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Mental Energy: Assessing the Cognition Dimension

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INTRODUCTION

Many techniques have been developed to assess cognitive state, both directly and indirectly. When certain types of cognitive tests are used to assess factors that influence mental energy, such as drugs, food constituents, and disease states, consistent changes in cognitive performance are observed. If mood states related to mental energy, such as fatigue and alertness, are assessed in the same studies, they vary in the expected manner, thereby validating the observed changes in cognitive performance. Cognitive tests assessing vigilance and choice reaction time appear to be the optimal performance tests for assessing mental energy. These tests have been widely used to assess a variety of factors that increase or decrease mental energy in both normal volunteers and patient populations with reduced or increased levels of mental energy.

METHODS FOR MEASURING COGNITIVE FUNCTIONS

Psychologists and other scientists have developed many techniques that can be used to assess an individual's cognitive state, both directly and indirectly. These tests are briefly reviewed in this section.

Cognitive Tests

Behavioral tests of cognitive performance provide reliable, quantitative information on a variety of abilities in healthy volunteers and can also be used to diagnose and monitor patients with various mental and physical diseases. They are administered using paper and pencil, on microcomputers, and with testing equipment ranging from sophisticated simulators of real-world tasks to devices as simple as a pegboard. They are accepted across a variety of research and applied fields as an established standard for assessing human behavior. Cognitive tests can assess a variety of functions, including sensation, perception, attention, vigilance, learning, memory, language, gross and fine motor performance, decision making, and complex mental processes such as face recognition and mathematical reasoning. Although many tests are available for the evaluation of most categories of cognitive function,[1,2] little information is available on the use of cognitive tests to assess mental energy.

Mood

Depending on the particular mood assessed, mood questionnaires can be highly correlated with tests of cognitive function.[3-5] They are accepted as valid methods for the assessment of mental states, some of which are closely related to the concept of mental energy. O'Connor[6] recently conducted a comprehensive review of the utility of these questionnaires for the assessment of metal energy and concluded that mood states such as fatigue and vigor are appropriate measures of mental energy.

Electrophysiological Methods

A variety of electrophysiological techniques have been developed and refined to assess particular aspects of cognitive function. These techniques can assess spontaneous electrical activity in the brain or activity evoked by particular stimuli. Although these methods are indirect measures of an individual's cognitive state, they can be highly correlated with particular cognitive functions. One widely used electrophysiological technology is polysomnography, which is classically used to assess sleep. Closely related electrophysiological assessment techniques that have evolved from polysomnography can be used to assess alertness, a parameter associated with mental energy.[7-9]

Brain Scanning Technologies

A variety of sophisticated techniques for the assessment of brain metabolism, neurotransmission, and regional blood flow have emerged. These techniques in-

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clude functional magnetic resonance imaging, single-photon emission computed tomography, and positron emission tomography scans. These tests assess different aspects of brain function and, in addition to clinical use, are used to explore relationships between cognitive functions and physiological processes. Several of these techniques measure brain metabolic activity, and therefore correspond in some respects to classical measures of physical energy such as calorimetry. However, changes in metabolic activity in the brain are highly specific to particular regions of the brain and are not directly related to the underlying mental processes. In the future, the use of these techniques in combination with cognitive and mood assessment technologies may lead to important advances that define the physiological basis for the concept of mental energy.

Ambulatory Monitoring Technologies

A limitation of cognitive tasks and mood questionnaires is that subjects must stop ongoing activities to participate in the tests. Recently, methods that rely on the increasing sophistication and miniaturization of electronic technology to monitor subjects as they continuously engage in their typical daily activities have emerged.[10] The most widely used of these methods is the activity monitor or actigraph, a device that is worn on the wrist or waist and can record and store data for many days. Actigraphs assess the physical activity associated with patterns of rest and activity on a minute-by-minute basis and can be used to estimate the duration and fragmentation of sleep.[10] Although activity monitors do not provide precise information on subjects' cognitive state, they do provide continuous, quantitative information on their physical activity.[11] The capabilities of these monitors—especially their ability to measure sleep and circadian rhythms of rest and activity indirectly—make them potentially useful in studies of mental energy.[10,12-14]

Ambulatory devices that assess cognitive performance or mood continuously and automatically throughout the day are of greater utility. A device worn on the wrist that assesses self-reported mood state and activity several times a day for many days is available (MiniMitter Co., Inc., Bend, OR, USA). A wrist-worn ambulatory monitor that measures behavioral parameters such as vigilance and reaction time, as well as activity, has also been developed.[15,16] These monitors have been used to assess the effects of frequent doses of a carbohydrate-containing beverage (energy supplementation) on cognitive performance in soldiers engaged in intense physical activity in a field exercise conducted over 10 hours. They established that the soldiers receiving carbohydrate supplements had significantly improved vigilance and reaction times compared with those receiving a placebo beverage. A standard mood questionnaire (Profile of Moods State, or POMS) administered periodically during the study documented reduced fatigue in volunteers receiving the carbohydrate supplement compared with placebo-treated volunteers.

Peripheral Markers of Mental Energy

To date, no peripheral marker of mental energy in healthy individuals has been identified. A variety of sources could potentially provide such markers, including plasma, saliva, urine, interstitial fluid, and breath. It is clear that in disease states or in studies in which abnormal physiological conditions are artificially generated, factors such as plasma glucose levels are related to perceived fatigue and, presumably, mental energy. Glucose, the principal substrate for brain metabolism, is under tight homeostatic control, so levels in healthy, non-exercising individuals will not generally reach the low levels associated with impaired cognitive performance, including reduced alertness and increased fatigue. However, these signs can be observed in individuals with diabetes or in healthy individuals who are given insulin to artificially lower their plasma glucose levels.[17-19] Decrements in cognitive performance have also been observed in individuals engaged in sustained aerobic physical activity.[20]

Other metabolic factors can also be related to cognitive status under certain conditions. For example, high levels of cortisol are released under stressful conditions and are associated with impaired cognitive performance.[21] Melatonin, which humans release at night when they are in a dark environment, is associated with increased sleepiness and impaired performance.[22–26] A recent review by Lieberman et al.[27] discusses some of the issues regarding metabolic markers of cognitive function.

MENTAL ENERGY AND COGNITIVE PERFORMANCE

Although many tests for assessing human cognitive functions exist, only a few of these functions relate directly to mental energy. Furthermore, the alertness or mental energy of the subject influences the results of most cognitive tests; such effects are usually a secondary consequence of altered attentiveness and do not suggest a direct relationship between mental energy and a particular cognitive function. For example, the effects of moderate doses of caffeine on rested individuals are limited to functions such as vigilance and reaction time, and not to complex cognitive abilities such as learning,

memory, or complex information processing.[28–33] However, when subjects are sleep deprived, the effects of caffeine generalize to many other cognitive functions, including learning, memory, and complex information processing.[32,34–36] These extensive effects of caffeine on sleep-deprived volunteers are probably a secondary consequence of the improved ability of the subject to maintain attention to the task.[35]

In a recent review, Lieberman[27] drew from a wide variety of experimental and clinical research studies to determine which cognitive tasks can be used to assess energy and fatigue in populations of healthy subjects and patients with different diseases or conditions. Consistent associations between cognitive tasks and energy-related mood states were of particular importance in arriving at definitive conclusions, because such associations cross-validate the construct of mental energy as it is applied to cognitive performance.

The diverse literature on treatments that modify mental energy provided clear guidance as to optimal cognitive tasks for measuring this factor. Of particular value were parametric studies on sleep loss, hypnotics, and stimulants. Studies of caffeine and melatonin—which have discrete but opposite effects on mental energy apparently without affecting other cognitive functions—provided especially useful insight regarding optimal tests to assess mental energy. Carefully selected reaction time tasks (especially those assessing choice reaction time) and vigilance tasks consistently detected changes in mental energy.

When employed in well-designed studies, these tests detected even modest effects of a variety of parameters that increase and decrease alertness. Measurable changes in vigilance and choice reaction time were observed with the following conditions: 1) administration of low doses of hypnotic drugs/dietary supplements such as diphenhydramine and melatonin; 2) treatment with a variety of stimulants including low doses of caffeine; 3) a single night of disrupted sleep or a few hours of chronic sleep loss; and 4) various diseases that lower mental energy, such as chronic fatigue syndrome, Parkinson's disease, and depression.

At least four tests of vigilance and choice reaction time have been used effectively to detect changes in mental energy in multiple studies: the Psychomotor Vigilance Test,[37,38] the Wilkinson four-choice visual reaction time test,[3,24,39] the Wilkinson Auditory Vigilance test,[24,28,29,38] and the Scanning Visual Vigilance test.[36,40,41] A variation on the Wilkinson Auditory Vigilance test is particularly sensitive to experimental treatments that both raise and lower an individual's levels of mental energy, including low doses of melatonin and caffeine.[23–25,29]

SUMMARY

The cognitive dimension of mental energy can be assessed by tests of vigilance and choice reaction time. These behaviors are relatively simple cognitive functions and can be measured with precision and reliability if carefully designed and implemented tests are used. Because the concept of mental energy is still evolving, the selection of appropriate tests to assess it must be tentative. However, vigilance and choice reaction time seem to have the necessary psychometric properties for assessing mental energy, including construct, predictive content, and face validity. Tests of reaction time and vigilance are correlated with questionnaires that measure mood states corresponding to mental energy—such as sleepiness, fatigue, and alertness—in the expected manner and are of approximately equivalent sensitivity.

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