001

Note. WAIS–III = Wechsler Adult Intelligence Scale–Third Edition

able in the standardization control group. The amounts of variance (R^2) that were accounted for by education in this nonclinical group were, respectively, .13 for Letter–Number Sequencing [$F(1,98) = 14.93$, $p < .001$]; .14 for Matrix Reasoning [$F(1,98) = 16.03$, $p < .0001$]; and .05 for Symbol Search [$F(1,98) = 4.59$, $p < .05$]. When compared with the corresponding values presented in Table 3, it appears that for the two subtests that had demonstrated sensitivity to injury severity (Letter–Number Sequencing and Symbol Search), education explained about the same amount of variance in the standardization sample as in the clinical sample. Only for Matrix Reasoning, which had not demonstrated sensitivity to injury severity, did education explain less of the variance in clinical patients than in the standardization controls.

DISCUSSION

The goal of this investigation was to determine the sensitivity of WAIS–III subtests to both injury severity and level of education in patients with TBI. Of the three new subtests, Letter–Number Sequencing and Symbol Search were both affected by injury severity as well as level of education. Matrix Reasoning did not demonstrate sensitivity to the severity of TBI as indexed by variables such as length of coma or the presence of intracranial lesions.

The current results are consistent with previously reported findings regarding the sensitivity of the PS factor index to acquired cerebral dysfunction (Hawkins, 1998; Martin et al., 2000). Digit Symbol–Coding and Symbol Search both demonstrated medium effect sizes in distinguishing patients with moderate–severe injuries from both demographically matched standardization controls and patients with mild TBI. This suggests that Symbol Search is a clinically useful addition to the evaluation of sequelae of acquired brain injury. The fact that Symbol Search (or any other subtest, for that matter) did not suggest impairment in the subgroup with mild, uncomplicated TBI is consistent with previously reported findings that such injuries are typically not associated with persistent neuropsychological deficits (Binder et al., 1997; Mittenberg & Strauman, 2000).

Despite the apparent clinical utility of Symbol Search, one should never rely exclusively on this subtest in the determination of the presence or absence of cognitive deficits. The current findings indicate that there is a sizable minority of patients with moderate–severe TBI who may not demonstrate clearly impaired scores on this task, whereas at the same time there is an almost equally large minority of persons without TBI who may demonstrate low-average to below-average scores on this subtest. Thus, the positive and negative predictive powers of depressed scores on Symbol Search or on the associated factor index (PS) are somewhat limited. As a result, it is crucial that neuropsychologists supplement their assessment with other measures when evaluating persons with known, suspected, or disputed brain injuries.

The present findings also support the potential clinical utility of Letter–Number Sequencing; again, within the context of a broader neuropsychological evaluation. The problem is, however, that this subtest is typically combined with Arithmetic and Digit Span into the WM index. The validity of this factor index in the evaluation of sequelae of TBI and other neurological conditions may be compromised by the fact that it is based on three subtests, two of which did not demonstrate any sensitivity to injury severity in the current investigation. Previous research with the children's analogue of the WM index, the Freedom from Distractibility factor from the Wechsler Intelligence Scale for Children–Third Edition (FD; Wechsler, 1991), has also raised considerable doubt about the validity of this index as a measure of attention skills (Reinecke et al., 1999). In this context, it is relevant that the FD index is based on the same subtests (Arithmetic and Digit Span) that failed to demonstrate criterion validity in the current investigation. In addition, it needs to be realized that relatively more of the variance in Letter–Number Sequencing was accounted for by level of education than by injury severity in this investigation (a pattern that was opposite to that found for Symbol Search). For all of these reasons, it is suggested that performance on Letter–Number Sequencing can be interpreted with some caution in the evaluation of the possibility of cognitive deficits associated with known, suspected, or disputed brain dysfunction, but that there is insufficient support for utilization of the WM index for such differential diagnostic purposes.

The findings from this investigation may cast doubt on the clinical utility of Matrix Reasoning when evaluating sequelae of TBI. This new subtest failed to differentiate

https://doi.org/10.1017/S1355617701777132 Published online by Cambridge University Press

even patients with moderate to severe TBI from the matched control participants, despite the fact that half of the persons in the former group had been in coma for at least 2 days (range 0–34). In a previous investigation (Martin et al., 2000) we had found a similar lack of sensitivity of the GAMA, a task that is very similar to Matrix Reasoning. Thus, these kinds of tasks may be relatively robust to the effects of TBI. This may also suggest the possibility of suboptimal sensitivity of the PO factor index as well as Performance IQ to TBI. Previous research with the WAIS–R has suggested that the Performance IQ on that instrument was relatively more sensitive to the effects of TBI than was Verbal IQ (Crosson et al., 1990). However, all of the Performance subtests on the WAIS–R involved time limits, bonus points for fast performance, or both. The fact that Matrix Reasoning does not involve time constraints may be an important reason why it is not sensitive to the sequelae of even moderate to severe TBI. Recent research by Dugbartey et al. (1999) has also suggested that this subtest correlates just about as strongly with measures of verbal skills as with measures of problem solving. Although this does not rule out the potential diagnostic utility of Matrix Reasoning with other populations where speed of performance is typically not a core deficit (e.g., dementia of the Alzheimer type), the application of Matrix Reasoning to assess problem-solving skills in patients with TBI is without sufficient empirical support at this time. Neuropsychologists should supplement the WAIS–III with empirically validated tests (e.g., Wisconsin Card Sorting Test: Heaton et al., 1993; Wiegner & Donders, 1999b) to assess such skills in patients with TBI.

A final issue is that the new WAIS–III subtests that demonstrated clear covariance with injury severity in this investigation (Letter–Number Sequencing and Symbol Search) were also affected by level of education. In fact, education explained about as much of the variance in performance on these subtests in the clinical group as it did in the standardization control group. This reinforces the importance of considering level of education in the context of brain–behavior relationships in patients with TBI (Sherrill-Pattison et al., 2000; Wiegner & Donders, 1999a), despite the claims of some authors (Reitan & Wolfson, 1997) to the contrary. The development of education-adjusted norms for WAIS–III scores, similar to the demographic corrections that have been provided previously for other psychometric measures (Diehr et al., 1998; Norman et al., 2000), appears to be desirable.

Potential limitations of this investigation must also be considered. The vast majority of our participants were White. This prohibited the investigation of ethnic influences on WAIS–III performance, which may be an important additional consideration in light of recent research by Manly and colleagues (Manly et al., 1998, 2000). Because we did not have access to many of the original neuroimaging scans, we could not perform analyses involving precise lesion location and volume in relation to WAIS–III performance, which is an opportunity for future research. Our sample was also limited to patients with TBI, and replication in samples with different neurological disorders is still needed. At the same time, relative strengths of this investigation include the fact that our clinical sample had been screened for potentially confounding factors while maintaining a broad range of injury severity, as well as the use of a demographically matched control group.

In conclusion, the results from this investigation suggest that Letter–Number Sequencing and especially Symbol Search are clinically useful and valid additions to the WAIS–III. These subtests can complement the findings of a more comprehensive neuropsychological evaluation of patients with TBI and other conditions. On the other hand, reservation is suggested in the interpretation of Matrix Reasoning. This subtest does not have adequate sensitivity to sequelae of TBI. A goal for future research is the evaluation of the utility of the WAIS–III in the evaluation of possible invalid response sets, such as can be associated with financial compensation-seeking after claimed TBI (Iverson, 2000).

ACKNOWLEDGMENTS

Portions of this paper were presented at the Annual Meeting of the American Psychological Association, August 24 to 28, 2001, San Fransisco. This research was supported by a grant from the Campbell Foundation (#2000-MFB-JD to Jacobus Donders) and was based in part on standardization data derived from the Wechsler Adult Intelligence Scale–Third Edition (WAIS–III).

REFERENCES

Binder, L.M., Rohling, M.L., & Larrabee, G.J. (1997). A review of mild head trauma. Part 1: Meta-analytic review of neuropsychological studies. *Journal of Clinical and Experimental Neuropsychology*, *19*, 421–431.

Charter, R.A. (1994). Determining random responding for the Category, Speech-Sounds Perception, and Seashore Rhythm Tests. *Journal of Clinical and Experimental Neuropsychology*, *16*, 744–748.

Crosson, B., Greene, R.L., Roth, D.L., Farr, S.P., & Adams, R.L. (1990). WAIS–R pattern clusters after blunt-head injury. *Clinical Neuropsychologist*, *4*, 253–262.

Diehr, M.C., Heaton, R.K., Miller, W., & Grant, I. (1998). The Paced Auditory Serial Addition Task (PASAT): Norms for age, education, and ethnicity. *Assessment*, *5*, 375–387.

Dikmen, S.S., Machamer, J., Winn, H.R., & Temkin, N. (1995). Neuropsychological outcome at 1-year post head injury. *Neuropsychology*, *9*, 80–90.

Dugbartey, A.T., Sanchez, P.N., Rosenbaum, J.G., Mahurin, R.K., Davis, J.M., & Townes, B.D. (1999). WAIS–III Matrix Reasoning test performance in a mixed clinical sample. *Clinical Neuropsychologist*, *13*, 396–404.

Hawkins, K.A. (1998). Indicators of brain dysfunction derived from graphic representations of the WAIS–III/WMS–III technical manual samples: A preliminary approach to clinical utility. *Clinical Neuropsychologist*, *12*, 535–551.

Heaton, R.K., Chelune, C.J., Talley, J.L., Kay, G.G., & Curtiss, G.

(1993). *Wisconsin Card Sorting Test manual: Revised and expanded*. Odessa, FL: Psychological Assessment Resources.

Heaton, R.K., Ryan, L., Grant, I., & Matthews, C.G. (1996). Demographic influences on neuropsychological test performance. In I. Grant & K.M. Adams (Eds.), *Neuropsychological assessment of neuropsychiatric disorders* (2nd ed., pp. 141–163). New York: Oxford University Press.

Heaton, R.K., Taylor, M., & Manly, J. (2000, November). *The effects of demographic variables and the development of demographically corrected norms for the WAIS–III and WMS–III*. Paper presented at the conference of the National Academy of Neuropsychology, Orlando, FL.

Iverson, G. (2000, August). *Detecting malingering on the WAIS–III and WMS–III*. Paper presented at the conference of the American Psychological Association, Washington, DC.

Jones, R.D., Anderson, S.W., Cole, T., & Hathaway-Nepple, J. (1996). Neuropsychological sequelae of traumatic brain injury. In M. Rizzo & D. Tranel (Eds.), *Head injury and postconcussive syndrome* (pp. 395–414). New York: Churchill Livingstone.

Kaufman, A.S., & Lichtenberger, E.O. (1999). *Essentials of WAIS–III assessment*. New York: Wiley.

Manly, J., Heaton, R.K., & Taylor, M. (2000, August). *The effects of demographic variables and the development of demographically adjusted norms for the WAIS–III and WMS–III*. Paper presented at the conference of the American Psychological Association, Washington, DC.

Manly, J.J., Jacobs, D.M., Sano, M., Bell, K., Merchant, C.A., Small, S.A., & Stern, Y. (1998). Cognitive test performance among nondemented elderly African Americans and Whites. *Neurology*, *50*, 1238–1245.

Martin, T.A., Donders, J., & Thompson, E. (2000). Potential of and problems with new measures of psychometric intelligence after traumatic brain injury. *Rehabilitation Psychology*, *45*, 402–408.

Millis, S.R. & Putnam, S.H. (1997, June). *The California Verbal Learning Test in the assessment of financially compensable mild head injury: Further developments*. Paper presented at the meeting of the International Neuropsychological Society, Bergen, Norway.

Mittenberg, W. & Strauman, S. (2000). Diagnosis of mild head injury and the postconcussion syndrome. *Journal of Head Trauma Rehabilitation*, *15*, 783–791.

Moses, J.A., Pritchard, D.A., & Adams, R.L. (1999). Normative corrections for the Halstead-Reitan neuropsychological battery. *Archives of Clinical Neuropsychology*, *14*, 445–454.

Naglieri, J.A. & Bardos, A.N. (1997). *General Ability Measure for Adults*. Minneapolis, MN: National Computer Systems.

Norman, M.A., Evans, J.D., Miller, S.W., & Heaton, R.K. (2000). Demographically corrected norms for the California Verbal Learning Test. *Journal of Clinical and Experimental Neuropsychology*, *22*, 80–94.

Rees, L.M., Tombaugh, T.N., Gansler, D.A., & Moczynski, N.P. (1998). Five validation experiments of the Test of Memory Malingering (TOMM). *Psychological Assessment*, *10*, 10–20.

Reinecke, M.A., Beebe, D.W., & Stein, M.A. (1999). The third factor of the WISC–III: It's (probably) not Freedom from Distractibility. *Journal of the American Academy of Child and Adolescent Psychiatry*, *38*, 322–328.

Reitan, R.M. & Wolfson, D. (1995). Influence of age and education on neuropsychological test results. *Clinical Neuropsychologist*, *9*, 151–158.

Reitan, R.M. & Wolfson, D. (1997). The influence of age and education on neuropsychological test performances of persons with mild head injuries. *Applied Neuropsychology*, *4*, 16–33.

Reynolds, C.R. (1997). Forward and backward memory span should not be combined for clinical analysis. *Archives of Clinical Neuropsychology*, *12*, 29–40.

Sattler, J.M. & Ryan, J.J. (1999). *Assessment of children: Revised and updated third edition, WAIS–III supplement*. San Diego, CA: Author.

Sherrill-Pattison, S., Donders, J., & Thompson, E. (2000). Influence of demographic variables on neuropsychological test performance after traumatic brain injury. *Clinical Neuropsychologist*, *14*, 496–503.

Teasdale, G. & Jennett, B. (1974). Assessment of coma and impaired consciousness: A practical scale. *Lancet*, *2*, 81–84.

Tombaugh, T.N. (1996). *Test of Memory Malingering*. Toronto, Canada: Multi Health Systems.

Tombaugh, T.N. (1997). The Test of Memory Malingering (TOMM): Normative data from cognitively intact and cognitively impaired individuals. *Psychological Assessment*, *9*, 260–268.

Vanderploeg, R.D., Axelrod, B.N., Sherer, M., Scott, J., & Adams, R.L. (1997). The importance of demographic adjustments on neuropsychological test performance: A response to Reitan and Wolfson (1995). *Clinical Neuropsychologist*, *11*, 210–217.

Warrington, E.K. (1984). *Recognition Memory Test*. Berkshire, UK: NFER-Nelson.

Wechsler, D. (1981). *Wechsler Adult Intelligence Scale–Revised*. San Antonio, TX: The Psychological Corporation.

Wechsler, D. (1991). *Wechsler Intelligence Scale for Children–Third Edition*. San Antonio, TX: The Psychological Corporation.

Wechsler, D. (1997a). *Wechsler Adult Intelligence Scale–Third Edition*. San Antonio, TX: The Psychological Corporation.

Wechsler, D. (1997b). *WAIS–III/WMS–III technical manual*. San Antonio, TX: The Psychological Corporation.

Wiegner, S. & Donders, J. (1999a). Performance on the California Verbal Learning Test after traumatic brain injury. *Journal of Clinical and Experimental Neuropsychology*, *21*, 159–170.

Wiegner, S. & Donders, J. (1999b). Performance on the Wisconsin Card Sorting Test after traumatic brain injury. *Assessment*, *6*, 179–187.

Williamson, D.J.G., Scott, J.G., & Adams, R.L. (1996). Traumatic brain injury. In R.L. Adams, O.A. Parsons, J.L Culbertson, & S.J. Nixon (Eds.), *Neuropsychology for clinical practice: Etiology, assessment, and treatment of common neurological disorders* (pp. 9–64). Washington, DC: American Psychological Association.