ABSTRACT

The Army Cognitive Readiness Assessment (ACRA) system is an enhanced approach to evaluating an individual’s readiness to perform a specific job or mission. It consists of an armory of behavioral and biological probes of 18 job-relevant cognitive functions. These include traditionally-tested functions such as short term and working memory, sustained attention, and visual-motor control, as well as complex constructs such as planning and problem solving, cognitive flexibility, situation awareness, and decision making. In addition, ACRA incorporates a modeling procedure designed to assess the operational impact of any measured decrement in the person. Unlike traditional test batteries, ACRA utilizes a quantified description of the cognitive demands of a job or mission to automatically select, weight, and configure an individualized test battery that is optimized to probe those demands. Rather than simply presenting test scores, results are summarized and presented to the subject or field commander in terms of the person’s readiness to perform each of the cognitive skills demanded by the mission, as well as providing an estimate of the overall probability of the person completing the mission successfully. Finally, a sleep/fatigue/performance model (the Sleep, Activity, Fatigue, and Task Effectiveness (SAFTE) – and a new workload/performance model are used to project the person’s performance capacity over the next 24 hours or more, and these results are similarly translated into a probability of successful mission completion at each point in the future. The model therefore allows operational planners to explore alternative sleep and workload schedules to achieve optimal performance. Planned addition of behavioral tests and integration of biological probes such as actigraphy, cardiac variability, EMG, and biochemical stress analysis (e.g., sodium amylase) will further enhance and instantiate this new neuroergonomic approach to more precisely defining human cognitive readiness “in relation to performance at work and in everyday settings” (Parasuraman, 2011).

INTRODUCTION

This paper briefly describes some new developments in the area of human cognitive performance testing. These developments have produced the first version of the Army Cognitive Readiness Assessment (ACRA) system, which is currently in use at the Army Research Laboratory, Aberdeen Proving Ground. The system differs from traditional test battery approaches in that it begins with a quantified description of the cognitive demands of any defined job or mission and automatically selects and configures a test battery optimized to probe those demands. Results on that test battery are then translated into estimates of the person’s readiness to meet specific cognitive mission demands, and these estimates are amalgamated into an overall assessment of the probability of successful mission completion. The “Person-System-Mission” (PSM) model underlying these analyses also contains sub-models estimating the performance effects of sleep, fatigue, and workload, permitting both diagnosis of degraded readiness and projection of the person’s cognitive status into the future, and allowing operational planners to explore the effects of various work/rest schedules to maximize the probability of mission success.
In the following sections, each of the steps in the ACRA system approach is described briefly.

DEVELOPMENT AND EVOLUTION OF THE ACRA SYSTEMS APPROACH

Cognitive performance testing has a long and generally successful history. Although individual test procedures have been developed since the beginning of scientific psychology, perhaps the most easily identifiable first test “batteries” arose from the work of Alluisi and Chiles in the middle of the last century (Chiles, 1966). In the mid-70s, Dr. Fred Hegge led a tri-service effort to consolidate the best of the existing cognitive measurement approaches, and this resulted in the “Unified Tri-Service Cognitive Performance Assessment Battery” (UTCPAB) which, after a number of iterations and enhancements, has been commercialized as the “Automated Neuropsychological Assessment Metrics” (ANAM) battery. In the interim, many other test batteries were developed by different agencies (e.g., the NATO STRESS battery, NASA’s PAWS, WinSCAT, and Multitask Performance Batteries, the Air Force Criterion Task Set and Neuropsychological Workload Test Battery, and the Canadian CANTAB, among others). In fact, in the early development of the ACRA system, 18 identifiable batteries were reviewed, and the various test procedures they utilized constituted the ‘exhaustive’ compendium of probes from which the ACRA armory was selected.

By the turn of the century, however, there was a general feeling that traditional test batteries were not addressing the need to assess cognitive capacities in the human as they related to the increasingly complex cognitive demands of modern systems. In 2001, therefore, Dr. Susan Chipman of the Office of Naval Research (ONR) requested exploration of a ‘next generation’ approach to cognitive performance testing. This resulted in the development of new cognitive assessment tool containing a number of new elements (O’Donnell, Moise, and Schmidt, 2004). One of most innovative of these was the concept of developing a “test armory” rather than a test battery. This concept, first suggested by Hunt (1991), replaced the fixed set of tests in a battery with an array, or “armory” of tests from which individualized and targeted batteries could be developed. To make this approach practical, a mathematical technique described by DiBello, Stout, and Roussos (1995) was modified and adapted to the matching and selection of tests in the armory. This “T-Matrix” approach uses an optimization algorithm to determine the minimum set of tests in the armory that optimally probe the cognitive demands of the mission. Programming of these capabilities laid the foundation for responding to a plea by Dr. Brett Giroir of DARPA for an assessment technology that provided a more field-usable feedback to operational personnel. This led to a further elaboration of the way the results of the T-Matrix analysis could be used to generate job-relevant batteries automatically, and to present the results to the user (O’Donnell, Moise, and Schmidt, 2005). The overall armory of tests has also recently been delivered to the Air Force Research Laboratory at Wright-Patterson AFB, Ohio.

During the early development period, ARL became interested in developing an armory of tests that could be related directly to the many cognitive demands placed on the dismounted warrior. As a result, with guidance from Linda Fatkin and Pam Burton, the original ACRA armory was developed. This consisted of a sub-set of tests from the overall armory that probed the widest range of cognitive demands on the ground-based soldier. This battery was used successfully by ARL in several field studies, including a field exercise in 2004, the National Guard and Bureau 2006 Patriot training exercise, and a continued wakefulness study.

A significant enhancement of the existing armory concept was requested by NASA (Houston) in 2007. Dr. Lauren Leviton envisioned a testing approach that could provide predictive capabilities regarding an astronaut’s cognitive capabilities for specific mission activities, as well as providing diagnostic and remediation clues for any decrements observed. As a result, a model of human performance was
developed that used the armory tests as a basis for estimating the actual operational impact of a person’s current cognitive capacity. Using the “criticality” of each cognitive skill to the mission, this “Person-System-Mission” (PSM) model developed an overall estimate of the probability of mission success based on the individual’s current measured cognitive readiness. Diagnostic and prescriptive clues are obtained in the PSM model by incorporation of a sub-model for sleep/rest effects on performance, and another sub-model for the performance effects of a given workload schedule.

For the near future, ARL has supported plans for the next version of the ACRA system. In addition to adding all of the remaining behavioral tests to the original ACRA armory, the plan calls for addition of several physiological measures, and their integration with the behavioral measures. Studies indicated that several mature physiological assessment technologies are feasible at this time to achieve this goal while others, while not currently field-usable, should be monitored for new developments. Enhancement of the existing ACRA system will therefore not only expand its applicability to virtually all military and civilian jobs and missions, but will permit exploration of the underlying physiological and metabolic causes of any observed decrement in cognitive capabilities, thus expanding the diagnostic and prescriptive capability of the ACRA system.

ELEMENTS OF THE ACRA SYSTEM

The “Test Battery Generator”

The first step in creating the ACRA system was to develop the capability of generating test batteries that targeted the specific cognitive demands of a wide variety of jobs and missions. Traditional test batteries typically either take a “shotgun” approach to this, incorporating a universal set of tests that hopefully probe the skills of interest, or at best utilize an “armchair” approach to nominally identify the skills of interest. Neither approach provides a quantified audit trail allowing independent investigators to evaluate results adequately.

The “armory” concept described above provided a solution for this. As envisioned by Hunt (1991) and Hunt and Pelliigirino (2002), this approach provides a comprehensive set of tests spanning as broad a taxonomy of cognitive skills as can be identified. The degree to which a given test probes the skills required by a defined mission would then indicate how appropriate that test was in assessing the mission. The task, then was first to create such a taxonomy of cognitive skills, and then to identify an armory of tests that probe those skills. This was done through an extensive survey of physiological, architectural, and functional models of cognition, and a list of 18 cognitive skills was synthesized in a meeting of cognitive scientists (O’Donnell, Moise, and Schmidt, 2005). Based on this list, and on a survey of existing cognitive test batteries, 21 test procedures were identified that appeared to span the taxonomy of cognitive functions. These procedures are listed in table 1. The sub-set of these selected for the original ACRA armory is also shown in that table. It can be seen that most of the tests selected are well-known and validated procedures (e.g., tracking, continuous memory, tower of Hanoi, Wisconsin card sorting, etc.) while some are new tests designed to probe more complex cognitive skills such as problem solving, divided attention, and situation awareness (e.g., NovaScan, rapid decision making, precision timing, etc.). These procedures were programmed, and are currently available for use.

The next step in generating test batteries in the ACRA system is a two-stage process. Since the goal is to relate the test battery to a specific job or mission, it is essential that the cognitive demands of that activity be defined by actual users. This has rarely been done in the past. Engaging the operational user early in test development not only assures content validity, but increases the chance that results will
have face validity and greater acceptance by the user community. In practice, defining such cognitive demands can be achieved in a number of ways, ranging from an exhaustive cognitive task analysis to less structured subject-matter-expert interviews, or even from a study of training manuals or other documents. In any case, the demands of the job are defined in terms of the cognitive taxonomy, and estimates of the criticality of each cognitive skill to the eventual success of the mission are obtained. In the ACRA system, these values are rated on an ordinal scale ranging from “1” (very little importance to the mission) to “9” (catastrophically important).

**TABLE 1**

**TEST PROCEDURES CURRENTLY IN THE FULL ARMORY**

<table>
<thead>
<tr>
<th><strong>TESTS IN THE ACRA BATTERY</strong></th>
<th><strong>ADDITIONAL TESTS CURRENTLY AVAILABLE</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Continuous memory</td>
<td>14. Digit span</td>
</tr>
<tr>
<td>2. Motion inference</td>
<td>15. Match to sample</td>
</tr>
<tr>
<td>3. NovaScan C</td>
<td>16. Mathematical processing</td>
</tr>
<tr>
<td>4. Rapid decision making</td>
<td>17. Sternberg (letters)</td>
</tr>
<tr>
<td>5. Unstable tracking</td>
<td>18. Sternberg (symbols)</td>
</tr>
<tr>
<td>8. Dichotic listening</td>
<td>21. Precision timing</td>
</tr>
<tr>
<td>9. Peripheral information processing</td>
<td></td>
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<tr>
<td>10. Procedural memory</td>
<td></td>
</tr>
<tr>
<td>11. Visual vigilance</td>
<td></td>
</tr>
<tr>
<td>12. Wisconsin card sorting</td>
<td></td>
</tr>
<tr>
<td>13. Relative motion</td>
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</tbody>
</table>

The criticality values from the above exercise are used to form a vector quantifying the unique “cognitive demand signature” of that particular job or mission. If similar vectors describing what each test in the armory measures could be determined, it would become possible to match the demand line with one or more of the measurement lines to select those tests that provide the maximum measurement of the job’s cognitive demand. In fact, this is done automatically in ACRA, using a variation of a procedure originally described by DiBello, Stout, and Roussos (1995), and used by the Educational Testing Service for selecting items in a test. In ACRA, this is called the “T-Matrix”, and consists of assuming that each test in the armory depends on several cognitive skills for its successful completion. In other words, instead of assuming that a test is a uni-dimensional probe of a single cognitive skill (e.g. the Sternberg test measures short-term memory functions) the T-Matrix takes a multi-dimensional approach which recognizes that every test calls on a number of cognitive skills (to varying degrees – again defined on a scale of 1 to 9) for successful performance. By defining the skills and their dependencies for each test in the armory, a matrix of test vs. skills is created. An initial matrix of this type was created at a meeting of cognitive scientists in 2004, and currently forms the basis in the ACRA system for the “test battery generator”. In effect, an optimization algorithm is used to determine which set of tests from the armory optimally and most efficiently matches the “job demand” line of the
T-Matrix. This “battery” is then automatically configured. This “test battery generator” process is shown schematically in figure 1.

![Figure 1. Schematic representation of the test battery generator](image)

**Operational interpretation of ACRA tests**

As noted above, one of the main goals of the ACRA system is to make the output of the tests more operationally useful to the mission planner or field commander. Simply presenting test scores, even if they are in terms of percentiles or decrement from the individual’s baseline, tells the actual user little about what these results actually mean in terms of successful mission completion. This has led to the situation where tests are ignored or, even worse – misinterpreted operationally. ACRA attempts to go beyond the simple score to estimate what that score means in terms of the demand for a given skill in a specific mission. Ultimately, this permits an estimate of the overall impact of the person’s current cognitive status on the mission being performed within a given system or environment. The model carrying out these calculations has been called the **“Person-System-Mission” (PSM)** model (O’Donnell, Moise, and Eddy, 2011).

The reason this is possible in the ACRA system is that the T-Matrix approach breaks the mission’s overall cognitive demand into its component skills. The demand for each cognitive skill in the taxonomy is identified in the process of carrying out the task analysis. Similarly, the degree to which each test in a battery measures that skill is also identified. It is therefore possible to determine the person’s status in each of the skills demanded by a mission.

Although this provides a finer-grained analysis than is available from most test batteries, it is only the starting point for the PSM model. Knowing that a person is degraded in a given cognitive skill does not yet indicate how that degradation will affect the mission. A severe decrement in a skill that is used but not critical to the mission (or that may be easily worked-around) may have little effect, whereas a small
decrement in an absolutely essential skill might be catastrophic. Therefore, the PSM model utilizes the “criticality”, or demand, of each skill as a modulator in order to arrive at an estimate of the true operational impact of a test score on the mission. This is illustrated schematically in figure 2.

![Operational Interpretation of ACRA](image)

**Figure 2. Schematic representation of the PSM model**

At this stage, the output of the PSM model is a second-level analysis of the ACRA test results – one that incorporates each of the mission’s cognitive demands and indicates how “ready” the individual is to meet it. However, it is possible to go one step further in the analysis. Since the above data provide estimates of the subject’s “readiness” in each of the mission’s cognitive demands, weighted by the importance of each one, a logical next step is to amalgamate these estimates into an overall assessment of the person’s current ability to carry out the mission. An algorithm in the PSM model carries out the operation, resulting in a single “score” estimating the probability of the person successfully carrying out the mission.

**Operational feedback in ACRA**

The ACRA system stores and archives all raw data and intermediary analyses so that these will be available for extended study at any time. However, a major focus was to produce feedback data that is easily interpreted in the field or planning center. In this regard, a graphical representation was considered most efficient for summarizing a group of data points such as those generated in calculating the person’s readiness in each of the cognitive skills demanded by a mission. A graphic display of the results of the calculations was therefore incorporated into the PSM model. This display is in the form of a “radar” display, in which the person’s “nominal” performance capacity in each cognitive skill for a mission activity is illustrated at the outer limit of a circle. Figure 3 presents an hypothetical example of what such a display might look like for a mission to “clear and secure” a building. Each cognitive skill is represented as a spoke on a wheel emanating from the circle. The person’s cognitive readiness in each cognitive skill (as measured above) is then represented as a point on the spoke, with “0” being the
center of the wheel. Thus, at a glance, the individual or commander can assess cognitive readiness in each of the cognitive skills required by the mission activity. In addition, the overall estimate of mission success calculated by the PSM model based on these individual capacities is also given on this graph (not shown in the figure).

![PSM Operational Feedback](image)

**Figure 3.** Example of feedback display for an individual’s cognitive readiness to perform a specific mission

### Planned Extensions to ACRA

Under the sponsorship of ARL, three major additions to the current ACRA system have been designed and are ready for implementation. These consist of the addition of two sub-models to the PSM model, as well as the integration of several physiological measures into the system. Addition of the two sub-models will change the PSM model from a static estimate of a person’s current cognitive status to a dynamic, predictive model of future cognitive status. Introduction of physiological measures integrated with the behavioral probes will further the goal of making the entire ACRA system truly a neuroergonomic tool that utilizes brain and other biological processes to study the human “in relation to performance at work and in everyday settings” (Parasuraman, 2011). These enhancements are described briefly below.

**Fatigue/sleep model.** The Sleep, Activity, Fatigue, and Task Effectiveness model within the Fatigue Avoidance Scheduling Tool (FAST) is a well-documented and validated predictive instrument currently used extensively in DoD and civilian applications (Eddy and Hursh, 2006). It permits a user to input a sleep/work schedule for a given period of time, and generates a prediction of the individual’s “performance capacity” for any defined period in the future. With modifications, such a program can
accept the individual’s cognitive status as measured by ACRA, and predict how that will change in the future as a function of the person’s fatigue status.

Workload model. Although there has been an enormous amount of work done studying workload, little data exist on the effects of given workloads on subsequent performance capacity (O'Donnell and Eggemier, 1986). Therefore, a new model of workload/performance effects had to be generated (O'Donnell, Moise, and Eddy, 2011). This model assumes that workload is a multi-dimensional construct in which different “reservoirs”, or types of workload, are depleted at rates determined by the amount of each type of workload being performed. The cumulative level of depletion determines the person’s remaining performance capacity. As with the FAST model, this yields a moment-by-moment modulator of the person’s ACRA-measured cognitive performance capacity.

Together, the two sub-models, when integrated into the PSM, constitute the beginning of a time-based, dynamic, predictive model of human readiness to perform specific missions. They provide the template for later addition of other performance determinants (stress, motivation, etc.). They also provide the user with the opportunity to experiment with alternative sleep/work schedules in order to yield optimum performance in the future.

Physiological measures. A survey of currently available field-usable physiological measurement techniques revealed that several are (or are nearly) ready for practical implementation. Most notably, actigraphy has developed to the point that it is not only usable in operational settings, but also that it is capable of providing data in addition to simple movement assessment. For instance, the Safety Watch® can record many physiological measures from the wrist, including heart rate, temperature, humidity, and light level, as well as activity. From these measures, the on-board software can compute core temperature, sleep, and a physiological stress index. Further, using telemetry, the data can be downloaded to a computer for deeper analysis including heart rate variability. From these signals, a number of other physiological systems can be assessed, including heart rate and respiration. The hardware and capabilities of this system are described in some detail in Russo, Vo, Labutto, et al (2005).

Similarly, it was found that measurement of eye behavior could provide significant data on an individual’s information processing capabilities and approach, and that biochemical measures such as sodium amylase could provide psychological state assessments to serve as adjuncts for interpreting behavioral changes.

Final incorporation of these time-based models and physiological metrics into ACRA and the PSM model will provide a comprehensive picture of the person’s cognitive capacity and readiness to perform any mission in the context of any system.

REFERENCES


