Determining Neuropsychological Impairment Using Estimates of Premorbid Intelligence: Comparing Methods Based on Level of Education versus Reading Scores

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INTRODUCTION

Deficit Measurement

Neuropsychological assessment, in contrast to traditional psychological assessment, is based upon the measurement of deficits (Lezak, 1983). In general, when inferring brain dysfunction, obtained test scores are compared to average test scores from a “normal” sample, in order to determine which neuropsychological abilities are intact and which are impaired. However, Lezak (1983) states that use of population averages “is not an appropriate comparison standard since it will not necessarily apply to the individual patient” (p. 591).
In essence, if individuals are of premorbid low average abilities, comparing their intact low average scores to "average" norms will overestimate their degree of injury/disease related impairment. Conversely, individuals of above average premorbid abilities may have deficits minimized if their scores are compared to the "average" population. These problems illustrate the necessity of estimating premorbid abilities if degree of neuropsychological impairment is to be accurately determined. Unfortunately, there is not consensus regarding the best method by which to estimate premorbid abilities.

Estimating Premorbid Intelligence

Over the past two decades there has been increasing interest in identifying methods to estimate accurately individual's premorbid cognitive abilities (for a review see Crawford, 1992). The most commonly used estimates of premorbid abilities are based on level of education (e.g., Heaton, Grant, & Matthews, 1991) or reading scores (e.g., Wiens, Bryan, & Crossen, 1993), or demographically based regression equations using education (e.g., Barona, Reynolds, & Chastain, 1984) or reading scores (e.g., Karaken, Gur, & Saykin, 1995). Unfortunately, there has been minimal research investigating potential differences that may exist between these different methods. Given this lack of critical evaluation, the need exists to determine if use of these different methods leads to different results, and if any method has advantages over the others.

Inferring Impairment Based on Level of Education

Level of education is hypothesized to be an accurate measure of premorbid abilities as greater educational attainment is associated with higher levels of intelligence (education generally accounts for 30% of variance in IQ; Neisser et al., 1996). When determining impairment based on level of education, individuals' test scores are compared to a normative sample of the same educational level. The most commonly used education-based norms are likely those published by Heaton et al. (1991), which report T-scores to estimate degree of impairment in various neuropsychological abilities. These norms are frequently used given the large normative sample and the available educational and age stratifications. Heaton's "normal" group (n = 486) had a mean age of 42.0 (SD = 16.8), mean education of 13.6 (SD = 3.5), and consisted of 65.6% males. Their average WAIS-R FIQ was 113.8 (SD = 12.3). T-scores were calculated according to six different educational levels (6-8, 9-11, 12, 13-15, 16-17, and 18+) and 10 age ranges (20-34, 35-39, 40-44, 45-49, 50-54, 55-59, 60-64, 65-69, 70-74, and 75-80).

Although the Heaton norms are frequently used in clinical practice today, a recent series of articles note several weaknesses of this comprehensive norms package (Fastenau & Adams, 1996; Heaton, Matthews, Grant, & Avitable, 1996). In addition, a weakness inherent in estimating premorbid abilities based on education is the assumption that individuals with the same level of education are of the same level of cognitive functioning. Heaton et al. (1996) acknowledge that "(o)ccasionally, an adult patient's level of formal education appears to be a poor estimate of his or her premorbid abilities" (p. 36), and that reading recognition tests may be another accurate method by which to estimate premorbid abilities.

Estimating impairment based on educational norms can be problematic, in that educational level is at best only an imperfect proxy for ability, as education-based norms assume little variability among individuals with a given level of education. This is especially problematic in light of educational "ceilings" imposed by the structure of the educational system (e.g., 12th grade), whereby individuals of widely varying abilities are grouped together as "high school graduates." In truth, it is likely that abilities among high school graduates are more
normally distributed. This is especially true given the wide variation in educational standards in different school systems, the practice of "social promotion" to 12th grade for students who lack 12th grade academic skills, and the financial constraints of pursuing college education among even the most gifted students. Educational attainment provides crucial supplemental clinical information regarding premorbid levels of functioning, but in all likelihood offers limited direct correspondence to premorbid intelligence.

Inferring Impairment Based on Reading Scores

The use of reading scores as estimates of premorbid intelligence has grown over the past decade, and is based on the assumption that reading is an ability that is very resilient to the effects of brain dysfunction (Crawford, 1992). In addition, it has been reported that reading scores account for 38% of the variance in WAIS-R VIQ scores in a population with TBI (Johnstone, Callahan, Kapila, & Bouman, 1996). If reading scores do approximate premorbid intelligence more precisely than does level of education, they can be used to calculate better estimates of impairment.

In an attempt to determine degree of impairment based on reading scores, Johnstone, Hexum, and Ashkanazi (1995) used Wide Range Achievement Test (WRAT-R/WRAT3) Reading scores to estimate premorbid intelligence (presented as a baseline z-score) in a population with traumatic brain injury (TBI). Test scores from other cognitive measures were also transformed into z-scores based on appropriate normative data for these measures (Fromm-Auch & Yeudall, 1983), and were then subtracted from the Reading z-score to estimate degree of impairment for various neuropsychological abilities.

Using this method, Johnstone et al. (1995) reported that there was an uneven pattern of mean impairment scores associated with their TBI sample, as follows: Wechsler Adult Intelligence Scale-Revised (Wechsler, 1981; WAIS-R) VIQ M z-score = -0.27; Wechsler Memory Scale-Revised (Wechsler, 1987; WMS-R) Attention Index M z-score = -0.31; WMS-R Verbal Memory Index M z-score = -0.41; WMS-R General Memory Index M z-score = -0.51; WMS-R Delay Memory Index M z-score = -0.57; Trails A M z-score = -1.90; Trails B M z-score = -2.65.

Although this method of determining degree of impairment using reading scores as estimates of premorbid intelligence holds promise, several limitations of the method should be noted. First, although reading scores have been shown to be resilient to brain dysfunction, several studies have shown that even reading skills change over time for different types of brain dysfunction (Johnstone & Wilhelm, 1996; Paque & Warrington, 1995). In addition, this method is not appropriate to use with individuals who have learning disabilities or developmental or acquired language/reading disorders, as premorbid intelligence is likely to be underestimated in these instances.

Similarly, when highly localized deficits associated with alexia are suspected (e.g., portions of the left occipital lobe, splenium of the corpus callosum, some posterior cerebral artery infarcts; left angular gyrus), reading scores may yield a faulty estimate of premorbid abilities.

Profile Analysis for Diagnostic/Rehabilitation Purposes

Determining profiles of impairment associated with different cognitive disorders also holds important implications for the diagnosis and treatment of cognitive deficits. From a diagnostic standpoint, profile analysis may assist in differentiating between different cognitive disorders (e.g., Alzheimer’s vs. alcohol dementia; anoxia vs. traumatic brain injury, etc.). Reitan and Wolfson (1985) note the importance of determining patterns of strengths and
deficits (and not just level of performance) related to different cognitive disorders, and Heaton et al. (1991) imply that “patterns of demographically corrected T-scores may eventually prove more informative than raw score patterns for neurodiagnostic purposes” (p. 38).

Heaton et al.’s (1991) suggestion that profile analysis may assist in differential diagnosis appears to be supported by studies that show that different disorders/injuries produce differing profiles of cognitive impairment. For instance, Tate, Fenelon, and Manning et al. (1991) suggest that memory is most significantly affected following TBI, and Lezak (1979) suggests that memory is slower to recover than other cognitive deficits. In addition, the previously cited study by Johnstone et al. (1995) demonstrated that speed of processing and flexibility were the cognitive abilities most impaired following TBI, with less impairment noted in memory, attention, and intelligence. Similarly, Christensen, Hadzi-Pavlovic, and Jacomb (1991) estimated degree of impairment in a wide spectrum of cognitive and behavioral areas in a population of individuals with dementia. Using meta-analysis, they presented mean size effect differences between clinical and normal populations, and suggested that orientation (2.64), memory (2.78), and language (1.94) were the abilities most affected in dementia, with social skills (1.55), problem solving (1.32), and perception (1.24) being the least affected. In addition, Desmond, Tatemichi, Stern, and Sano (1995) suggest a variable pattern of cognitive deficits for a population who suffered strokes, with greatest estimated impairment in memory. These studies suggest that profile analysis may assist in differential diagnosis.

Profile analysis appears to hold equally important implications for rehabilitation purposes. By determining which abilities are most impaired in any cognitive disorder (regardless of etiology), it is possible to target those abilities most in need of remediation. Determining functional strengths and weaknesses is of increasing importance, given the likelihood of a decreased need for solely diagnostic neuropsychological evaluations, with a concomitant surge in demand for functional assessments (Heinrichs, 1990; Johnstone & Frank, 1995; Kreutzer, Leininger, & Harris, 1990; Mapou, 1988). Determining degree of cognitive impairment may assist in demonstrating the efficiency of cognitive-behavioral treatments for cognitive disorders by providing pre- and post-treatment estimates of deficits and subsequent recovery of function.

Basis for Study

Although education based norms are commonly used by clinicians in practice today, and the method of using reading scores to estimate an individual’s premorbid abilities shows promise, these two methods have never been compared. Given the differences in results that are likely to occur between these two methods, and the clinical and forensic implications these differences may hold, it is necessary to compare the methods in a large sample. If there are minimal differences between these methods, it can be assumed that they are equivalent. If not, it may help to determine guidelines for use of each method, based on factors such as individual patient characteristics, lesion site, goal of the evaluation, diagnostic group, etc.

It was hypothesized that estimates of impairment based on educational level and reading scores would produce different profiles of impairment, with more variation across abilities apparent in the reading based profiles. This hypothesis was based on the fact that reading scores were hypothesized to have greater accuracy in predicting premorbid intelligence (and be more sensitive to relative strengths and weaknesses in each individual), whereas education based profiles would have less variability given the wide range of abilities represented at each educational level.
METHOD

Subjects

Patients were 174 individuals with a primary diagnosis of medically substantiated TBI referred for neuropsychological testing over a 3-year period at a university-based rehabilitation hospital. Subjects were tested as outpatients in the post-rehabilitation phase of their recovery (to control for diffuse neuropsychological impairment related to acute TBI), often as part of a vocational rehabilitation planning process. TBI was documented by physicians’ treatment records, CT or MRI scans, and/or Glasgow Coma Scale ratings. All levels of injury severity and post-injury functioning were included in order to maximize generalizability to the head-injured population and to approximate the range of severity seen in clinical settings. This was deemed appropriate, given that each subject served as his or her own comparison (study compared two methods using the same sample). Ninety-seven of the 174 subjects from this study were also participants in the previously cited study by Johnstone et al. (1995).

In order to rule out confounding effects of aging and other medical disorders on neuropsychological performance, subjects over age 40 were excluded, as were those with other medical conditions. Subjects as young as 18 were included as this is the youngest age for which T-scores are provided by the Heaton et al. (1991) computer-based normative data. The mean age of the sample was 27.3 years \( (SD = 6.7; \text{ range } = 18-40 \text{ years}) \). The sample was 89.7% right-handed and 10.3% left-handed. Mean education was 12.3 years \( (SD = 1.86; \text{ range } = 7-17 \text{ years}) \), with a mode of 12 years representing over half of the subjects. Subjects were excluded if they were aphasic or had a previous diagnosis of learning disability. One hundred seventy-two of the patients were Caucasian, and 2 were African American: 118 (62%) were male and 56 (38%) were female.

Measures

Measures were administered as part of a larger comprehensive evaluation of each patient’s cognitive functioning. Tests were given on an outpatient basis by trained psychometrists under the supervision of a neuropsychologist. Tests were chosen for this study in order to assess various cognitive and motor functions.

The Wechsler Adult Intelligence Scale-Revised (WAIS-R; Wechsler, 1981) was administered to assess current intellectual abilities. The WAIS-R Full-Scale intelligence index (FIQ) was used in the analyses. The Trail Making Test (Trails A and B; Reitan, 1986) was used to estimate cognitive processing speed (Trails A) and cognitive flexibility (Trails B), measured in seconds. Motor speed for dominant and nondominant hands was measured with the Finger Tapping Test of the Halstead-Reitan Neuropsychological Test Battery (HRNB; Reitan & Wolfson, 1985). Motor strength for dominant and nondominant hand was measured by the HRNB’s Dynamometer (Reitan & Wolfson, 1985). Memory was not evaluated in this study, as normative data for the Wechsler Memory Scale-Revised (WMS-R; Wechsler, 1987) is not available in the Heaton et al. (1991) educational norms.

Procedure

Estimating premorbid functioning. The Reading subtest of the Wide-Range Achievement Test-Revised (WRAT-R; Jastak & Wilkinson, 1984) or the WRAT3 (Wilkinson, 1993) was used to estimate premorbid functioning. Both the WRAT-R and WRAT3 were used in this study, given that the tests have been shown to be highly related, with similar psychometric properties (Wilkinson, 1993). The WRAT-R/3 Reading subtest was chosen to estimate
TABLE 1
Normative Data from Studies of Normal Populations

<table>
<thead>
<tr>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Number of subjects</td>
<td>193</td>
<td>225</td>
<td>365</td>
<td>486</td>
</tr>
<tr>
<td>M Age (SD)</td>
<td>25.4 (8.2)</td>
<td>24.7 (6.2)</td>
<td>42.1 yearsb</td>
<td>42.0 (16.8)</td>
</tr>
<tr>
<td>M Education (SD)</td>
<td>14.8 (3.0)a</td>
<td>14.6 (2.8)a</td>
<td>12.1 yearsb</td>
<td>13.6 (3.5)</td>
</tr>
<tr>
<td>% Males</td>
<td>57.5%</td>
<td>56.4%</td>
<td>48.8%</td>
<td>65.6%</td>
</tr>
<tr>
<td>% Right-handers</td>
<td>83.4%</td>
<td>85.8%</td>
<td>91.5%</td>
<td>Not reported</td>
</tr>
<tr>
<td>M FIQ (SD)</td>
<td>119.1 (8.8)</td>
<td>118.6 (8.8)</td>
<td></td>
<td>113.8 (12.3)</td>
</tr>
<tr>
<td>M Tapping DH (SD)</td>
<td>46.3 (6.3)</td>
<td>42.32</td>
<td>49.9 (7.9)</td>
<td></td>
</tr>
<tr>
<td>M Tapping NDH (SD)</td>
<td>43.2 (5.4)</td>
<td>39.5b</td>
<td>45.2 (7.3)</td>
<td></td>
</tr>
<tr>
<td>M Grip Strength DH (SD)</td>
<td>40.7b</td>
<td>37.9b</td>
<td>43.4 (13.1)</td>
<td></td>
</tr>
<tr>
<td>M Grip Strength NDH (SD)</td>
<td>38.3b</td>
<td>35.2b</td>
<td>39.7 (12.7)</td>
<td></td>
</tr>
<tr>
<td>Trails A (SD)</td>
<td>26.3 (7.9)</td>
<td>28.6b</td>
<td>29.0 (12.5)</td>
<td></td>
</tr>
<tr>
<td>Trails B (SD)</td>
<td>57.6 (15.5)</td>
<td>70.5b</td>
<td>75.2 (42.8)</td>
<td></td>
</tr>
</tbody>
</table>

*a*Includes vocational/technical training.  
*b*Weighted mean composite calculated from stratified data.

premorbid intelligence, as it has been shown to be more accurate than other commonly used reading tests (i.e., North American Adult Reading Test) in estimating lower IQ ranges, has superior normative data compared to other reading tests, and has a range of standard scores and a standard deviation roughly equal to that of the WAIS-R among both normative (Jastak & Wilkinson, 1984) and clinical populations (Johnstone et al., 1996).

*Estimating impairment by educational level.* Each subject’s scores were converted to education-corrected T-scores according to normative data from the computer software package published by Heaton et al. (1991). T-scores were then converted to z-scores to allow for direct comparisons with the reading based z-score estimates.

*Estimating decline based on reading scores.* Premorbid functioning was estimated by converting WRAT-R/3 Reading Scaled Scores to z-scores: each WRAT-R/3 Reading score was subtracted from the WRAT-R/3 test mean of 100, then divided by the standard deviation of 15. This z-score was used as the baseline estimate of premorbid intelligence. To estimate decline from baseline levels, z-scores were calculated for each domain of functioning assessed (i.e., current intelligence, cognitive processing speed, cognitive flexibility, motor strength, motor speed) using appropriate normative data (WAIS-R manual for FIQ; norms published by Fromm-Auch and Yeudall, 1983, for other cognitive and motor skills). These cognitive z-scores were then subtracted from the reading z-score, yielding an estimate of impairment for each ability. Z-scores on Trails A and B were reverse-scored, as low scores on Trails indicate relatively better performance.

Normative data from Fromm-Auch and Yeudall were used for this study, as Heaton et al. (1991) note that their data were “similar to those of . . . Fromm-Auch & Yeudall,” (p. 12). Even though the data reported for these two samples are similar, it is necessary to note a limitation of Fromm-Auch and Yeudall’s normative sample. The average FIQ of the sample was 119.1 ($SD = 8.8$). Because the sample was of high average intelligence, it is not truly representative of an “average” sample. We identified other large normative samples for potential use in the study (Bornstein, 1985; Yeudall, Fromm, Reddon, & Stefanyk, 1986), although they had similar limitations. For example, norms published by Yeudall et al. (1986) had a mean FIQ of 118.6 ($SD = 8.8$); and those published by Bornstein (1985) did not provide any information regarding FIQ of the sample. In addition, normative data for these samples
showed very similar means and standard deviations for all variables evaluated in this study (see Table 1). Due to the generally similar means and standard deviations of these samples, as well as Heaton et al.’s (1991) noted similarity to the Fromm-Auch and Yeudall norms, it was determined to use Fromm-Auch and Yeudall’s normative data.

RESULTS

Table 2 summarizes raw scores, education-based z-scores, and reading based z-scores for all measures. Figure 1 illustrates these differences.

The mean for the WRAT-R/3 Reading Scale Score was in the average range (M = 94.5) and the WRAT-R/3 Reading standard deviation (14.1) approximated the standard deviation of 15 as defined in the manual. Calculated as a z-score, this sample of TBI patients was estimated to have a premorbid intellectual z-score baseline of -0.37. The average FIQ for this sample was 89.4, roughly one third of a standard deviation (i.e., 5 points) below premorbid abilities as estimated by the WRAT-R/3 Reading subtest.

Wilcoxon signed rank tests were performed in order to determine whether education based and reading based estimates of impairment differed for each measure. The Wilcoxon test (two-tailed) was chosen because the data were not normally distributed. For each measure, education and reading score based estimates of impairment were significantly different at the p < .0001 level. Education based z-scores estimated a greater degree of impairment than did reading based z-scores for Finger Tapping (dominant and nondominant), Grip Strength (dominant and nondominant), and WAIS-R FIQ. Reading based z-scores estimated greater decline than education-based scores for Trails A and Trails B (see Table 2 and Figure 1).

It needs to be noted that Trails A and B scores were not normally distributed (i.e., negatively skewed). As a result, the degree of deficit computed for these measures may have been overestimated. However, this study used Wilcoxon comparisons to correct for violations of the normality assumption.

DISCUSSION

The results hold important clinical implications by demonstrating that different methods of estimating neuropsychological impairment (based on level of education vs. reading scores) produced very different results. These differences may lead to different conclusions regarding
the nature and extent of cognitive deficits associated with brain dysfunction. These conclusions may in turn impact diagnostic, forensic, and rehabilitation decisions. Differences between these methods cannot be overstated, as all cognitive and motor tests evaluated were statistically different at the .0001 significance level. Because different methods may lead to very different conclusions, clinicians will need to be aware of differences between these methods, and know the limitations of each.

**Variability in Patterns of Decline**

Consistent with expectations, the two methods produced very different profiles of cognitive deficits associated with TBI. In general, the education-based results suggested a pattern of global decline in abilities (z-score range = −0.59 to −0.97), although the reading-based results suggested a much more variable pattern of neuropsychological deficits associated with TBI (z-score range = +0.21 to −2.95).

The education-based method suggested a greater degree of impairment in intelligence and motor skills, whereas the reading based method suggested a greater degree of impairment in speed of processing and flexibility with relatively intact motor skills, consistent with findings reported by Seidenberg, Giordani, Berent, and Boll (1983). Clearly, it cannot be the case that both reading and educational level accurately estimate premorbid functioning.

The pattern of global and relatively consistent impairment evident from the use of education based norms was not expected, as previously cited studies suggest a variable pattern of neuropsychological deficits in various cognitive disorders (Christensen et al., 1991; Desmond et al., 1995; Tate et al., 1991). Most surprisingly, data from the education-based method suggested that Trails A (z-score = −0.97) was equally or more impaired than Trails B (z-score = −0.90) in this study. This is contrary to assertions that Trails B “is clearly the more sensitive part of the Trail Making Test” (Spreen & Strauss, 1991; p. 327), as well as other studies that suggest Trails B is one of the most sensitive measures of brain dysfunction (Powell, Cripe, & Dodrill, 1991). This finding is difficult to reconcile with commonly held beliefs about tests that are most sensitive to brain dysfunction, and further investigation of the factors associated with these unexpected findings is warranted. Consistent with concerns

Different Patterns of Decline in Cognitive and Motor Abilities

Another finding of interest was the different pattern of results obtained for cognitive versus motor skills. Estimates based on reading scores indicated greater impairment in cognitive abilities with less impairment in motor skills (psychomotor speed, strength). In contrast, differences between cognitive and motor skills were less evident in profiles generated using educational level. The reading based method suggested that psychomotor speed (Finger Tapping) declined minimally \( [z\text{-score} = -0.17 \text{ (dominant)} \text{ and } -0.19 \text{ (non-dominant)}] \) compared to cognitive abilities assessed (cognitive \( z\text{-score range} = -0.34 \text{ to } -2.95 \)). In addition, Grip Strength \( [+0.15 \text{ (dominant)} \text{ and } +0.21 \text{ (nondominant)}] \) was marginally above what was expected based on reading score estimates. This finding may be related to having a greater proportion of males than females in the sample, consistent with the typical TBI populations, but is also consistent with Seidenberg et al.’s (1983) findings suggesting intelligence has a minimal relationship with motor functioning.

In contrast, the education based method suggested Finger Tapping (dominant \( z\text{-score} = -0.94; \text{nondominant } z\text{-score} = -0.93 \)) is equally if not more impaired than cognitive abilities. Estimated impairment in Grip Strength (dominant \( z\text{-scores} = -0.67; \text{nondominant } z\text{-score} = -0.59 \)) is also relatively large compared to the reading-based results, and the significant differences obtained between the two methods regarding motor skills is difficult to explain.

These findings raise the question of whether or not motor abilities should even be interpreted based on normative data. It is easily argued that motor skills are not normally distributed, and it is more important to consider such factors as physical size, strength, age, and vocational background when inferring central nervous system-based motor dysfunction.

Implications for Rehabilitation

The results of the reading-based method hold promise for rehabilitation planning as this method appears to be superior in identifying relative cognitive strengths and weaknesses that can be targeted for remediation. This method may also allow for more accurate demonstration of the efficacy of commonly used remediation strategies, something that will become increasingly important as managed care necessitates empirical demonstration of the utility of our services.

Limitations of the Study

Although these findings are important, several limitations of the study must be noted. Generalization of these results should be made with caution, as almost all subjects were Caucasian. In addition, the use of a heterogeneous sample without specific data related to TBI history limits the extent to which inferences about specific subpopulations can be drawn, although including a broader range of TBI subjects allows for greater generalizability of results to typical outpatient TBI populations.

As previously stated, estimates based on reading scores may be limited for several reasons. This method assumes a general consistency of premorbid functioning across neuropsychological domains. As stated earlier, individuals with pre-existing disparities in abilities (e.g., learning disabilities) are not appropriate candidates for this method. In addition, individuals with trauma/disease-related language deficits may have uneven performance
across testing due to their dysphasias. Education-based norms appear more appropriate for these populations due to the implicit variability in their functioning.

FUTURE DIRECTIONS

Given these findings, future research should: (a) compare other methods used to infer premorbid intelligence (e.g., Barona et al., 1984); (b) compare different methods of determining neuropsychological impairment among different populations (e.g., multiple sclerosis, AIDS, stroke, Alzheimer's, Parkinson's, alcohol dementia, specific toxin exposures, infectious processes, systemic disorders, etc.); (c) apply these methods in evaluating other cognitive domains (e.g., verbal memory, visual memory, visual-spatial perception, abstract reasoning, etc.); (d) determine if profiles of impairment can differentiate between different cognitive disorders; (e) compare methods of inferring dysfunction using other factors known to influence neuropsychological performance (e.g., age, education, intelligence, age X education, age X estimated intelligence, etc.); and (f) report data on a truly “average” (compared to “normal”) population to improve the ability to infer degree of deficit in neuropsychological abilities.

REFERENCES


