Neurobehavioral Testing in Monitoring Hazardous Workplace Exposures

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Exposure to workplace toxins, particularly organic solvents, lead, and pesticides, has been shown to cause both transient and persistent derangements of CNS function. Neurobehavioral testing is described as a means of evaluating the health effects of exposure to toxic chemicals. The use of neurobehavioral testing is most appropriate where an exposure has been characterized and the diseases of interest specified. Most investigators use batteries of tests to evaluate psychomotor function, memory, verbal ability, mood, and visual/spatial abilities. Because of the shortcoming of the interviewer-administered test batteries, existing neurobehavioral tests have been adapted to a computer-administered format. This tool offers promise for future efforts to monitor CNS function in exposed workers.

Since Hanninen[1] introduced neurobehavioral testing as a method for evaluating health effects of workplace chemical exposures, a variety of studies have used these testing instruments. These studies have been used, in part, to establish workplace exposure standards to reduce the risk of health impairment following chronic or acute exposure to neurotoxic agents.[2] In addition to their use in epidemiological studies as a tool for quantifying functional status, neurobehavioral tests may be used for a variety of reasons in working populations (Table 1). In evaluating symptomatic persons or job applications, neurobehavioral testing is used relatively widely. Less frequently, neurobehavioral testing may be used in screening to identify early functional impairment. In rare instances, neurobehavioral testing can be used to evaluate the effectiveness of a workplace control program.

In our experience, employment of neurobehavioral testing methods is most appropriate in situations where defined chemical exposures are present and some effort to quantify their intensity is made simultaneously with functional assessment (Table 2). These methods have limited usefulness in testing populations such as those living near hazardous waste sites, where characterization of the intensity of exposure to specific substances is not possible. In general, prior studies of humans or animals should have demonstrated that some substances (eg, certain metals, solvents, and pesticides) cause CNS dysfunction.

In a typical survey, groups of exposed workers are tested and compared with unexposed populations tested with the same methodology. Such studies are potentially susceptible to bias created by selection factors or by inadequate control of confounding variables.[3] Frequently, inadequate exposure assessment, either poorly designed or inadequately implemented, leads to random misclassification and attendant reduced study power. By far the most desirable circumstance is to test workers prior to exposure and to follow them prospectively with periodic testing. Simultaneous measurement of exposure intensity through either biological or environmental monitoring should be performed to allow development of meaningful dose-response relationships. In view of the significant issues of validity discussed above, cross-sectional studies should be interpreted with great caution.

In addition to specifying exposure conditions, it is desirable, in surveys where neurobehavioral testing is used, to attempt to specify the health conditions of interest. For CNS dysfunction, three syndromes have been defined. First, transient CNS depression resulting from overexposure to organic solvents, carbon monoxide, and other intoxicants is a well-recognized sequela

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TABLE 1
Uses of Neurobehavioral Testing in the Workplace

Quantify CNS function in epidemiological studies
Evaluate symptomatic persons
Determine ability to perform a specific job
Detect early, reversible CNS impairment in exposed workers
Evaluate the effectiveness of an intervention program

TABLE 2
Condition Favorable to Use of Neurobehavioral Testing in Screening Programs

Specified exposure situation (eg, lead, solvents, or pesticides) in which environmental and/or biological monitoring is used for exposure estimation
Prior animal or human studies which show evidence of CNS dysfunction caused by agent of interest or structurally related compound
Prospective monitoring where workers may serve as their own controls

of short-term, high-level exposures.[4] Such acute CNS dysfunction is analogous to that following the administration of inhalation anesthetics or the consumption of ethanol. Chamber studies have been used to evaluate this condition following exposure to workplace agents.[5] A small number of field investigators have also studied this acute condition.[6] A second condition, described extensively in the Scandinavian literature, is referred to as the "neurasthenic syndrome." This symptom complex, characterized by increased complaints of fatigability, irritability, increased rates of sleeping, confusion, and loss of interest, has been reported in increased frequency among populations exposed to lead and organic solvents.[4] The condition appears to last from days to weeks following the termination of solvent exposure and appears to be associated with impaired performance on neurobehavioral tests. Finally, the most severe form of CNS impairment, toxic encephalopathy, is usually considered irreversible and is characterized by signs and symptoms of diffuse CNS damage. Formal neurobehavioral testing shows deficits in memory function, psychomotor ability, and complex reasoning ability in persons with toxic encephalopathy. In the early phases of this condition, patient may recognize and complain of these functional deficits. Mood disturbances are also frequently seen.

Once the exposure situation has been identified and the disease of interest specified, neurobehavioral techniques must be selected to evaluate the population. In the past, most investigators have used batteries of tests that evaluate five functional areas (Table 3): psychomotor, memory, verbal, mood, and visual/spatial.[7–12] In every instance, tests used in clinical neuropsychology have been identified and selected for the test batteries. Several points should be considered in reviewing the contents of these batteries. First, most test elements contain a relatively large number of tests which evaluate psychomotor function. Although psychomotor function is an important area to monitor in exposed workers, it has received disproportionate emphasis in prior batteries. Second, most test elements fail to include a mood inventory despite the increased report of affective disorders among workers excessively exposed to neurotoxins in the workplace.[13] Additionally, in some instances, the length of time required to administer the full battery exceeds the time available for persons being tested at the work site. In our experience, generally no more than 50 to 60 minutes are available for testing at the workplace during normal work hours.

Current test batteries are administered by a trained technician, and the person being tested typically provides a verbal or written response. Thus, the role of the interviewer is to present the tasks, record responses, and calculate scores. Although existing neurobehavioral techniques offer significant advantages for screening programs designed to evaluate nervous system function (Table 4), some limitations are apparent. One shortcoming of interviewer-administered testing is that the tests require highly trained and closely supervised technicians to achieve reproducible results. Once the tests are administered, time-consuming and occasionally subjective scoring procedures must be used. Furthermore, if repeated testing is anticipated, variability of interviewer's technique and the testing conditions will contribute significantly to random measurement error. An additional concern, specific to testing working populations, is that some workers consider the tests embarrassingly judgmental, particularly when the worker perceives his or her test performance to be relatively poor. Finally, reference data obtained from working populations are sparse for many of these tests. These concerns are addressed in part by adapting a set of existing neurobehavioral tests to a computer-administered format (Table 5).[14]

The primary advantages of this computer-administered system are ease of administration, ease of data handling, reproducibility of testing conditions, and reduction of the judgmental character of interviewer-administered tests. Additionally, the adoption of a computer-administered format increases comparability of testing conditions between different research groups. As a result, pooling data from unexposed populations to generate reference data becomes more feasible.

To date, a series of validation studies has been performed to evaluate the reproducibility of our computer-administered tests and to compare selected tests with similar, interviewer-administered tasks. Reproducibility testing performed up to 5 months after initial testing has shown stability coefficients ranging from 0.6 to 0.84. Comparability of these tests to existing standard tests is also high with correlation coefficients ranging up to 0.76.

In addition to validation studies, we have used our system in field studies of unexposed and exposed workers. Data analysis performed to date has shown that these tests are affected by age and educational level in a manner consistent with previously described standard instruments.[15] Studies of spray painters exposed to solvents in Boston, Forth Worth, and Memphis have been completed; data analyses are under way.

In summary, neurobehavioral testing, begun in the workplace less than 15 years ago, holds clear promise for monitoring populations exposed to hazardous substances in the workplace. As a tool for epidemiological

TABLE 3
Neurobehavioral Test Batteries for Monitoring Occupational Groups

Ability	Cherry et al[7] (London School of Hygiene)	Valciukas and Lilis[8] (Mt Sinai School of Medicine)	Hogstedt et al[9] (Swedish Board of Occupational Health)	Hanninen and Lindstrom[10] (Finnish Institute of Occupational Health)	Baker et al[11] (Harvard, Boston University)	World Health Organization/ National Institute for Occupational Safety and Health
Psychomotor (speed and dexterity)	Simple Reaction Time Lafayette Pegboard Dotting; Trail Making Digit Symbol	Santa Ana Digit Symbol	Simple Reaction Time; Bolts, Pins, and Cylinders Dots Save Number Digit Symbol	Mira Symmetry Drawing Bourdon-Wiersma Santa Ana Digit Symbol	Continuous Performance Santa Ana Digit Symbol	Aiming Simple Reaction Time Santa Ana Digit Symbol
Memory	Buschke		Benton Visual Retention Claeson-Dahl	Benton Digit Span	Verbal Paired Associate Learning Digit Span Digit Symbol Recall	Benton Digit span
Verbal	Adult Reading		Synonyms Antonyms	Similarities Vocabulary	Similarities	
Mood				Rorschach	Profile of Mood States	Profile of Mood States
Visual spatial ability	Visual Search Block Design	Embedded Figures Block Design	Unfolding Figure Class Block Design	Block Design Picture Completion	Block Design	
Administration time	40–50 min	20–25 min	2 h	95 min	40 min	30–40 min

TABLE 4
Characteristics of Existing Neurobehavioral Tests of Relevance to Screening Programs

Advantages
- Functions of interest (eg, memory, dexterity, speed, mood) are directly tested.
- Test scores correlate with ability to perform specific work-related tasks.
- Functional impairment is seen in early, potentially reversible stages of toxin-induced disease.
- Tests are noninvasive.
- Tests are reasonably reproducible, sensitive, and specific.

Limitations
- Test performance is influenced by motivation.
- Performance is heavily influenced by factors unrelated to exposure (eg, age, sex, education, socioeconomic status, drugs, sleep deprivation).
- Tests are unfamiliar to nonpsychologists (and often unavailable).
- Adequate reference data on unexposed workers are lacking.
- Testing requires significant time commitment of highly trained interviewers.

TABLE 5
Neurobehavioral Evaluation System (NES) Computer-Administered and World Health Organization (WHO) "Core" (Manual) Tests

Functional Domain	NES Test	WHO "Core" Test
Perceptual-motor		
Motor Speed	Finger Tapping	
Visuomotor speed	Simple Reaction Time Continuous Performance Test	Simple Reaction Time
Motor coordination	Hand-eye Coordination	Santa Anna
Motor steadiness		Aiming (Pursuit Aiming)
Coding speed	Symbol-Digit Substitution	Digit-Symbol Substitution
Visual perception	Pattern Comparison Test	
Memory and learning		
Visual memory	Visual Retention Test Pattern Memory Test	Benton Visual Retention
Short-term memory	Digit Span (Visual) Memory Scanning Test	Digit Span (Auditory)
Learning/memory	Serial Digit Learning	
Verbal learning	Associate Learning	
Intermediate memory	Associate Recall	
Cognitive		
Verbal ability	AFQT Vocabular Test	
Calculation	Horizontal Addition	
Mental flexibility	Switching Attention	
Affect:		
Mood	Mood Scales	Profile of Mood States

studies and as a detection technique in ongoing surveillance programs, standardized neurobehavioral testing provides an important mechanism for monitoring CNS function. The use of a prospective study design in which repeated testing is performed over an interval of hours, days, months, or years is extremely desirable for high study validity. In view of the potential biases introduced by selection and confounding factors, interpretation of cross-sectional investigations is limited. Work is under way to improve the general usefulness of neurobehavioral testing by adapting it to a computer-administered format. Through further refinement of and experience with neurobehavioral testing methods, the full potential of computer-administered tests in monitoring workplace populations will undoubtedly be realized.

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The National Binge

Americans now consume 60 percent of the world's production of illegal drugs. An estimated 20 million are regular users of marijuana, 4 million to 8 million more are cocaine abusers and 500,000 are heroin addicts.

Drugs are flooding the nation. This year, more than 12 tons of heroin, 64 tons of marijuana and 150 tons of cocaine will spread across the land—from big cities to rustic hamlets. Sales of illegal narcotics total $100 billion annually, more than the total net sales of General Motors, more than American farmers take in from all crops. And it's a business that is sickening and killing people in record numbers. Between 1981 and 1985, cocaine-related deaths in 25 major metropolitan centers more than doubled and cocaine-related emergency-room visits tripled.

Studies by the National Institute on Drug Abuse find that 30 percent of all college students will use cocaine at least once before they graduate, that up to 80 percent of all Americans will try an illicit drug by their mid-20s. The institute reports: "Clearly, this nation's high-school students and other young adults still show a level of involvement with illicit drugs greater than can be found in any other industrialized nation in the world.

—From "Horizons: America on Drugs" by J. S. Lang and R. A. Taylor in *U. S. News and World Report*, July 28, 1986.