INVESTIGATION OF INFORMATION PROCESSING AND COGNITIVE PERFORMANCE CAPACITIES WITH DIFFERENT INSTRUMENTATION CONFIGURATIONS

by

SAJU JOHN MATHEW

Presented to the Faculty of the Graduate School of
The University of Texas at Arlington in Partial Fulfillment
of the Requirements
for the Degree of

MASTER OF SCIENCE IN BIOMEDICAL ENGINEERING

THE UNIVERSITY OF TEXAS AT ARLINGTON

May 2007

Dedicated to my parents

ACKNOWLEDGMENTS

The author wishes to express his heartfelt gratitude to his supervising Professor Dr. George V. Kondraske for providing many invaluable insights into the theory and practical advise on the implementation. It’s been a real learning experience, his constant patience and support have been inspirational. The author would also like to thank Dr. Hanli Liu and Dr. William E. Dillon for serving on the author’s thesis committee and providing their advice when needed.

Thanks to Mr. John Stevens for the help he rendered in troubleshooting the system as and when required and also for his helpful hints.

I deeply appreciate the efforts my subjects put in to volunteer on such short notice at a busy time during the semester.

The author would like to acknowledge the support of the HPMM project by the Human Performance Institute, the Human Performance Laboratory at Presbyterian Hospital of Dallas, and the Horace Cabe Foundation. In addition, the generous support of the investigation of situational awareness measures by Mr. Charles Sitter is greatly appreciated.

Finally, the author would like to express his gratitude for the support and encouragement given by his family and friends.

December 15, 2006

ABSTRACT

INVESTIGATION OF INFORMATION PROCESSING AND COGNITIVE PERFORMANCE CAPACITIES WITH DIFFERENT INSTRUMENTATION CONFIGURATIONS

Publication No. ______

Saju John Mathew, M.S.

The University of Texas at Arlington, 2007

Supervising Professor: Dr. George V. Kondraske

The focus of this thesis is the investigation of two new performance capacity tests related to a concept known as "situational awareness": 1) Visual Motor Multitask Performance Capacity (VMMPC) and 2) Visual Auditory Information Processing Dexterity (VAIPD). These represent major components of human information processing and are therefore important in situations ranging from driving and other activities of daily living to occupational and sport tasks. These tests have been recently designed and implemented on a laboratory-based instrument called the BEP I. In the present project, they are implemented on a different, more portable platform that is under development and known as the Human Performance Multimeter (HPMM).

Both lab-based and HPMM implementations of the tests were evaluated for reliability and evidence of validity in an experiment involving twenty healthy adult volunteers (10 males, 21 to 60 years, mean – 28.6 years; 10 females, 22 to 27 years, mean – 23.9 years). A test-retest paradigm was used. Good test-retest reliability (repeatability) was obtained for both implementations ($r > 0.70$) for most measures and VAIPD reliability generally better than VMMPC reliability. Performance capacity values obtained from the HPMM were found to be comparable to those obtained with the BEP I. VAIPD measures did not correlate with VMMPC results, suggesting that each test measures a different capacity. It is concluded that the current test designs are fundamentally sound and that these tests hold promise for efficient characterization of important performance capacities. that may eventually impact neurology, physical therapy, rehabilitation, vocational, and other domains where human information processing is of interest.

TABLE OF CONTENTS

Chapter

Appendix

LIST OF ILLUSTRATIONS

LIST OF TABLES

CHAPTER 1

INTRODUCTION

The study of human performance and measurements associated with it have been of interest in a wide range of disciplines for many years (Kondraske, 2006). Almost any task, when coupled with instructions that specify maximal performance, can be used as a test of human performance. This, in part, has contributed to the development and introduction of a number of different tests, many times without consideration of broader purpose and key issues. Kondraske recognized the lack of a conceptual framework to guide the approach to performance measurement and to organize the many different types of measurements that are of interest. This led to the development of General Systems Performance Theory (GSPT) and the Elemental Resource Model (ERM) for human performance (Kondraske, 1995; Kondraske, 2006), which have enabled a more rigorous and structured approach to measurement of human performance capacities. A wide variety of performance capacity measurement systems and modeling tools have been developed using this approach, covering many different performance capacities of different human subsystems and targeting several different application environments. The consistent use of key constructs across all tests and measures incorporated in these systems is unique in the field. In this thesis, two new tests associated with human information processing, and specifically the notion of situational awareness, are investigated.

1.1 Background: The Human Performance Capacity Measurement System

While many researchers have contributed to performance measurement, few have addressed issues that pertain to integrating an array of performance measurements into a single system that covers a broad scope of human subsystems. Since developments in this context shape criteria for new tests, relevant history in this area is reviewed.

Initial work done by Potvin, Tourtellotte, Syndulko and colleagues dating from the late 1960s brought out the necessity of quantifying what was then termed "neurologic function" (Potvin et al, 1985). They investigated and established many basic methods and the first subset of devices for a "neurofunction laboratory", and addressed key issues of measurement quality such as reliability, validity, age and gender effects, and subject motivation. Tests of sensation, motor performance, and information processing performance were included in their battery.

A first generation computer-based measurement system was developed by Kondraske as the focus of his dissertation research (Kondraske, 1982; Kondraske et al, 1984). A new set of specially designed instruments were incorporated that implemented modified versions of test items in Potvin and Tourtellotte's neurofunction laboratory, as well as new items that broadened the measurement scope of what was still called a "neurologic function" measurement system. A key aspect of this work was the decision to place primary emphasis on items which could be viewed as being "application independent"; i.e., those items which reflected more intrinsic characteristics (e.g. strength, speed, etc.) of human subsystems. This is contrasted with approaches that look more toward performance of the individual in relatively complex higher level tasks such as gait or activities of daily living. As stated by Kondraske (Kondraske, 1990):

> “The rationale employed was that there are an infinite variety of such higher level tasks and combinations of them (leaving content of the measurement system always open to debate), while there is a finite set (albeit large) of the more intrinsic characteristics associated with a fairly well defined set of subsystems.”

The "application-independent" philosophy served as the basis for expansion of the basic system to include modules that met broader needs within rehabilitation. Also, Kondraske noted that professionals from a variety of different disciplines (neurology, orthopedic surgery, physical therapy, occupational therapy, and psychology) helped to identify measurement issues that existed across these disciplines (Kondraske, 1990). Reflecting these circumstances, the name applied to describe the overall measurement system evolved from "neuro-function laboratory" (Kondraske, 1984) to "sensori-motor performance laboratory" (Smith and Kondraske, 1987), and then to "human performance" (Kondraske, 1987a). Important factors considered for the design of each test incorporated into this integrated measurement system were the amount of time that can be devoted to each test and the need for measurements to be internally consistent; i.e., to agree with a set of common philosophies.

Observations supporting the need for an improved conceptual framework for human performance measurement are detailed elsewhere (Kondraske, 1987a; Kondraske, 2006a). One of particular relevance here was the observation that in situations where multiple performance-related measures were employed (Fleishman and Quaintance, 1984), no clear distinction was made with regard to the hierarchical level within the human system addressed by such measures. Measures associated with different levels were often mixed together and treated essentially in the same fashion. As noted previously, as a result of this and other observations, GSPT and the ERM for human performance (Kondraske, 1987a; Kondraske, 1987b; Kondraske, 2006a) were introduced in 1987.

GSPT and the ERM motivated a review of what was now called the Human Performance Capacity Measurement System (HPCMS) and revision of many of its components and techniques employed in order to take advantage of new insights, which are further discussed below. As noted by Kondraske (Kondraske, 1990):

> "This not only changed the nature of our research, but also dictated the need for subtle but important transformation of measures as well as improved definition of measures and protocols under which they are acquired (third generation system)."

The current HPCMS is a result of more than 25 years of developmental effort and the 20 different modules that comprise it are collectively capable of acquiring over 400 different measurements. These measures all have been carefully defined or redefined to conform with GSPT constructs and address performance capacities of sensory, motor, information processing, and cognitive subsystems. A subset of the prototype devices are commercially available through Human Performance Measurement Inc., Arlington, Texas. Users can select specific modules appropriate to their application which are integrated into a seamless system via software running on a single host personal computer. These commercially available versions are in use in 13 countries in a wide variety of application contexts (Kondraske, 2006b).

1.2 The Human Performance Multimeter

The HPCMS is essentially considered a lab-based system. While most modules exhibit a degree of portability, the system is generally set-up in a room and bears the typical characteristics of a laboratory. Driven by new technology that offers the promise to make anything and everything in a compact, pocket sized form with all features intact, an instrument dubbed the Human Performance MultiMeter (HPMM) was proposed (Kondraske, 1992). The HPMM concept is consistent with the notion that no general single performance test can be used to characterize a subject's overall capacity. Instead a battery of tests is required. Whereas the HPCMS is considered to be lab-based, the HPMM is characterized as being primarily clinic-based (Kondraske, Mulukutla, and Stewart, 2006). It is desired to integrate as much of the measurement functionality of the HPCMS into the HPMM as is feasible, allowing for reasonable trade-offs in measurement fidelity when appropriate. Table 1.1 summarizes the development history of the HPMM.

Table 1.1 Summary of HPMM Development Milestones

Year	Development Status	Context
1992	First conceptualization of HPMM	Small Business Innovative Research Grant Proposal (Kondraske, 2002)
1996	Version 1.0 Design and Prototype based on the 1992 proposal. Definition of key operational modes, partial functionality, limited implementation of specific tests bench top realization (no packaging issues addressed).	Senior capstone design course in Electrical Engineering – Spring semester
2000	Version 2.0 Design and Prototype: Two successive total system designs were worked on, partially implemented and tested. It led to the preliminary realization of version 3.0 of the HPMM.	Senior capstone design course in Electrical Engineering – Spring semester
2002	Version 3.0 Design, Implementation of Five Tests and Human Subject Testing: First formal human subject tests for generic performance capacity tests (isometric strength, simple response speed, rapid alternating movement quality, upper extremity neuromotor channel capacity, and steadiness/tremor)	EE Master's Thesis (Sriwatanapongse, 2002)
2002	Version 4.0 Hardware Platform Design and Preliminary Prototype: More powerful processor, low power, increased display capacity, touch screen, enhanced sensor, "near final" portable packaging.	Senior capstone design course in Electrical Engineering – Fall semester
2005	Version 4.0 Hardware with Implementation, Enhancement, and Evaluation of V3.0 Tests": Implemented the five V3.0 tests on the V4.0 hardware platform. Conducted rigorous evaluations.	EE Master's Thesis (Mulukutla, 2005; Kondraske, Mulukutla, and Stewart, 2006)

In the latest effort (Mulukutla, 2005; Kondraske, Mulukutla, and Stewart, 2006), the five tests implemented were isometric strength, simple response speed, rapid alternating movement quality, upper extremity neuromotor channel capacity, and steadiness/tremor. These were evaluated experimentally with 20 healthy subjects for reliability and preliminary validity. Very good test-retest results have been found for all measures except for neuromotor channel capacity. For that measure, it was recommended that the final measure be based on more than just two trials. In addition, it was noted that the healthy subject group involved in the study is a worst case evaluation of repeatability since subjects exhibit a rather narrow range of performance. Thus, with minor concern about that one test, the researchers concluded that the HPMM measures evaluated have demonstrated good reliability and acceptable validity.

1.3 General Systems Performance Theory and Performance Capacity Measurement

As mentioned previously, following the introduction of GSPT and the ERM, all performance capacity measures incorporated into the HPCMS and the HPMM were designed using constructs of GSPT. Given that two new tests and associated measures are being evaluated in this thesis (see Chapter 2), it is useful to review these aspects of GSPT. The following is excerpted from a recent publication that sets forth these constructs (Kondraske, 2006):

1. Use a **resource construct** to model the system's *performance*. First, consider the unique intangible qualities that characterize *how well a system executes its function*. Each of these is considered to represent a unique **performance resource** associated with a specific **dimension of performance** (e.g., speed, accuracy, stability,

smoothness, "friendliness", etc.) of that system. Each performance resource is recognized as a *desirable* item (e.g., endurance vs. fatigue, accuracy vs. error, etc.) "possessed" by the system in a certain quantitative amount. Thus, one can consider *quantifying* the amount of given *quality* available. As illustrated, an important consequence of using the resource construct at this stage is that confusion associated with duality of terms is eliminated.

2. Looking toward the system, identify all "I" dimensions of performance associated with it.

3a. Keeping the resource construct in mind, define a parameterized metric for each dimension of performance (e.g. speed, accuracy, etc.). If the resource construct is followed, values will be produced with these metrics that are always non-negative. Furthermore, a larger numerical value will consistently represent *more* of a given resource and therefore *more* **performance capacity**.

3b. Measure system performance with the system *removed from* the specific intended task. The general strategy is to *maximally stress* the system (within limits of comfort and/or safety, when appropriate) to define its **performance envelope** or more specifically, the envelope that defines *performance resource availability.* Also note that unless all dimensions of performance and parameterized metrics associated with each are defined using the resource construct, a performance envelope cannot be guaranteed.

3c. Define estimates of single-number *system figures-of-merit*, or **composite performance capacities**, as the mathematical product of all or any selected subset of performance resource availabilities (i.e. performance capacities) associated with the system.

It is clear from these statements that the targets of testing are performance capacities. Therefore, such tests are called performance capacity tests and not merely performance tests. Each of the performance capacity tests included in the HPCMS and HPMM consists of a special, brief “test task” which is designed to isolate (to the maximum degree possible) a given system at a given hierarchical level (i.e., basic element or generic intermediate level of the ERM) and maximally stress that system along one or more dimensions of performance while time series data is collected. The term “maximally stressed” is implemented via careful test instructions to the subjects. In general, this is accomplished with phrases such as “as fast as you can”, “as hard as you can”, etc. Time series data is processed via a variety of parameterizations (specific to different types of tests) to produce single number results that represent *availability of the isolated performance resource* (e.g. visual information processor speed) or resources (e.g., speed and accuracy). This type of paradigm is generally known as a maximal capacity test.

1.4 Objectives

The ERM suggests a hierarchical model for human performance that has specific rules for achieving an exhaustive definition of what are termed the basic elements of human performance and generic intermediate level performance capacities. One consequence of this is that existing performance capacity measurements and tests can be mapped to these items and gaps in measurement capability can be identified. Recently, this led to the identification of performance capacities, considered to be at the so-called "generic intermediate level" of the ERM, related to what is generally known as "situational awareness". In turn, two new tests have been proposed and subsequently implemented on an existing module within the HPCMS (Kondraske and Vijai, 2004):

1) Visual-Motor Multi-task Performance Capacity (VMMPC), and

2) Visual-Auditory Information Processing Dexterity (VAIPD)

These have been implemented on a module that is part of the HPCMS referred to as the "BEP I - Central Processing and Upper Extremity Motor Control Performance Capacity Measurement System". However, these tests have not yet been systematically evaluated. Thus, the objectives of the thesis are as follows:

1. Review the design and implementation of the VMMPC and VAIPD tests on the BEP I and enhance documentation as necessary.
2. Define an implementation of the VMMPC and VAIPD tests on the HPMM, attempting to achieve a result that closely mimics that of the lab-based implementation on the HPCMS's BEP I module.

3. Develop appropriate software for the HPMM that implements the VMMPC and VAIPD tests and add this to the previous version (version 4.0) of the HPMM to yield version 4.1.
4. Evaluate the test-retest repeatability of the VMMPC and VAIPD measures on both the HPCMS and HPMM platforms.
5. Carry out an initial comparison of results obtained for the VMMPC and VAIPD tests with the HPMM to those obtained with the HPCMS (BEP I).
6. Discuss the conclusions and recommendations for future work.

CHAPTER 2

MEASUREMENT CONCEPTS AND TEST DESIGNS

2.1 Overview

This chapter reviews additional background that is specifically related to the need for and conceptualization of the two tests under investigation. In addition, the BEP I hardware platform and how it has been utilized to realize preliminary versions of VMMPC and VAIPD tests is presented. This serves as the basis for implementation of these tests on the HPMM platform, which is detailed in Chapter 3.

2.2 Situational Awareness

"Situational awareness" (SA) is a term that originated in the human factors field, initially in the context of military aircraft pilot performance. Recognizing this as a more intrinsic aspect of human performance that is drawn upon in numerous situations, it has also been discussed in the context of driving automobiles (Walker, Stanton, and Young, 2006) and other similar situations. There are enigmatic aspects to this term reflecting the fact that it represents a more complex, and not basic, hierarchical level of human performance (Wikipedia, 2006):

"Despite its popularity and ubiquity there is much debate within the scientific literature about what SA is, how it works and whether we need such a concept at all."

Even though controversy exists, Endsley is credited with proposing the most established definition of SA currently (Endsley, 1988):

> "Level 1 - perception of elements, Level 2 - comprehending what those elements mean and Level 3 - using that understanding to project future states."

It appears that most of the controversy pertains to the Level 3 aspect of Endsley's definition, implying that it may be "something different" to be aware of what is going on around you and having the expertise to know what is likely to happen next.

Another insightful comment has been offered (Sarter and Woods, 1995):

> SA "should be viewed as a label for a variety of cognitive processing activities that are critical to dynamic, event driven and multi-task fields of practice"

SA is thus some type of human performance capacity involving information processing and multi-tasking. The motivation and initial basis for the VMMPC and VAIPD tests as a means to address the broader notion of the capacity of the human information processing system to "be aware of situations" has been described as follows (Kondraske and Vijai, 2004):

> "When disease or injury reduces the capacity of an individual to process multiple stimuli and manage multiple tasks simultaneously, it is observed that such individuals are often said to be "more distractible" or "lack the ability to concentrate". Our approach to understanding and measuring human performance focuses on identification of the desirable system characteristics (e.g.,

> "performance resources") that underlie such observations. That is, when an individual's "visual motor multi-tasking ability" or "visual information processing dexterity" falls below a certain threshold level, they are likely to be distractible to a degree that places them at great risk when executing certain high risk tasks. Another way to consider this is in terms of the ability to manage (i.e., prioritize) multiple types of information simultaneously while continuing to ensure a minimum level of performance on a primary task."

From this discussion, it is clear that GSPT concepts are being used to define two specific performance resources associated with "more complex" information processing (relative to more basic information processing tasks): 1) visual motor multi-task performance capacity and 2) visual auditory information processing dexterity. These terms do not reflect prediction ability. However, the terms themselves do involve "perception of elements" (Level 1), where the elements are objects in the environment – including visual and auditory objects. It is also implied, as will be more evident, that the evaluation of these capacities would require a "comprehension of the meaning of the elements" (Level 2). Therefore, these capacities are considered to encompass Level 1 and Level 2 of Endsley's definition of situational awareness. Kondraske indicates that it is more consistent with the constructs of GSPT and ERM to identify components of a very complex process and develop means to measure these "intermediate level" performance resources (Kondraske, 2006).

2.3 Relevant Single-Task Test Paradigms

2.3.1 Single-Task Information Processing Performance Capacities

The HPCMS platform presently incorporates several tests of this type. One is termed “Simple Visual-Hand Response Speed”. These tests reflect a class of tests more commonly referred to as reaction time tests (Kondraske and Vasta, 2002). They involve responding “as quickly as possible” to some type of stimulus (e.g., visual, auditory, etc.)

in some specified manner (e.g., moving a body segment). The stimulus is required to have a low information load and thus requires minimal cognitive processing. This gives rise to the characterization of the test as “simple”, which also distinguishes it from other tests of information processing speed and places the test at the “basic element” level of the ERM.

Hick’s Law is stated as follows (Hick 1952):

$$\text{Reaction Time} = k_1 + k_2 \log_2 (n) \qquad \text{(Eq 2.1)}$$

where “n” is the number of choices involved in the task to which the subject must respond. The BEP I incorporates Hick’s Law by including multi-choice reaction time type tests (e.g., 2, 4, and 8 choice information processing loads).

These types of tests have long been used to characterize subjects with neurologic diseases (Potvin et al, 1985) as well as individuals who have sustained traumatic injuries such as concussions or other head injuries. They are also useful in detecting and characterizing neurologic side-effects of drugs (Callaghan et al, 1997). However, all reaction time test scenarios have been reconsidered in light of GSPT and are consequently now identified as “information processing speed” test paradigms when they are included in the HPCMS (Kondraske, 1990) and HPMM (Kondraske, Mulukutla, and Stewart, 2006) systems. This reflects the requirement to conform with the GSPT construct that performance measures must reflect desirable “performance resources”. While reaction time in ms is measured in the course of basic data acquisition, these measures are transformed to units of “responses/s” by inverting the reaction time to reflect a true measure of speed. This result also has the required characteristic that a numerically larger value reflects greater performance capacity.

Both the HPCMS (BEP I) and HPMM have incorporated tests of this type, which are considered to be at the “basic element” level within the ERM. These elements are also considered to be in the “Central Processing” domain of the ERM. This type of test is utilized to realize the VMMPC and the VAIPD test paradigms, as described in subsequent sections.

2.3.2 Neuromotor Channel Capacity

In 1954, Fitts introduced (Fitts, 1954) what has since become to be known as the relationship between speed, accuracy, amplitude of movement, and target size for upper extremity tasks. This was derived using basic information theory constructs of Shannon

(Shannon, 1948). The mathematical statement of what is now called Fitts' Law was defined originally only for translational motion in one dimension.

Fitts' work was not intended to produce a “measurement protocol”. In contrast, it was an experimental attempt to understand human motion in a more quantitative manner. In his experiment, subjects held a stylus in their hand and were asked to move alternately between targets as fast and as accurately as possible. Performance was controlled (i.e., results were filtered) to achieve a 96% accuracy rate; i.e., indicating that the system isolated (e.g., the neuromotor aspects associated with the upper extremity) was being maximally stressed with respect to both speed and accuracy dimensions of performance (using GSPT terminology). Target-to-target movement time (t_m) was measured. Target width (W) and movement amplitude (A) were varied across a series of experimental trials with different subjects. He found that data fit the relationship that is now known as Fitts' law. One way it is expressed is as follows:

$$\text{IP (bits/s)} = -\,(1/t_m)\,\log_2(W/2A) \qquad \text{(Eq 2.2)}$$

IP (dubbed by Fitts as the "Index of Performance") was shown to be relatively constant across a range of W and A values for a given subject. Kondraske and colleagues have adapted Fitts' Law for use in performance capacity measurement and termed the result to be a measure of “neuromotor channel capacities” (Potvin et al, 1985; Kondraske, 1990). The commercially available Model BEP I measures central processing and upper extremity neuromotor control performance capacities, including NMCC. It has been used and evaluated by others with a wide range of subjects (Swaine and Sullivan, 1992; Swaine and Sullivan, 1993; Kauranen and Vanharanta, 1996).

More recently, Kondraske used General Systems Performance Theory to approach Fitts' law from a different perspective (Kondraske, 1999; Kondraske, 2000). It was found that a near-perfect correlation existed between Fitts' Index of Performance and the mathematical product of movement speed (expressed as motions/s) and accuracy (expressed as percent accurate motions) in hitting fixed width (W) targets with a fixed separation distance (A). An almost exact prediction was obtained by scaling the product using a version of Fitts' task difficulty index. This provides a statement of Fitts' Law in a form that has greater utility in that it actually includes speed and accuracy variables:

$$\text{NMCC (bits/s)} = \log_2((A/W)+1) \times \text{Speed} \times \text{Accuracy} \qquad \text{(Eq 2.3)}$$

The logarithmic term is equivalent to Fitts' "Index of Task Difficulty" and is a constant for fixed target widths and separation.

Both the HPCMS and HPMM have incorporated versions of the NMCC test. This test will contribute to the implementation of the VMMPC test, as described below.

2.4 Multi-Task or Divided Attention Test Scenarios

An approach sometimes used in human performance measurement contexts incorporates a multi-task (usually dual-task) scenario that is designed to require use of attention resources in two different simultaneously executed tasks (e.g., see Wickens, 1984). This is also called a divided attention scenario. For example, visual tracking accuracy (primary task) and speed of response to an embedded visual stimulus (secondary task) can be measured. Details of the potential time sharing possibilities at play can be quite complex (Schneider and Shiffrin, 1977). Multi-Task scenarios are obviously related to comments made previously in section 2.2 regarding situational awareness.

In comparison to single-task performance test situations, in which the attention processor may not be working at capacity, the demand is designed to increase (relative to a single-task baseline reference) and this theoretically maximizes the stress on attention performance resources. Performance on both primary and secondary tasks, compared to levels attained when each task is independently performed, can provide an indirect measure of capacity associated with attention (Parasuraman and Davies, 1984). This approach has been useful in determining relative differences in demand imposed by two different primary tasks by comparison of results from respective tests in which a fixed secondary task is used with different primary tasks. Of more direct relevance to the present context, an appropriate secondary task can be used to control in part the conditions under which a given performance capacity (defined in a standard way and measured in association with the primary task) is measured; e.g., visual information processing speed can be measured with no additional attention load or with the presence of an added attention load level.

2.5 Implementation of VMMPC and VAIPD Tests on the BEP I Platform

The background thus far provided the basis for the definition of the VMMPC and VAIPD tests and their implementation on the BEP I platform (Kondraske and Vijai, 2004). The BEP I platform and the implementation of these tests on this platform are now described.

2.5.1 BEP I Platform Description

The BEP I, which is used to measure a wide range of performance capacities associated with central processing and upper extremity motor control, is shown in Figure 2.1 below. Eight high intensity red lights (LED1-LED8) are used for visual stimuli and an audible "BEEP" is used as an acoustic stimulus (e.g., to get subjects ready for trials, to announce the end of trials, etc.). Responses are sensed by one or more of fifteen touch sensors that are separated into two regions (A and B) on the module.

Figure 2.1 BEP I Identification of stimulus lights and response touch plates (Kondraske and Vijai, 2004)

In the center of the module, eight touch sensors A1-A8 are arranged in a semi-circle around a ninth sensor referred to as the “HOME” sensor. The eight sensors forming the semi-circle are individually paired with a corresponding LED; i.e., LED 1 is grouped with A1 etc. The front region of the module (nearest to the subject) contains six additional touch sensors, B1-B6. All of the touch sensors have the ability to respond with very high speed, which is necessary to achieve the desired level of accuracy of measurement. The BEP I contains its own microcontroller that manages all activities during the execution of a given test and then communicates test results to the host PC. A wide range of sophisticated, proprietary algorithms is incorporated in the software that runs this microcontroller. These algorithms allow the module to adapt to a wide range of test subjects (including those with pathologic conditions such as tremor) and are optimized to produce high quality measurements.

2.5.2 BEP I implementation of the VMMPC Test

A brief description is given here on how this test is implemented and conducted on the BEP I. The test is designed using a dual-task scenario and incorporates a primary and a secondary task, building fundamentally on the NMCC test (as the primary task) that is well-established within the HPCMS.

One test trial of “the test” as a whole lasts for 15 seconds. The primary task consists of the subject performing a task that is identical to that utilized for the NMCC test. This requires the subject to move his hand and arm to properly position his index finger to strike the targets (touch sensors B2 and B5) in an alternating fashion (see Figure 2.1). Movement is initiated either from Left-to-Right or from Right-to-Left depending on the subject’s preference. This task is to be performed with a combination of maximum speed and accuracy.

In addition to the primary task, the subject is instructed that a secondary task is also incorporated that must be executed along with the primary task. This involves responding to the presentation of a visual stimulus (i.e., the lighting of either LED 4 or LED 5) as quickly as possible. The proper response is to touch either touch sensor A4 (if LED 4 is lighted) or A5 (if LED 5 is lighted) using the finger tips of the same hand involved with the execution of the primary task. Thus, when responses are made to the secondary task, primary task execution must be interrupted temporarily. The maximum time allowed for a response to the LED stimulus is 3000 ms. If the subject contacts the wrong touch sensor (i.e., A4 if LED 5 is lighted) or does not respond with in the maximum allowed time, the response is considered to be an error. Trials of the secondary task are interspersed at random time intervals ranging from 1.5 to 3.0 seconds during the 15 seconds test. This inter-trial timing for the secondary task, along with the time required to respond to a secondary task stimulus, typically results in about five or six secondary task trials during a test.

The final results include performance measures for both primary and the secondary tasks. For the primary task, NMCC is computed as follows:

$$\text{NMCC (bits/s)} = \text{Index of Task Difficulty x Speed x Accuracy} \qquad \text{(Eq. 2.4)}$$

where speed is expressed in motions/s and accuracy is expressed as a percentage of the lateral motion attempts that resulted in target "hits" (i.e., 0 to 100). The Index of Task Difficulty (ID) used is given by:

$$\text{ID (bits)} = \log_2((A/W) + 1) \qquad \text{(Eq. 2.5)}$$

where A = amplitude of movement = center-to-center target separation and W = target width. ID is a constant for a given test instrument design. For the BEP I, A = 40.6 cm and W = 1.6 cm. Therefore, the value of ID = 4.721 bits.

The secondary task is basically a choice reaction time paradigm (see section 2.3.1) and therefore Hick's Law is of interest. As in Hick's Law, the information load (I) expressed in “bits” is related to the probabilities of choices. For equiprobable choices with probability p, it is given by:

$$I \text{ (bits)} = -\log_2(1/p) = \log_2 \text{ (number of choices)} \qquad \text{(Eq 2.6)}$$

Since the number of choices for the secondary task is two (i.e., one of two possible lights is randomly selected to light), I = 1.

$$I \text{ (bits)} = \log_2 (2) = 1 \qquad \text{(Eq 2.7)}$$

Dividing this by the measured reaction time (RT) provides an estimate of visual information processing speed (VIPS):

$$VIPS = I/RT = 1/RT \qquad \text{(Eq. 2.8)}$$

Accuracy, in percent, is also computed across the number of trials of the secondary task embedded in the overall test scenario. The final score for the secondary task is a type of visual information processing capacity (VIPC) and is computed using GSPT concepts as the product of speed and accuracy, with accuracy expressed numerically as 0 to 1.00:

$$VIPC = VIPS \times Accuracy \qquad \text{(Eq. 2.9)}$$

Table 2.1 Results sent to the host PC after completion of the VMMPC test on the BEP I

Result	**Computation**
Primary Task: Movement Accuracy (%)	(Number of Accurate Responses / Total Contacts) %
Primary Task: Movement Speed (cm/s)	(Total Contacts * 15.24)/Test Duration
Primary Task Main Score: Neuromotor Channel Capacity (bits/s)	Movement Accuracy (%) * Movement Speed (motions/s) * 4.721(Index of Difficulty)
Secondary Task: Response Accuracy (%)	(Number of Correct Responses to Secondary Task / Total Secondary Task Trials) %
Secondary Task: Processing Speed (bits/s)	Average of (1 bit / (Reaction Time for each Secondary Task))
Secondary Task: Visual Information Processing Capacity (bits/s)	Response Accuracy * Processing Speed (Secondary Task Measures)

2.5.3 BEP I implementation of the VAIPD Test

This test is based on the multi-choice visual information processing speed paradigm that was mentioned previously (see section 2.3.1). The BEP I currently has visual information processing speed tests with 1, 2, and 3 bit information loads (2, 4, and 8 equiprobable choices). For a given test mode, a series of test trials is performed in rapid succession. Each such test trial has the same operational rule. For example (refer to Figure 2.1), in the 8 choice test mode, LEDs 1 through 8 are involved. The subject starts with the fingertip of their hand placed on the HOME touch sensor. When the visual stimulus is presented (i.e., one of the LEDs is lighted), they must respond by touching the sensor (A1-A8) directly in front of the lighted LED. Thus, the rule is *always*: “respond by moving your hand from the HOME touch sensor to the touch sensor associated with the LED that is lighted.” Not only is the rule *always the same* across a series of test trials comprising a test, but the rule represents a natural tendency. That is, it is *intuitive* to touch the sensor directly in front of the lighted LED.

The concept of the VAIPD test is revealed by its name. It was desired to increase stimulus complexity to include both simple visual and auditory elements. In addition, it was also desired to increase the demand on coordination of: 1) processing of sensory information, 2) remembering an *incrementally more complex set of response rules*, and 3) producing an appropriate motor response. This complex coordination gives rise to the "dexterity" component of the test name.

In this test, a small set of "situations" are defined by a *combination* of visual and auditory stimuli. Each situation has its own response rule. For a given stimulus presentation, a situation is randomly selected from the pre-defined set. The subject must recognize a situation when the stimulus is presented and communicate that a specific situation was recognized by responding according to the proper rule. Rules are provided to the subject beforehand as part of the test instructions.

Four different situations and associated responses have been defined for this test, as summarized in the table below.

Table 2.2 Situations with their associated stimuli and required responses on BEP I implementation of the VAIPD test

Situation	Stimulus	Required Response
1	LED 4 lights without a BEEP	Subject moves finger from HOME touch sensor to touch sensor in front of LED 4 (i.e., sensor A4) as quickly as possible
2	LED 5 lights without a BEEP	Subject moves finger from HOME touch sensor to touch sensor in front of LED 5 (i.e., sensor A5) as quickly as possible
3	LED 4 or LED 5 lights with a BEEP	Subject moves finger from HOME touch sensor to touch sensor in front of LED 4 (i.e., sensor A4) as quickly as possible
4	A combination of any two LEDs from 3 to 6 light with or without a BEEP sound	Subject keeps his finger on the HOME touch sensor

Note that Situations 1 and 2 have intuitive responses, much the same as in the multi-choice Visual Information Processing Speed test. Situation 3 now adds a brief audible beep to the stimulus and, regardless of which LED is lighted, the subject must always move his/her hand from the HOME touch sensor to the touch sensor in front of LED 4. When LED 5 is lighted in situation 3, this requires suppression of the intuitive response and execution of the non-intuitive response that is dictated by the response rule. Similarly, in Situation 4, regardless of the stimulus, the subject must suppress the natural tendency to respond by moving, which would involve moving from the HOME sensor to one of the other touch sensors, and keep their fingertips on the HOME sensor.

As currently defined, a single test trial consists of 24 stimulus intervals. A pseudo-random sequence is used to determine which situations will be presented in random fashion. The pseudo-random sequence is designed so that: 1) each situation is presented six times over the course of the 24 stimulus intervals, and 2) no situation can be repeated more than twice consecutively. The test starts with a single audible beep and then the first stimulus interval is initiated. The first part of each stimulus interval consists of a random (2 to 5 s) time segment called the stimulus foreperiod. At the end of the foreperiod, the stimulus is presented and reaction timing is started. Then, the subject is allowed up to a maximum of 3 s to respond. For Situation 4 (which requires that the subject stay on the HOME touch sensor), the subject's response is also monitored for 3 s if he or she appears to be responding correctly (and less if the subject mistakenly moves). For any of the four situations, movement from the HOME touch sensor marks the end of the reaction time period. For Situations 1, 2, or 3, movement timing is then started. Movement timing ceases when the subject touches any of the "A" sensors (i.e., A1 through A8) or after the expiration of a 3 s maximum movement time.

For Situations 1, 2 and 3, the BEP I's microcontroller waits for the subject to return his or her hand back to the HOME touch sensor and then initiates a fixed inter-stimulus interval of 2.5 s. After this delay, the next stimulus interval is initiated. This sequence repeats until all 24 stimulus intervals have been presented, at which time the BEP I issues a double beep sound to signal the end of the test trial.

If the subject's fingers are not in contact with the HOME touch sensor just prior to the presentation of stimulus, it is considered as an "anticipation error" and that particular stimulus interval is re-initiated.

Measures of information processing speed and accuracy (percentage of correct responses) are computed for the 18 stimulus intervals corresponding to Situations 1, 2, and 3.

For information processing speed computation in this context, Hick's Law is also applicable. However, it is clear that the information load associated with each situation is different (which is in contrast to the circumstances present with the multi-choice visual information processing speed test). In addition, the information content (or load) for all situations is not known at present. If this was known, the information processing speed would be calculated as discussed previously (see Eq. 2.8). Pending separate efforts to experimentally estimate these information loads, an information load of 1 bit is assumed for each situation.

Accuracy associated with a single stimulus interval is simply counted as "correct" or "wrong". In addition, movement speed is computed for the 18 stimulus intervals corresponding to Situations 1, 2, and 3 (15.24 cm/(movement time)), where 15.24 cm is the center-to-center distance between the HOME sensor and any of the "A" touch sensors. Since the subject's hand would not normally move from the HOME sensor in Situation 4, processing speed and movement speed are not computed (nor can they be); only accuracy is considered. Careful thought will illustrate that this is equivalent to using the average processing speed over the 18 "other trials" (i.e., not involving Situation 4) as the processing speed associated with Situation 4.

Thus, there will be 18 individual processing speeds and movement speeds at the end of a test trial and 24 accuracy measures (i.e., correct or wrong response for each situation presented). From these three sets of measurements, several final test measures are computed: 1) average processing speed (over 18 values), 2) average movement speed (over 18 values), and 3) accuracy (over 24 stimulus intervals). The main test score, called VAIPD (with units of bits/s), is computed as the product of information processing speed (bits/s) and accuracy, with accuracy expressed as the ratio of correct to total responses (i.e., a percentage) and numerical values ranging from 0.0 to 1.0.

Table 2.3 Results sent to host PC after the completion of VAIPD test on BEP I

Result	**Computation**
Accuracy (%)	(Number of Correct Responses / Total Situations) %
Processing Speed (bits/s)	The average of (1 bit / (Reaction time for individual task)). Only the first three situations are considered
Movement Speed (cm/s)	15.24 cm / Average of the individual Movement Times for all the 18 situations
Visual Auditory Information Processing Dexterity Score (bits/s)	Accuracy * Processing Speed

CHAPTER 3

HPMM TEST IMPLEMENTATION

3.1 HPMM Platform Overview

As noted previously, all tests incorporated into the HPMM are based on a set of lab-based performance capacity tests developed, evaluated, and used over the last two decades. Analogy is made to a Digital MultiMeter (DMM), which can perform a basic set of generic measurements (e.g., voltage, resistance, etc.). Similarly, when used in its stand-alone mode (Mulukutla, 2005), the HPMM could be used to measure generic quantities such as force, speed, etc. Coupled with predefined test procedures (that pertain to involvement of selected body systems and requiring the subject to emphasize certain aspects of performance), measurements could be obtained that would represent strength of *specific muscle groups* (from force measurements), speed of movement about *specific joints* (from speed measurements), etc.

The HPMM attempts to leverage advancements in sensor, microcontroller, and low-power instrumentation technology to integrate selected, proven aspects of measurement functionality from the modular lab-based HPCMS instruments into a small, easy-to-use package. A detailed description of the latest version of the HPMM hardware platform is provided elsewhere (Mulukutla, 2005). A brief overview of selected aspects of the HPMM is provided here, along with a focus on aspects directly relevant to the implementation of the two new tests.

The HPMM version 4 system consists of the HPMM Main Unit, the Remote Sensor Module (RSM) and the host PC as shown in Figure 3.1. It was designed as a flexible hardware platform that could support the implementation of currently envisioned as well as future performance capacity measurements.

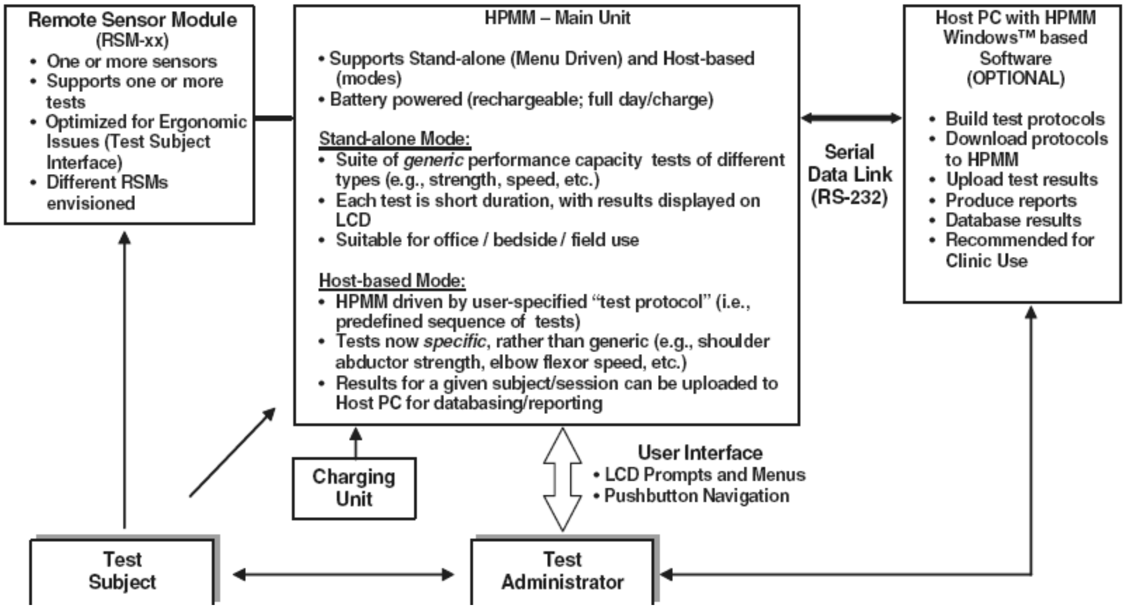

Figure 3.1 Major features of the Overall HPMM System Concept

The main unit (21 cm x 13.9 cm x 3.8 cm) includes: 1) a touch sensitive LCD graphics screen (240 x 128 pixels), 2) an 8051-based high speed, 8-bit microcontroller (Silicon Laboratories C8051F020), 3) a specially configured high speed touch sensor array with nine independently sensed regions, 4) a force sensor (designed into a handle on the main unit), 5) two high-intensity LEDs for high-speed visual stimulus generation,

6) interfaces for a Remote Sensor Module (RSM) and a host PC (for downloads and uploads), and 7) rechargeable battery and related power management circuitry.

The touch sensors are used for sensing subject responses via finger contacts. These sensors must be highly sensitive for accurate measurement. Response speed requirements (i.e., approximately 1 ms maximum) are met by using capacitive touch sensors (using Quantum QT310 and QT320 ICs). These system elements play a major role in the implementation of the VMMPC and VAIPD tests.

The RSM in the current implementation is dubbed "RSM-1" in anticipation of other types of RSMs. RSM-1 contains a dual-axis accelerometer, two inertial angular speed sensors, a microphone (for speech performance), signal conditioning, and a multi-channel 12-bit A/D converter. The RSM is not used in the implementation of the VMMPC or the VAIPD test.

Main components of software include the user interface (i.e., a basic HPMM "operating system") and a set of "generic test algorithms" (GTAs). One GTA is used for each type of performance capacity test. Operating system menus can be navigated and options selected by the use of four virtual buttons on the touch screen. In addition to the stand-alone mode of operation, a so-called protocol driven mode has also been described for the HPMM. Only the stand-alone mode is used in the present study. An RS-232 serial port on the main unit supports communication between the HPMM and other devices such as a host computer, which is primarily used in the protocol driven mode.

Procedures characterizing how these basic functional subsystems are employed to achieve the desired performance measurement capability for all tests incorporated into the HPMM are described in a separate Human Performance Institute technical report (Kondraske, Mathew, Mulukutla, and Sriwatanapongse, 2006).

The figure below shows details of the HPMM main unit, emphasizing key functional blocks.

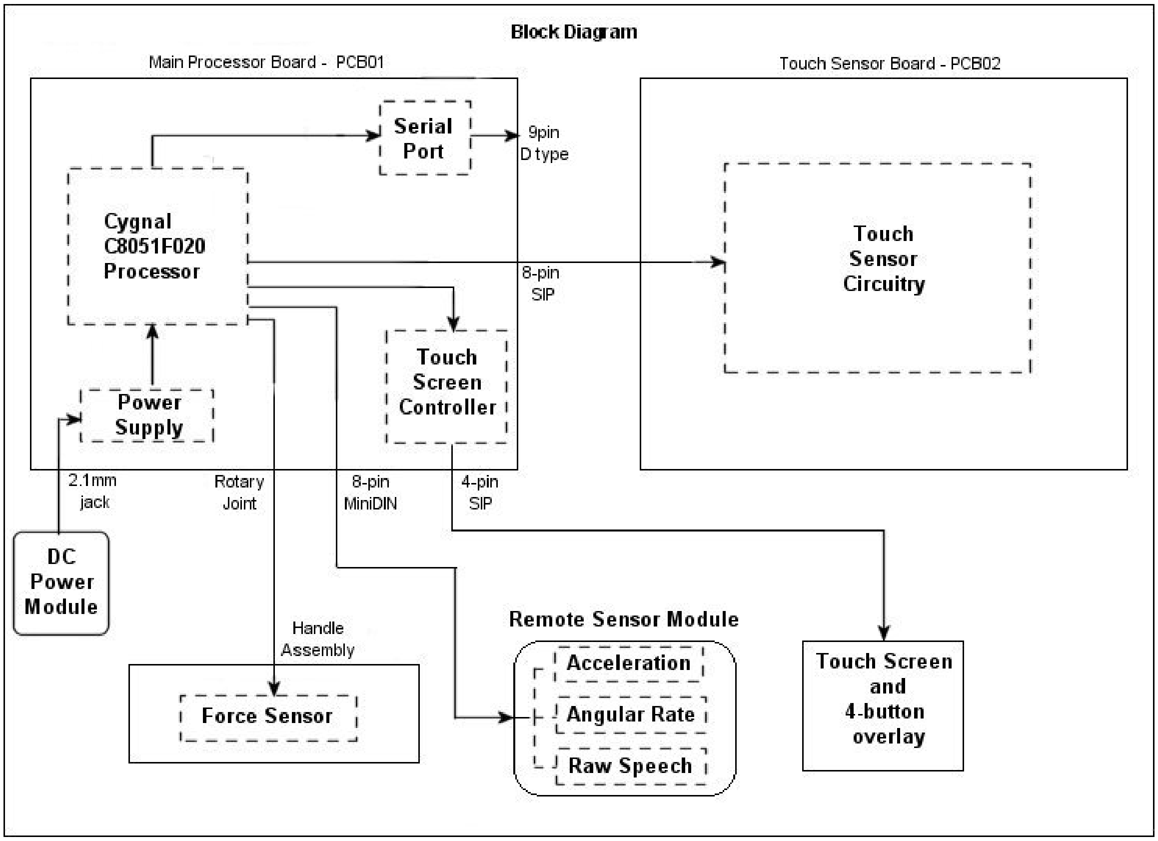

Figure 3.2 HPMM Main Unit System Block Diagram

Photographs of the HPMM version 4 prototype are shown below. The features that may be observed from the front view (Figure 3.3) are the handle assembly that doubles as the force sensor for isometric strength tests, LCD and touch screen with the button overlay and the RSM port.

Figure 3.3 HPMM System Top View

Figure 3.4 HPMM System Bottom View

The backside view (Figure 3.4) shows the two high intensity LEDs, and the array of touch sensors. The HPMM also has a special rubber pad located along the bottom edge of the unit. This pad is placed on the body part for force resistance tests (quantitative manual muscle strength test).

3.2 Touch Sensor Array and LED Stimuli

One side (i.e., considered the backside) of the HPMM main unit contains an array of nine touch sensors and two high intensity stimulus LEDs. The various items are shown in more detail and labeled in Figure 3.5. While referred to as “touch sensors”, each of these is a region of a printed circuit board below a printed plastic overlay where copper exists on the backside of the circuit board. These copper regions are connected to special integrated circuits (Quantum QT310 and QT320) that process capacitive signals from these copper regions. Thus, the combination of the plastic overlay, printed circuit board, and special integrated circuits form the so-called touch sensors. As these are the primary subsystems used in the VMMPC and VAIPD tests, it is useful to describe these aspects in more detail.

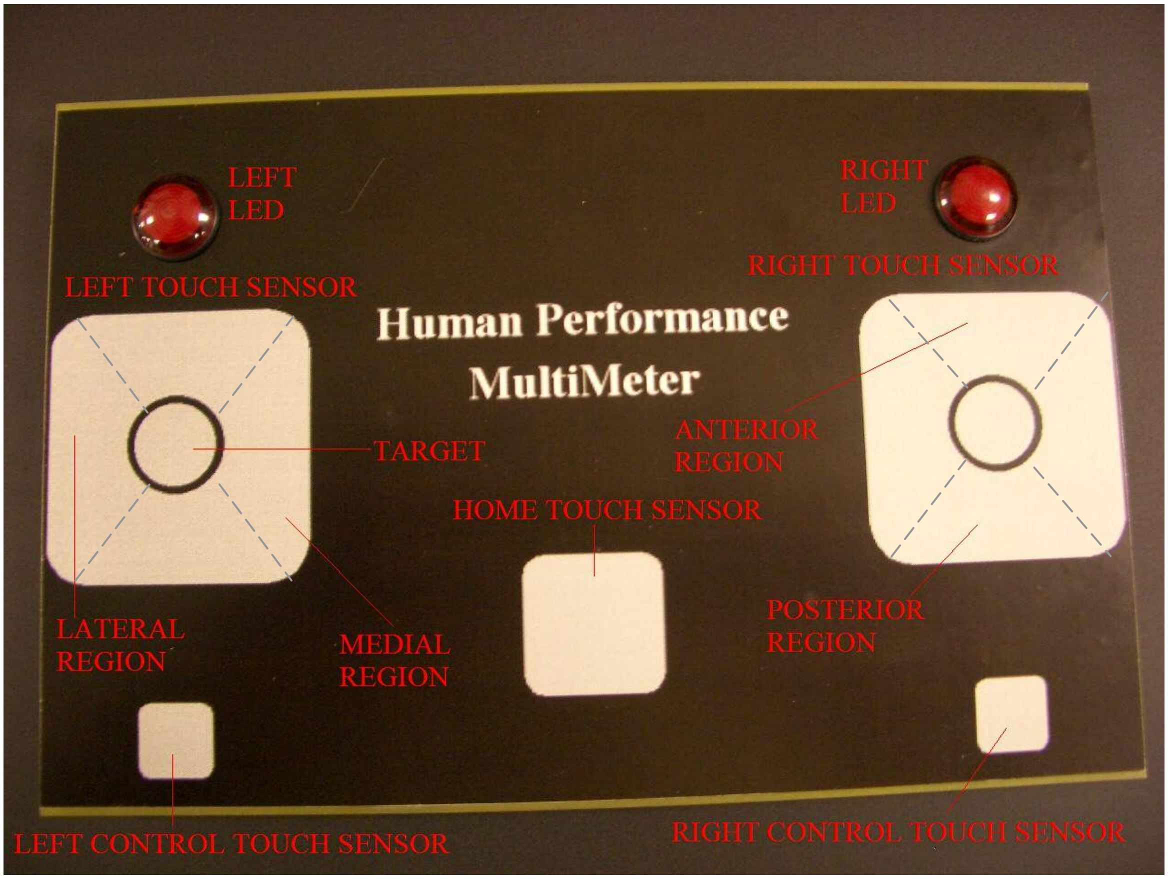

Figure 3.5 Touch Sensor Interface of the HPMM

The overall dimensions of this surface of the HPMM main unit are 21 cm x 13.9 cm. Two main touch sensor regions, called LEFT and RIGHT touch sensors (5 x 5 cm), contain six of the nine sensors. Each of these regions actually contains three separate touch sensors; i.e., the microcontroller can determine if there is contact with any of three distinct areas on each side. These are designated as follows: 1) LEFT target (1.58 cm diameter), 2) LEFT medial-lateral regions, 3) LEFT anterior-posterior regions, 4) RIGHT target (1.58 cm diameter), 5) RIGHT medial-lateral regions, and 6) RIGHT anterior-posterior regions. The center-to-center spacing between the LEFT and RIGHT target sensors is 15.24 cm.

Note that, from the subject's perspective, there is no distinction presented between medial-lateral and anterior-posterior regions on each side. The division of regions surrounding the circular target on each side were incorporated into the HPMM design to support future developments that may require knowing not only that a contact positioning error occurred, but also in which manner (e.g., medial-laterally) the error occurred.

There is also a HOME Touch Sensor (2.54 x 2.54 cm) located midway (horizontally) between the LEFT and RIGHT touch sensor regions. Vertically, the distance between the center of the HOME sensor and a line passing through the center of the LEFT and RIGHT target sensors is 8.255 cm.

The remaining two touch sensors are called LEFT and RIGHT Control Touch Sensors (1.4 x 1.4 cm). These were initially included to serve as input "keys" that the test administrator could use to control simple HPMM functions when the side of the device with the touch sensors was facing the test subject and the test administrator; i.e., without having to turn over the device to access the LCD/Touch Screen. However, they now play an important role in this initial implementation of the VMMPC test as described below.

3.3 VMMPC Implementation on the HPMM

The conceptual design for the VMMPC test is described in section 2.5.2 and is adopted here without modification. Thus, the implementation of this test on the HPMM is modeled after the implementation on the BEP I platform. Despite design similarities across the two platforms, due to hardware differences and to provide a clear description of the implementation of this test on the HPMM platform, the test implementation is described here in detail. As noted previously, tests implemented on the HPMM are designated by numbered "generic test algorithms" (GTAs) and this test is designated as GTA10. Processor code was developed in 8051 assembly language to implement the test as described below.

As noted in section 2.5.2, a dual-task scenario that incorporates a primary and a secondary task is used. In the HPCMS BEP I platform, this builds on the NMCC single-task test that is included on this platform. As in the BEP I, the VMMPC test as implemented on the HPMM builds fundamentally on the NMCC test that is incorporated into the HPMM (Mulukutla, 2005).

On the BEP I the primary touch sensors are on the lower aspect of the instrument's main "panel" while the secondary touch sensors associated with their respective LEDs are situated higher (i.e., further from the subject). To conform to the design hardware of the BEP I as close as possible when executing the VMMPC test, the HPMM is rotated 180 degrees such that the main touch sensor regions are closer to the subject than the control touch sensors. Figure 3.6 shows the picture of both the BEP I and the HPMM side by side for better understanding.

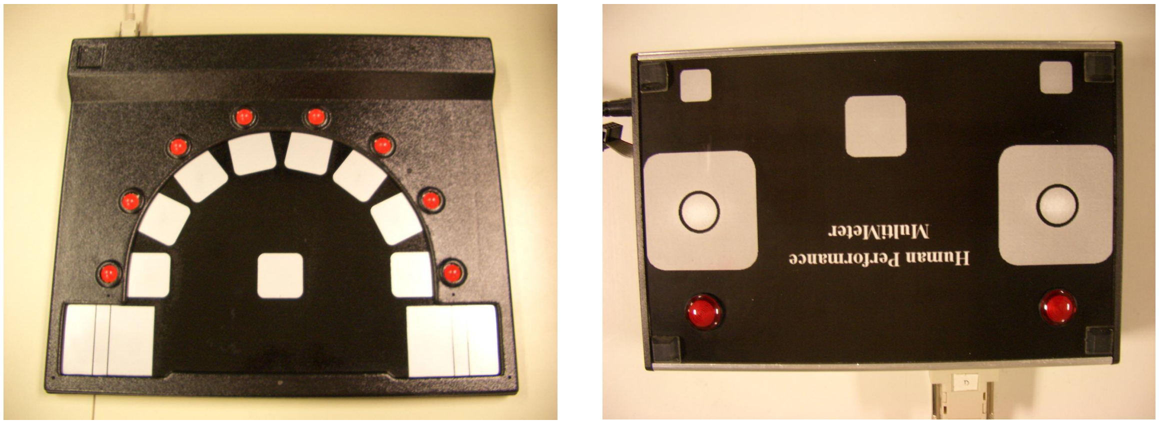

Figure 3.6 Picture of BEP I and the HPMM rotated 180 degrees

One test trial of the test as a whole lasts for 15 seconds. The test trial starts with a single beep. The subject is instructed to start the primary task movement whenever ready after hearing the beep. The primary task is the rapid alternating motion identical to that performed in the neuromotor channel capacity test (i.e., one of the standard single-task tests). This task requires the subject to move his hand and arm to properly position his index finger to strike the circular target touch sensors (see Figure 3.5) in a rapid alternating fashion (e.g., left-to-right, then right-to-left). This task is to be performed with a combination of maximum speed and accuracy.

In addition to a primary task that is equivalent to the neuromotor channel capacity test, a secondary task is included in the overall test that involves randomly timed presentation of visual stimuli. Specifically, either the left or right LED will be activated after a random time interval that ranges from 1.5 to 3.0 seconds. When one of these secondary task stimuli are presented, the subject is required to tap the Control Touch

Sensor on the same side (i.e., left or right) as the lighted LED. The subject is required to do this "as fast as possible" and then return to continue executing the primary task.

A stimulus LED remains lighted until: 1) the subject taps either the Control Touch Sensor corresponding to the lighted LED (which is counted as a correct response), 2) the other Control Touch Sensor (which is counted as a wrong response), or 3) 3000 ms has expired since the LED was lighted. When responses are being made to the secondary task, the NMCC task must be interrupted temporarily. Reaction time is defined as the time from the presentation of the stimulus (i.e., LED is turned on) to the time that the subject taps a Control Touch Sensor.

At the end of 15 s, the microcontroller generates a double beep marking the end of a test trial. Since the test trial accommodates the extra time the subject takes to finish executing the last motion of the NMCC task, each test trial will have slightly different durations but will nominally be 15 s.

Special features are incorporated into the algorithm to allow for smooth operation of this test. Note that the test administrator must select this test by using the HPMM LCD/touch screen, which is on the front side of the HPMM main unit. Once this is completed and the device is ready for test execution, the test administrator must turn over the main unit so that the back side (containing the touch sensor array) is facing up toward the subject. It is possible that the test administrator could inadvertently contact one or more of the touch sensors during this process – and therefore cause a problem with the "start-of-test" timing. To avoid this, special conditions are used (Figure 3.7):

1) The microcontroller samples the six LEFT and RIGHT touch sensors for 30 ms. If the contact lasts for less than 30 ms, then it is considered as a false start and such contacts are ignored. If a contact lasts for at least 30 ms, the algorithm moves on to evaluate if the next start-of-test condition is satisfied.
2) The algorithm looks for three consecutive "motion cycles" within a 3 s period. Tapping anywhere within the LEFT sensor region and then tapping anywhere within the RIGHT sensor region (or vice-versa) comprises one motion cycle. Therefore, if three taps are detected alternately within the LEFT and RIGHT touch sensor regions, then two motion cycles have been executed.

Thus the HPMM will start only if there is contact with any one sensor region for more than 30 ms (to avoid false starts), and if two primary task motion cycles are sensed within a 3 s time period. Once both these criteria are satisfied then the test is considered to have been "started" and timing of the nominal 15 s test period begins.

During all aspects of the algorithm execution, the microcontroller samples the status of touch sensors at a 1000 Hz rate (i.e., sample interval of 1 ms).

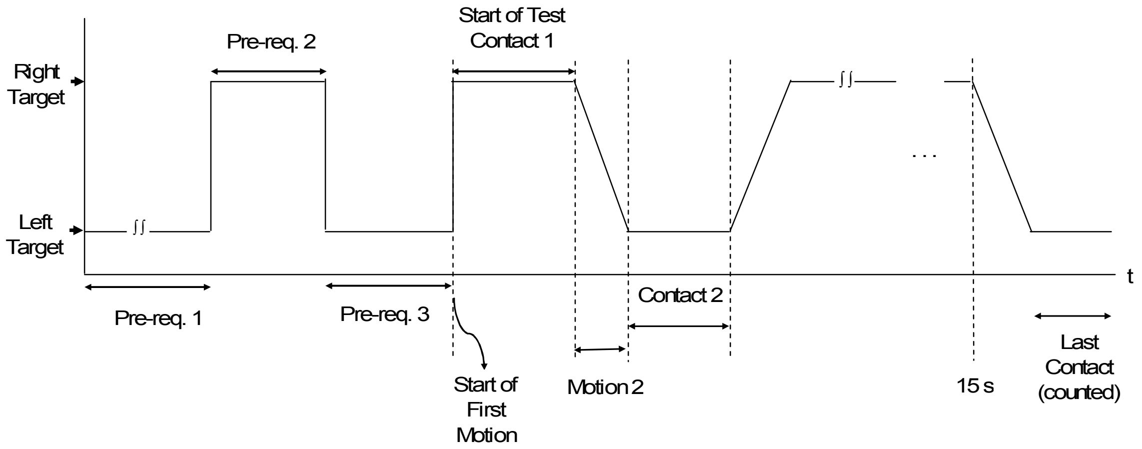

Fig 3.7 Diagram showing algorithm execution emphasizing the special conditions implemented before the start of the test

Table 3.1 Parameters that characterize the VMMPC Test

Parameters	**Values and Notes**
Target Spacing	15.24 cm, center-to-center distance between Left and Right Touch Sensor Regions
Target Width	1.58 cm
Primary Task: Index of Task Difficulty	3.41 bits/motion
Secondary Task: Inter-stimulus Interval	1500 ms to 3000 ms, random
Secondary Task: Maximum Reaction Time	3000ms
Test Duration	15000 ms + Extra Time
Extra Time	Time the subject requires to finish his task after the stipulated 15 s is over.
Measured Parameters	
Primary Task: Total Contacts	The number of taps on the Touch Sensor Regions registered during the Test Duration.
Primary Task: Number of Accurate Responses	The number of taps registered on the target of the Touch Sensor Regions while executing the Primary Task.
Secondary Task: Number of Correct Responses to Secondary Task	The number of taps registered on the Control Touch Sensors while executing the Secondary Task.
Secondary Task: Reaction Time	Time the subject takes to tap the Control Touch Sensor from the moment the corresponding LED lights.
Secondary Task: Total Secondary Task Trials	The number of Secondary Task Trials that were initiated during the test (typically from 3 to 5).

The calculation of the primary task scores is similar to that given for the BEP I, differing only in aspects that relate to the physical dimensions of the instrument. Appendix B describes implementation of computations to produce test results.

Table 3.2 Performance capacity measures computed for the VMMPC Test

Result	**Computation**
Primary Task: Movement Accuracy (%)	(Number of Accurate Responses / Total Contacts) %
Primary Task: Movement Speed (cm/s)	(Total Contacts * 15.24) / Test Duration
Primary Task Main Score: Neuromotor Channel Capacity (bits/s)	Movement Accuracy (%) * Movement Speed (motions/sec) * 3.41(Index of Difficulty)
Secondary Task: Response Accuracy (%)	(Number of Correct Responses to Secondary Task / Total Secondary Task Trials) %
Secondary Task: Processing Speed (bits/s)	Average of (1 bit / (Reaction Time for each Secondary Task))
Secondary Task Main Score: Visual Information Processing Capacity (bits/s)	Response Accuracy * Processing Speed (Secondary Task Measures)

Detailed instructions for administering the HPMM implementation of the VMMPC test are provided in Appendix A.

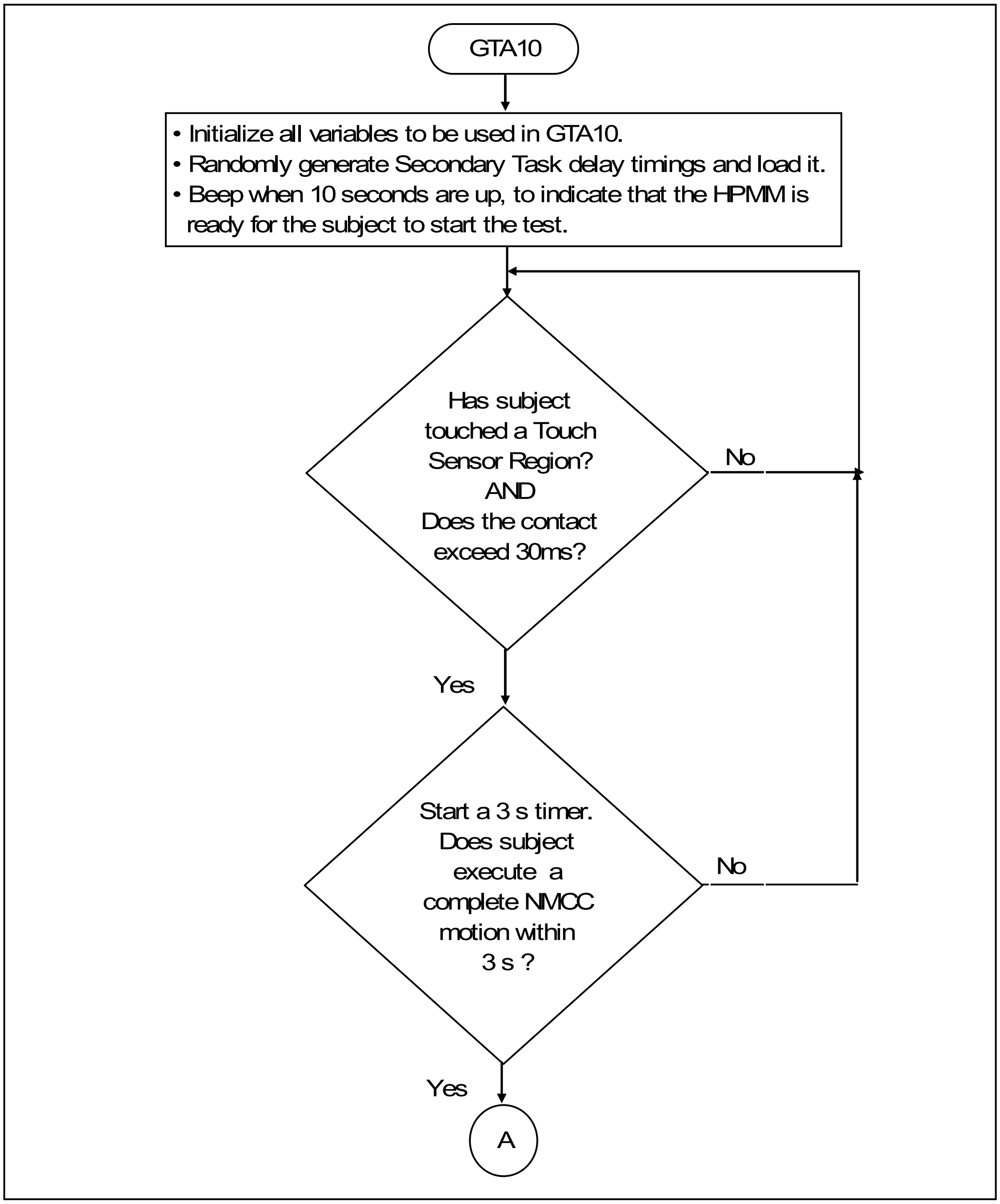

Figure 3.8 Flowchart (Part 1) for Visual Motor Multitask Performance Capacity Test (GTA 10)

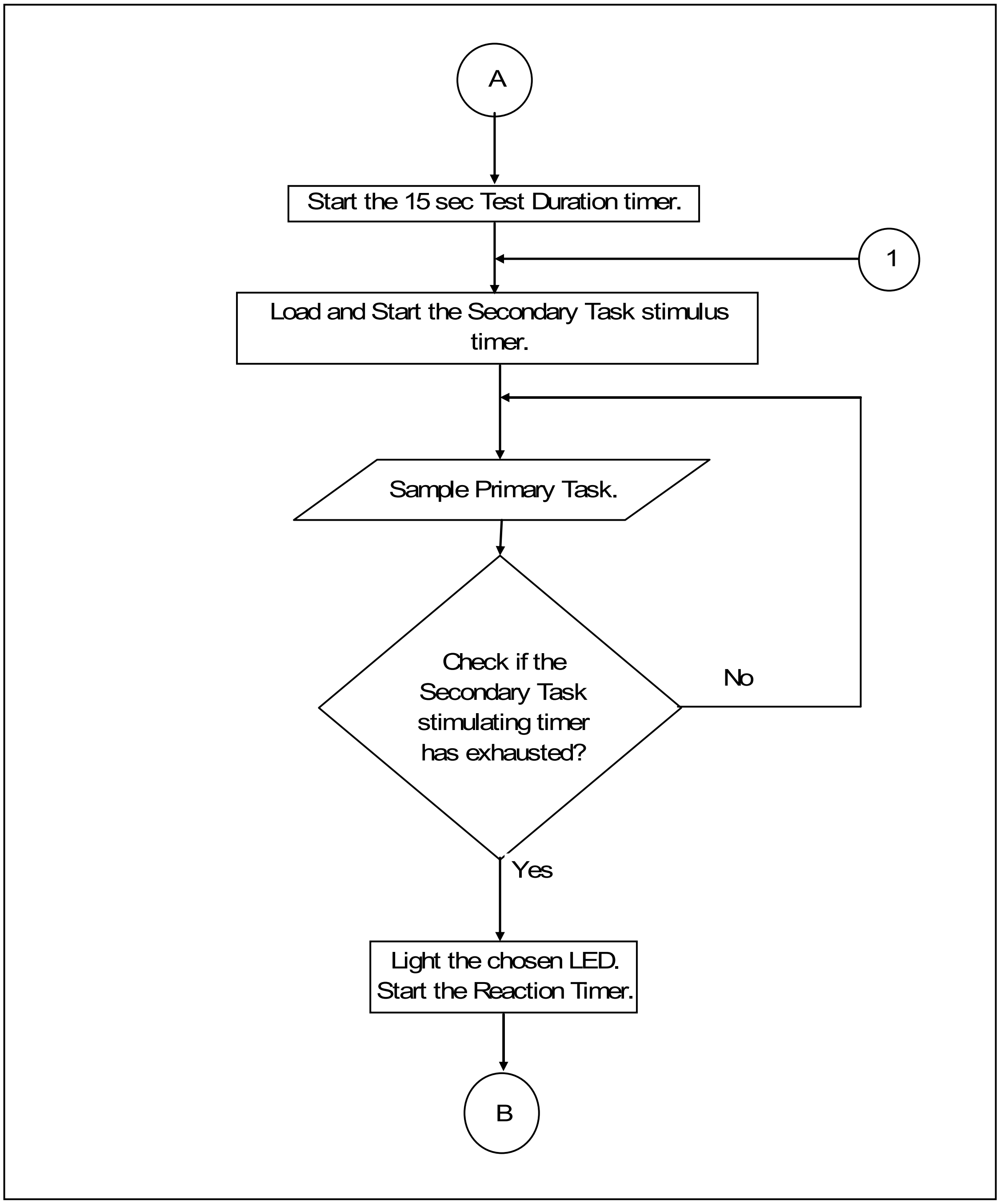

Figure 3.9 Flowchart (Part 2) for Visual Motor Multitask Performance Capacity Test (GTA 10)

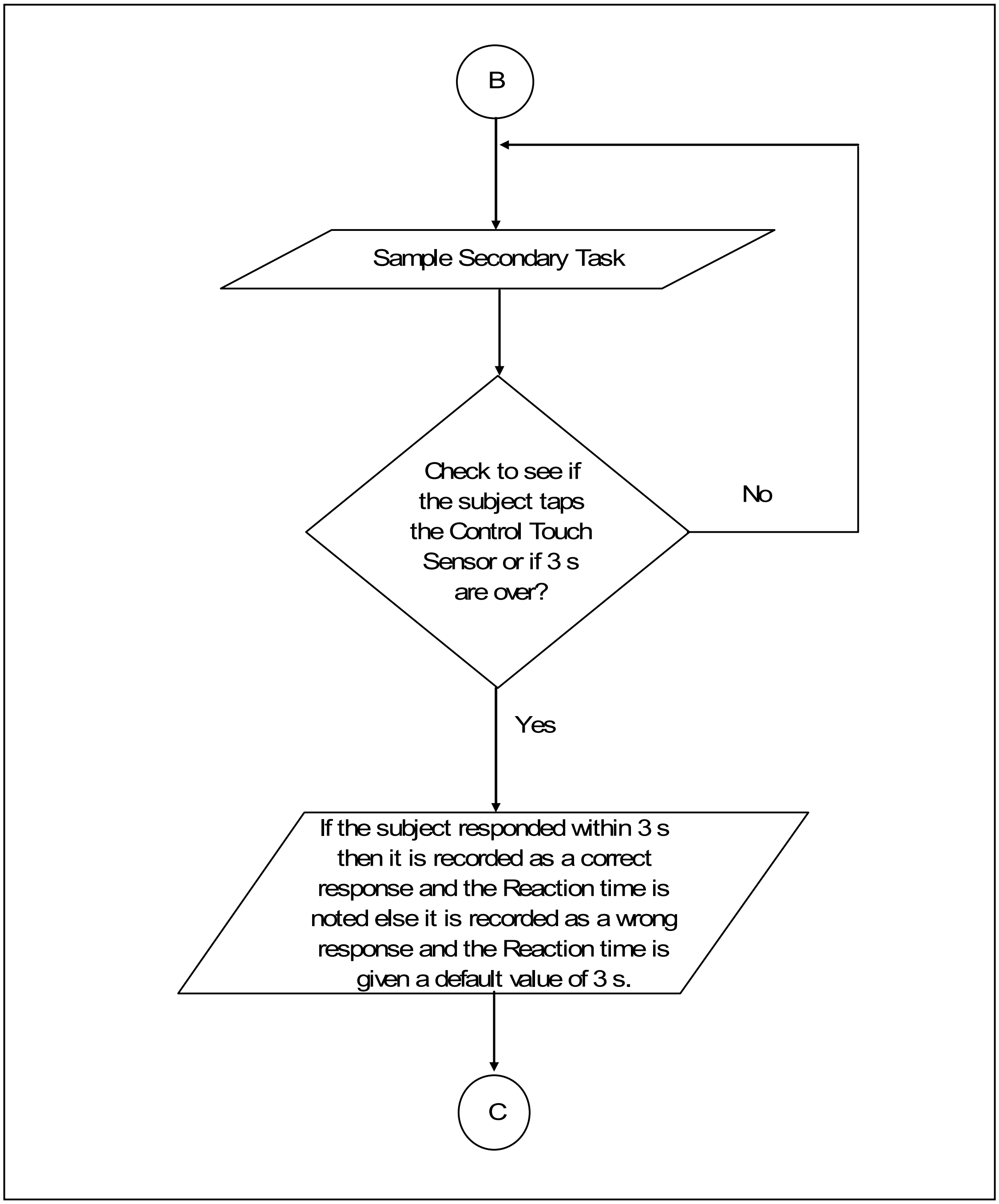

Figure 3.10 Flowchart (Part 3) for Visual Motor Multitask Performance Capacity Test (GTA10)

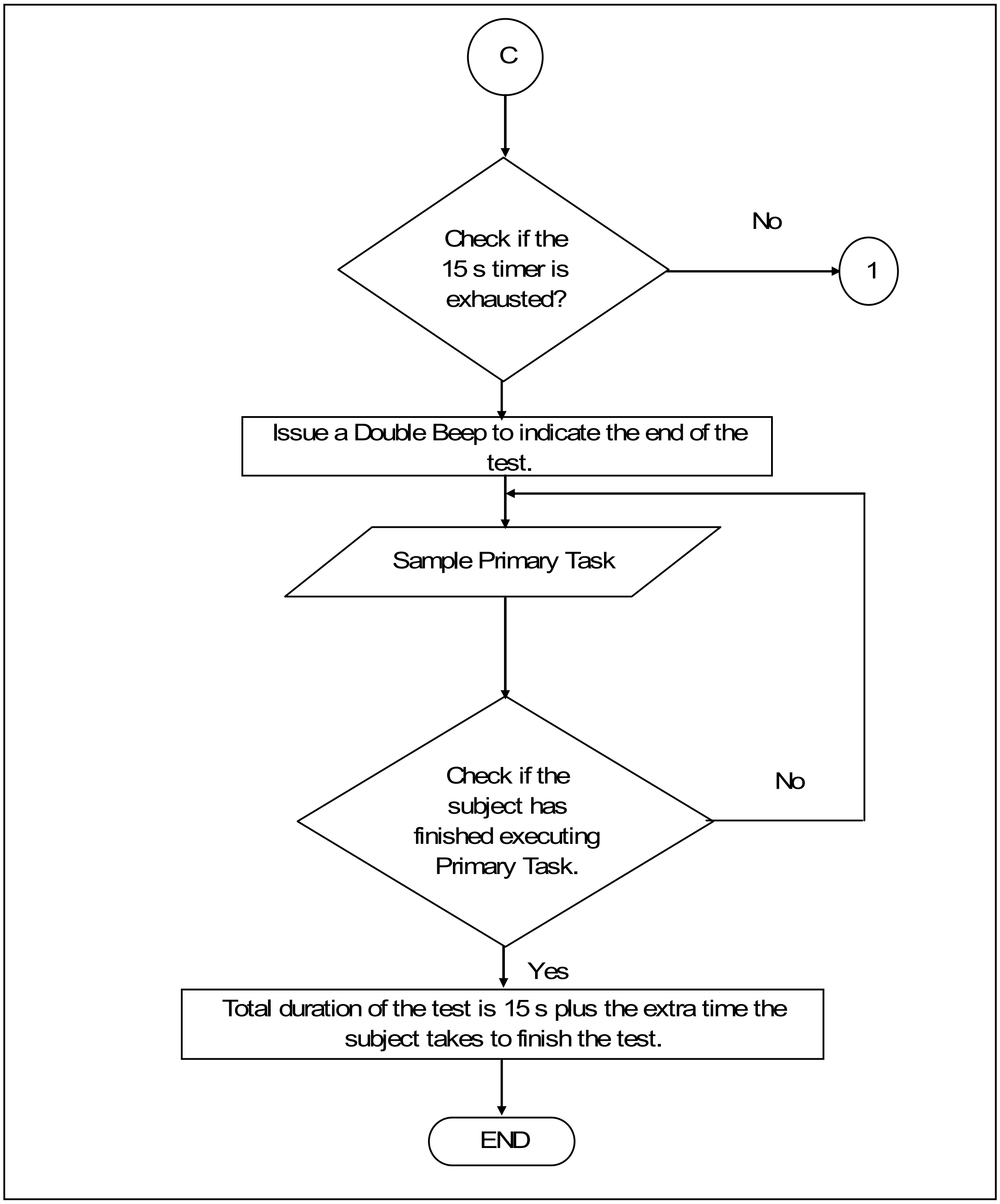

Figure 3.11 Flowchart (Part 4) for Visual Motor Multitask Performance Capacity Test (GTA 10)

3.4 VAIPD Implementation on the HPMM

The conceptual design for the VAIPD test is described in section 2.5.3 and is adopted here without modification or additional comment. Therefore, the implementation of this test on the HPMM is modeled almost identically after the implementation on the BEP I platform. Hardware differences between the two platforms for this test are less significant than those for the VMMPC test. Nonetheless, to provide a clear description of the implementation of this test on the HPMM platform, the test implementation is described here in detail. This test is designated as GTA11. Processor code was developed in 8051 assembly language to implement the test as described below.

As noted in section 2.5.3, on the HPCMS BEP I platform this test builds on the multi-choice visual information processing speed tests. As on the BEP I, the VAIPD test on the HPMM builds fundamentally on this test as well. However, multi-choice visual information processing speed tests are not yet implemented on the HPMM platform. Also, since there are only two visual stimulus sources (i.e., two LEDs), there are limited multi-choice capabilities on the HPMM. However, this hardware difference was deemed to be of minor relevance since, when implemented on the BEP I platform, visual stimuli are primarily focused around just two lights (even though two additional lights may come into play when Situation 4 is presented).

The test consists of presenting a series of “situations” (i.e., simple visual and auditory stimuli) to the subject, with a specific response required for each such situation. The situations and required responses are listed in Table 3.3. These compare very closely with the situation definitions used on the BEP I (see chapter 2) and therefore represent the realization of one of the design goals for HPMM implementation.

Table 3.3 The different situations with their associated stimuli and required responses on the HPMM

Situation	Stimulus	Required Response
1	LEFT LED lights without BEEP	Subject moves finger from HOME sensor to LEFT touch sensor region as quickly as possible
2	RIGHT LED lights without BEEP	Subject moves finger from HOME sensor to RIGHT touch sensor region as quickly as possible
3	RIGHT or LEFT LED lights with a simultaneous 150 ms BEEP	Subject moves finger from HOME sensor to LEFT touch sensor region as quickly as possible
4	Both LEDs light with or without a simultaneous BEEP	Subject keeps his finger on the HOME touch sensor

The flow of the HPMM VAIPD test very closely follows that described in section 2.5.3 for the BEP I implementation. A beep is initiated which signals the subject to start the test by placing his index finger on the HOME touch sensor. After the beep is generated, the microcontroller checks the HOME sensor status and requires that contact with it is maintained for at least 1 s to eliminate false starts. Another beep is generated when this criterion is met, signaling the start of the situation sequence in which 24 stimulus intervals are presented. The first part of each stimulus interval consists of a random (2 to 5 s) time segment called the stimulus foreperiod. At the end of the foreperiod, the stimulus is presented and reaction timing is started using a timer resolution of 1 ms. Then, the subject is allowed up to a maximum of 3 s to respond. The situation type for the current stimulus interval is pulled from a situation sequence table, which is loaded prior to the start of the test and was designed to conform to the rules given in Chapter 2, Section 2.5.3. For Situation 4 (where a “correct response” requires that the subject stay on the HOME touch sensor), the subject’s response is monitored for 3 s if the subject appears to be responding correctly (and less if the subject mistakenly moves). For any of the four situations, movement from the HOME touch sensor marks the end of the reaction time period and this time is saved for later result computations.

For Situations 1, 2, or 3, movement timing is then started using again a 1 ms timing resolution. Movement timing ceases when the subject touches any of the sensors within the LEFT or RIGHT touch sensor regions, or after the expiration of a 3 s maximum movement time. This marks the end of a stimulus interval. For Situation 4, the end of the stimulus interval is marked by either: 1) the expiration of 3 s while the subject maintains contact with the HOME sensor (i.e., a correct response), or 2) the subject removes his/her finger from the HOME sensor within 3 s of the stimulus presentation (i.e., a wrong response). There is no reaction time or movement time for Situation 4. It is only determined whether the response is correct or wrong.

Special mention is made here regarding Situation 3, for which a beep of 150 ms duration is included as part of the stimulus. This beep is generated by programming the microcontroller to produce a square wave signal (frequency = 2200 Hz) that is applied to the HPMM’s audio transducer. This requires constant processor attention at the same time that reaction timing must be accomplished. In the algorithm, the stimulus interval starts by: 1) turning on the required LED, and 2) starting to generate the 150 ms beep. After 150 ms have expired, the beep is terminated and reaction timing is started with this timer initialized to 150 ms. No subjects can respond more rapidly than this to situations of the complexity of the VAIPD test. This process is described as shown in Figure 3.12. For Situation 4, a beep may or may not be part of the stimulus. However, the beep does not have any impact on the implementation of time measurement since it is not possible to record a reaction time for this situation.

Parameters that characterize the HPMM VAIPD test are listed in Table 3.4.

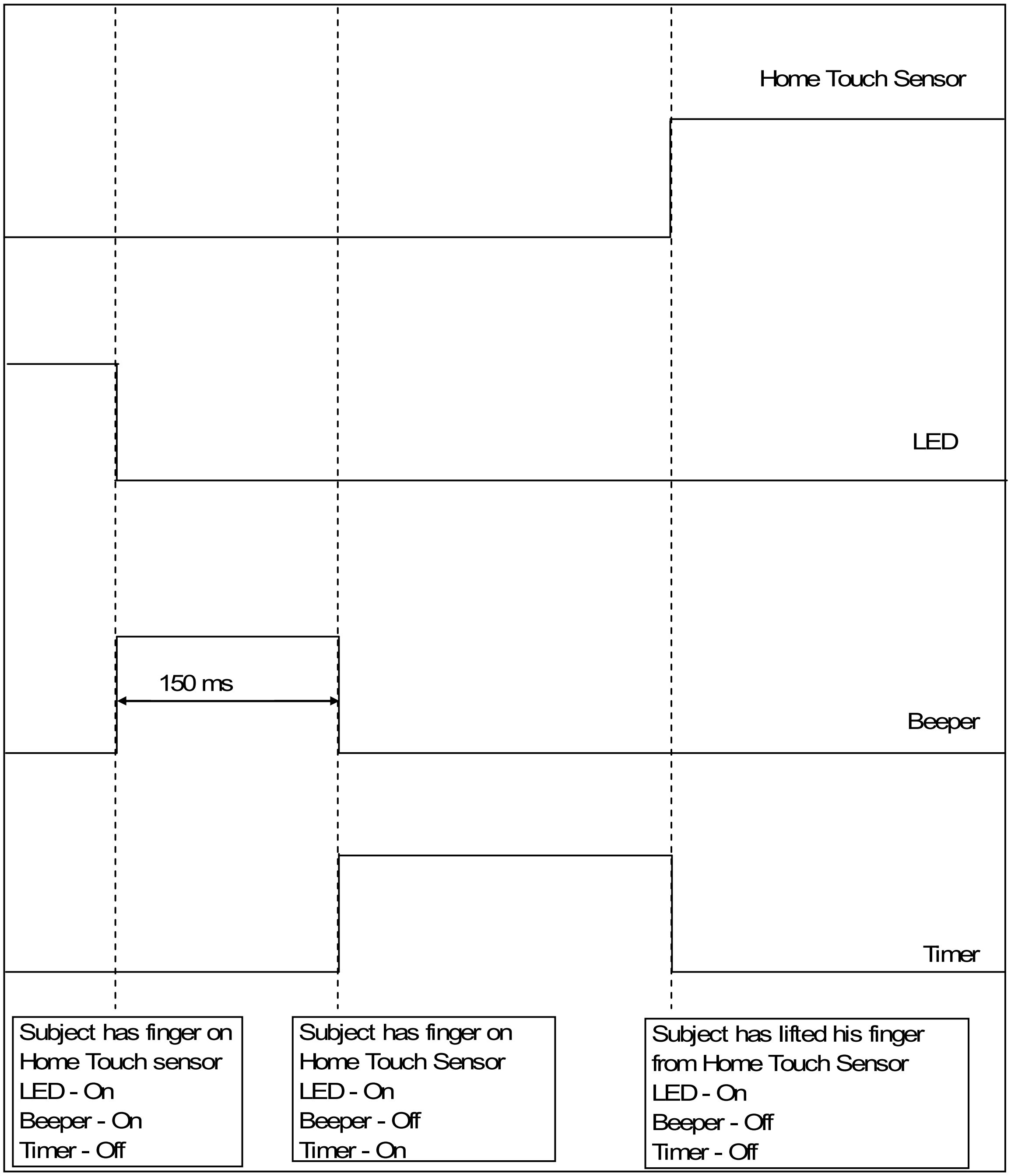

Figure 3.12 Diagram showing the sequence of the LED, Beeper and Timer with respect to the subject's response in Situation 3

Table 3.4 Parameters that characterize the VAIPD test

Parameters	Values and Notes
Situation Stimulus Foreperiod	1500 to 3000ms from end of inter-trial interval to the presentation of the stimulus (random)
Number of Situation Trials Comprising a Test	24
Inter-trial Interval	2500 ms
Distance from Home Touch Sensor to Left or Right Touch Sensor Regions	8.255 cm
Beep Duration	150 ms
Reaction Time	Time between initial presentation of the stimulus and the initiation of subject response (i.e., lifting finger from the Home Touch Sensor)
Maximum Reaction time	3000 ms
Movement Time	Time it takes for the subject to tap the respective Touch Sensor Region after he lifts his finger from the Home Touch Sensor.
Maximum Movement time	The max. Movement time for the subject is limited to 3000 ms.
No. of correct responses	The taps registered on the Touch Sensor Regions when the respective LED lights.

After the 24 situations are presented, a double beep is initiated to indicate the end of the test trial. The algorithm then processes results saved from each stimulus interval to compute final results. This aspect is the same as that described in Chapter 2, Section 2.5.3 for the BEP I implementation, with the exception that movement speed is calculated based on a different HOME sensor to response sensor distance (8.255 cm for the HPMM). The final measures and their units are described in Table 3.5. Appendix B describes implementation of computations to produce test results.

Table 3.5 Performance capacity measures computed for the VAIPD Test

Result	**Computation**
Accuracy (%)	(Number of Correct Responses / Total Situations) %
Processing Speed (bits/s)	The average of (1 bit / (Reaction time for individual task)). Only the first three situations are considered
Movement Speed (cm/s)	8.255cm / Average of the individual Movement Times for all the 18 situations
Visual Auditory Information Processing Dexterity Score(bits/s)	Accuracy * Processing Speed

Detailed instructions for administering the HPMM implementation of the VAIPD test are provided in Appendix A.

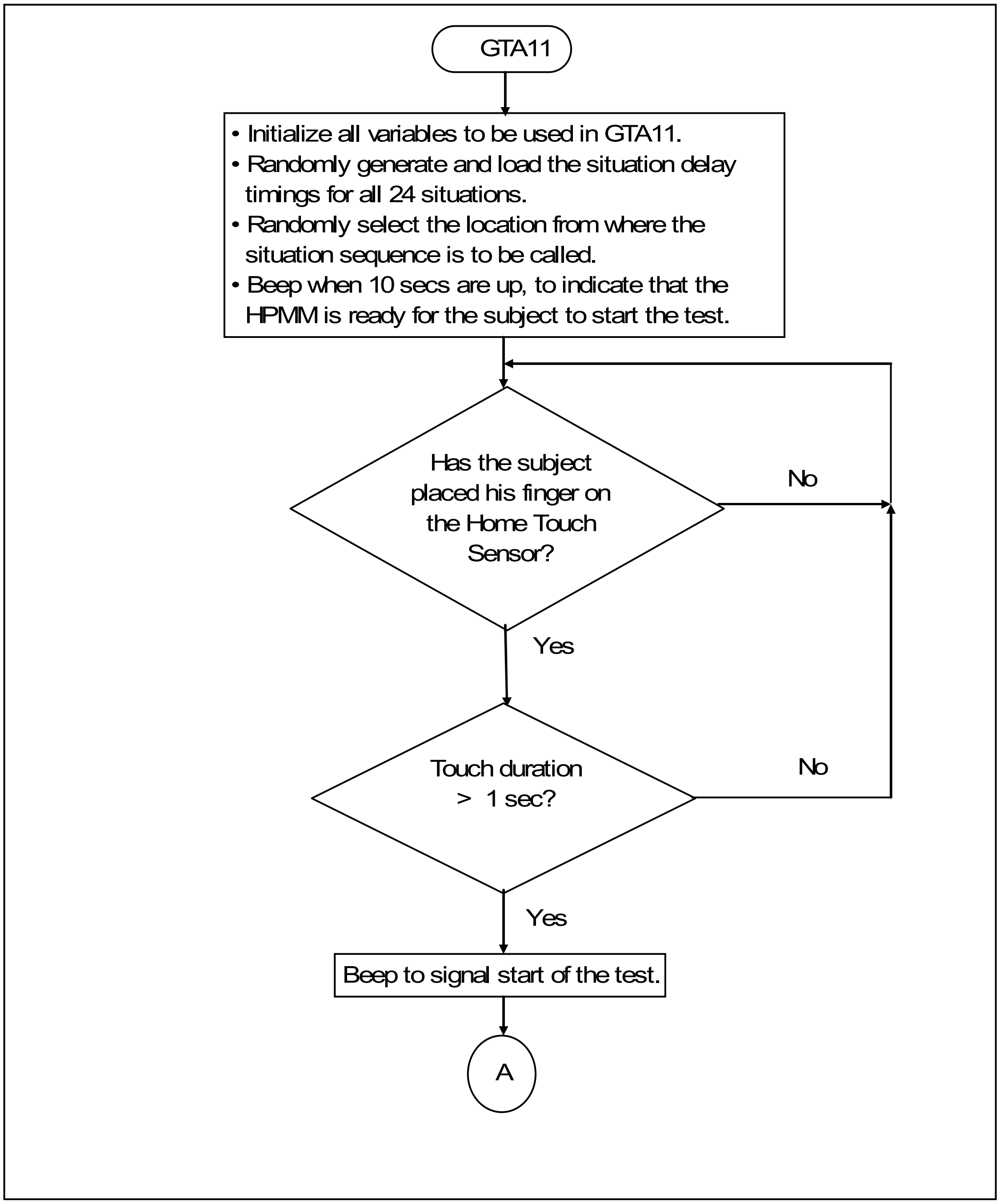

Figure 3.13 Flowchart (Part 1) for Visual Auditory Information Processing Dexterity Test (GTA 11)

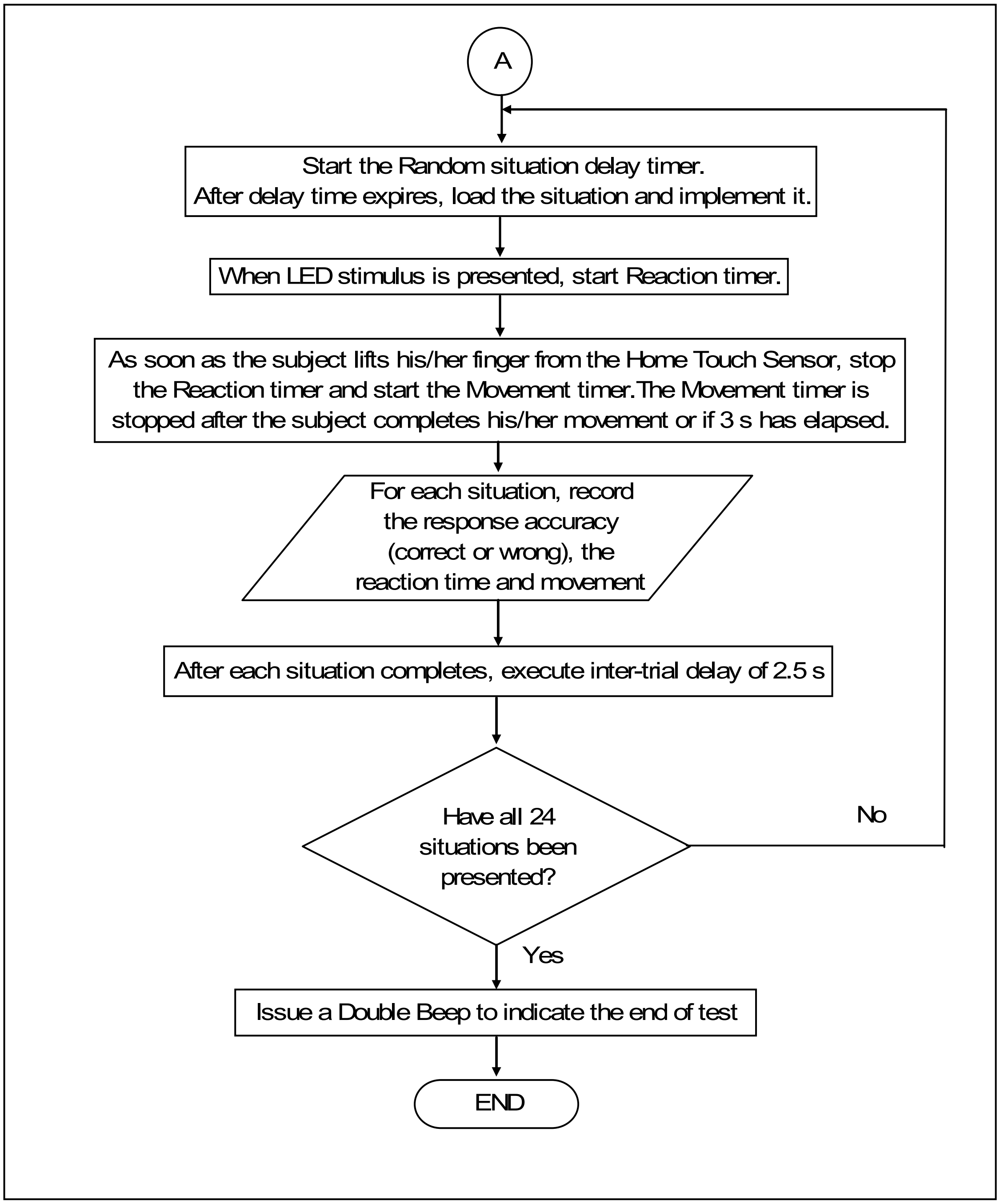

Figure 3.14 Flowchart (Part 2) for Visual Auditory Information Processing Dexterity Test (GTA 11)

CHAPTER 4

EXPERIMENTAL EVALUATION

4.1 Overview and Objectives

This chapter describes the results of the experiments conducted to investigate the VMMPC and VAIPD tests on both the BEP I and HPMM platforms. To evaluate measurement reliability (repeatability), the experiment is designed using a test-retest structure. The data collected also helps gain preliminary, useful insights into the validity of the measures. The methods are similar to those incorporated in studies of earlier laboratory based instruments as well as those used in the evaluation of other HPMM tests.

4.2 Methods

Twenty (20) subjects volunteered to participate in the study. The group included 10 males (21-60 yrs, mean = 28.6 yrs; s.d. = 11.4 yrs) and 10 females (22-27 yrs; mean = 23.9 yrs; s.d. = 1.66 yrs). Subjects were recruited from the staff and student community at the University of Texas at Arlington. Subjects were self declared healthy adults. All subjects except two declared their right hand to be their dominant hand. Individuals who were below 18 years of age, had any recent medical or surgical history that might affect performance and who could not comprehend instructions in English were excluded. The protocol was reviewed and approved by the University of Texas at Arlington's

Institutional Review Board. A signed informed consent document was obtained from each subject (Appendix C).

Unfortunately, standard terminology associated with studies such as this can be confusing. This is partly due to the fact that the study involves “testing” of “a test”. The VMMPC and the VAIPD tests were administered in one session with two components designated “test” and “retest”. This is a repeated measure designed with “test” and “retest” components consisting of identical procedures. The assumption is that, in healthy subjects, performance capacities are relatively constant. If so, and if the measurement instrument and procedures are reliable, repeat testing should yield the same values.

In both the “test” and “retest” components, each of the two performance capacity tests” (i.e., VMMPC and VAIPD) were administered on the BEP I as well as the HPMM platform. After the so-called “test” component, subjects were given a short break (5 minutes) and then the “retest” component was administered. To minimize the influence of learning effects, half of the subjects executed the VMMPC and VAIPD tests on the BEP I platform first and then the HPMM platform. The remainder of the subjects were administered the HPMM tests first. The order used was alternated for each subject as they were enrolled in the study. For a given subject, however, the same order was used in both the “test” and “retest” components. For both the VMMPC and VAIPD tests, three “test trials” were administered for each body subsystem. For the VMMPC tests, both dominant and nondominant body sides were tested. The VAIPD test involves, but does not stress motor performance, which is side dependent. Therefore, only one body side was included in the protocol. Each subject was allowed to use their “preferred hand” when executing this test. Detailed test administration instructions used for the VMMPC and VAIPD tests are provided in Appendix A.

It is common to repeat performance tests multiple times and then use some parameterization across the multiple intermediate results to obtain a final test result. In such cases, individual attempts to execute the basic task forming the basis of the test are generally called “test trials”. The optimal number of test trials that comprise “a test” is not yet defined for either the VMMPC or VAIPD tests. For this study and for the purpose of describing the test administration procedures, the VMMPC and VAIPD tests have been operationally defined to consist of three trials. This choice is based on previous experience with similar tests by Kondraske (Kondraske, 2006b), who noted that:

> “While more trials generally allows the reduction of intra-individual variability and therefore would tend to improve repeatability, a larger number of trials tends to turn any given test into one that focuses on endurance, especially in subjects with impairment. Therefore, repeatability, validity, and the amount of time that can be dedicated to measuring a given quantity must be carefully optimized.”

Various options for computing the final results were explored (e.g., average of all three trials, average of best two trials, etc.), as described in subsequent sections of this chapter.

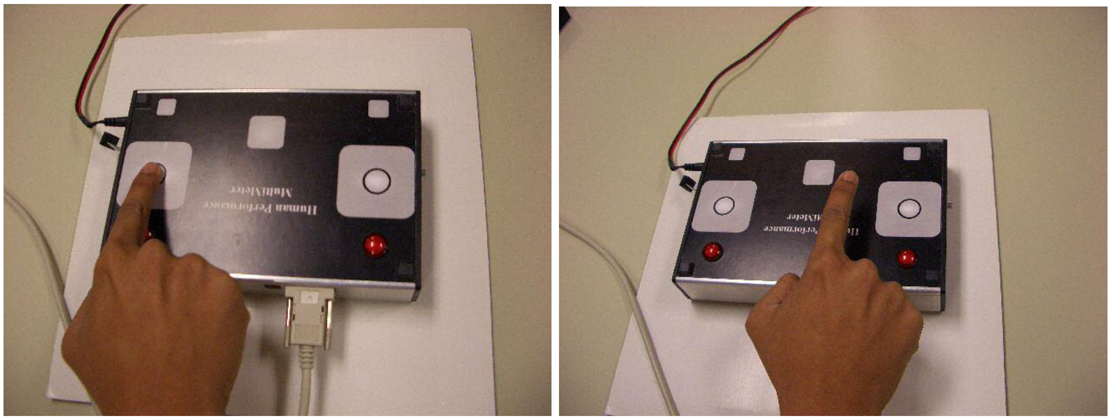

Figure 4.1 Picture of the subject executing the Visual Motor Multitasking Processing Performance Capacity Test (GTA 10). The subject is making contact with the Left Target (left) and then reverses motion and is moving toward (right) the Right Target

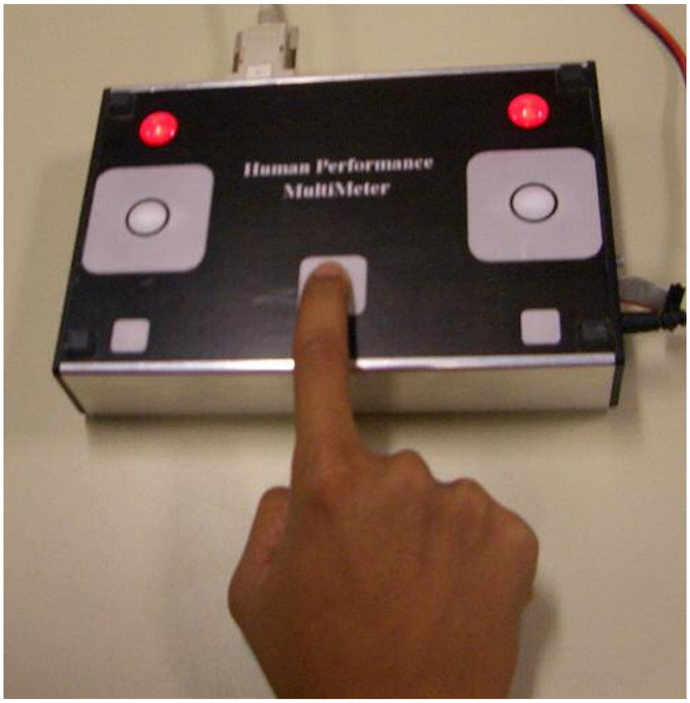

Figure 4.2 Picture of the subject executing the Visual Auditory Information Processing Dexterity Test (GTA 11). Subject has finger on HOME sensor. Both LEDs are lighted (Situation 4)

Data analysis first focused on the evaluation of several candidate approaches considered as the basis for determining "final" test results; e.g., average of all three trials, best two of three test trials, etc. This was closely tied to test-retest reliability analyses. First, the Pearson product moment correlation coefficient (Pearson's r) was computed for each test measure computed under each candidate "final measure" rule. For the sample size used in this study, Pearson's r is equivalent to the intra-class correlation coefficient (Mulukutla, 2005). In addition, the absolute value of the difference between measures obtained during "test" and "retest" components were computed for each subject and expressed as a percentage of the "test" component measurement value. These values were then averaged across subjects to provide a single number indicator of repeatability (e.g., mean of the absolute value of percent change). This reflects the average "size" of the difference between "test" and "retest" performances. The reliability results were then evaluated to determine which of the candidate approaches to the computation of "final" test results was best.

After determining the optimal approach for the computation of "final" measures for each test, descriptive statistics (mean, standard deviation and coefficient of variation) were computed for each measure. For the VMMPC test, dominant and non-dominant side measures were separately evaluated. Scatter plots were also prepared to illustrate "test" vs. "retest" results for overall performance capacities associated with the VMMPC and VAIPD tests.

Additional data analyses address the comparison of results obtained with the HPMM to those obtained with the BEP I. Ideally, these would be identical. However, due to the different physical configurations of each device, it is not expected that they will be in perfect agreement. To investigate this issue, descriptive statistics are compared and scatter plots of HPMM vs. BEP I results were prepared.

4.3 Results

4.3.1 Reliability and Selection of Final Performance Capacity Measures

Reliability refers to the degree to which results obtained are repeatable. The Pearson product moment correlation coefficient and average size of the difference between “test” and “retest” components are shown in Tables 4.1 and 4.2 for the VMMPC and VAIPD tests respectively. For each test, these values are shown for several candidate “final measures” computed using different rules as described. As noted, test-retest repeatability is a major criterion used in making a determination of which rule is optimal.

For the VMMPC test, the additional issue of how to combine scores from the primary and secondary tasks to obtain a single, overall performance measure for this test was also considered. The units of measure for the primary and secondary task are the same (e.g., bits/s), thus allowing for the possibility of using the sum of scores from these two components to represent “VMMPC”. A strong case has been made supporting the conceptual validity of this approach to obtaining the overall performance measure for this dual-task test (Kondraske, Vijai, and Mathew, 2006). This approach is therefore adopted herein. Thus, reference to VMMPC refers to the sum of the primary task score (reflecting neuromotor channel capacity in bits/s) and the secondary task score (reflecting visual information processing speed in bits/s).

Table 4.1 shows the Pearson product moment correlation coefficient and average percent change values for scores based on two different schemes for processing the VMMPC results from three trials: 1) using the average of all three trials, and 2) using the best two of three trials with judgment regarding the best trials based on the overall VMMPC score for each individual trial. Pearson correlation coefficients and average percent change values are also shown for primary and secondary task scores. Values are shown for dominant and nondominant side data separately.

Table 4.1 Test-retest reliability results for Visual Motor Multi-task Performance Capacity (VMMPC) tests and for different rules used to compute final measures

Platform: Measure Name (units)	**Rule used to Compute Candidate Final Measure**			
	Avg. of All (3) Trials		**Avg. Best Two Trials-Select Based on Sum Composite**	
	r *	**Δ (%) ****	**r ***	**Δ (%) ****
BEP I Platform:				
VMMPC – Sum Composite (bits/s)				
• Dominant Side	0.21	11.9	- 0.05	11.1
• Nondominant Side	0.66	09.8	0.64	10.5
Primary Task – NMCC(bits/s)				
• Dominant Side	0.27	13.6	- 0.02	12.9
• Nondominant Side	0.66	11.5	0.65	12.6
Secondary Task – VIPC(bits/s)				
• Dominant Side	0.43	08.9	0.36	10.0
• Nondominant Side	0.68	09.2	0.58	11.6
HPMM Platform				
VMMPC – Sum Composite (bits/s)				
• Dominant Side	0.71	09.2	0.75	08.0
• Nondominant Side	0.78	10.9	0.79	10.5
Primary Task – NMCC (bits/s)				
• Dominant Side	0.69	11.2	0.72	09.9
• Nondominant Side	0.81	11.7	0.79	11.9
Secondary Task – VIPC (bits/s)				
• Dominant Side	0.41	07.8	0.32	10.4
• Nondominant Side	0.00	11.2	- 0.04	11.9

r * = Pearson product moment correlation coefficient, the measure of reliability employed
Δ (%) ** = average (across subjects) of | ((retest value-test value)/test value)*100|

The following observations are made with regard to Table 4.1:

- With regard to test-retest reliability, it is only the overall score (i.e., VMMPC) that is of interest. Since test subjects are free to divide their VMMPC between the primary and secondary tasks in different ways each time the test is executed, high reliabilities for the primary and secondary task scores are not expected, nor are they required in order to achieve high reliability for the composite VMMPC score. The reliability measures for these constituent component values are included for reference and completeness.

- For the BEP I platform, reliability is clearly better when the average of all three trials is used to compute the final measure. For the HPMM platform, there is little difference in reliability for each of the two rules considered.
- Focusing on the results in Table 4.1 associated with the "average of all three trials" rule, the Pearson product moment correlation coefficient varies from 0.66 to 0.78 for three cases (BEP I non-dominant side, HPMM dominant side, and HPMM non-dominant side). The value for the fourth case (BEP I dominant side) is substantially lower (0.21).
- Again focusing on the results in Table 4.1 associated with the "average of all three trials" rule, the average size of the percent change between "test" and "retest" measures is very consistent (i.e., approximately 10%) across the four cases present (two body sides on two platforms).

Based on these observations, it was decided to use the "average of all three trials" rule as the rule for computing the final measure. All subsequent references to the measure "VMMPC" test result in this document will refer to this definition.

To further investigate and summarize VMMPC repeatability graphically, Figure 4.4 shows test-retest scatter plots for the VMMPC measure, with separate plots for BEP I and HPMM measurements. Dominant and nondominant side scores are shown on the same scatter plot for each platform. Of particular interest is the unusually low reliability value (0.21) obtained for the BEP I dominant side result, relative to the other three cases where reliability values ranged from 0.66 to 0.78. From Figure 4.4b for the HPMM, it is seen that there is considerable separation of dominant and non-dominant side scores, with dominant side scores being higher as would be expected for a task involving coordination. The same is not true for the BEP I (Figure 4.4a) where dominant side scores appear to be unusually "depressed"; i.e., VMMPC values are lower than would be expected and are distributed essentially "on top of" the non-dominant side scores.

It is noted that the platform used "first" during data collection was randomized across subjects. However, the dominant body side was always scheduled to be tested before the non-dominant body side – regardless of the platform used. The most likely cause of the circumstances for the BEP I dominant side case (i.e., lower than anticipated scores, as well as the low Pearson product moment correlation coefficient) is associated with the test instructions and training provided to the test subjects. Even though the platform used "first" was randomized, with a small sample size it is quite possible that those subjects who used the BEP I first were slower to fully comprehend the required task performance compared to those who used the HPMM first. Differences in perception of the test by the subjects could also be another related factor. Some were very keen and looked forward to the test trials with an attitude more associated with playing a video game. Others appeared to be bored at times, not very attentive or slightly frustrated.

Other possible causes such as hardware or software problems are ruled out because the poor result was obtained only for one body side. The nondominant side VMMPC results for the BEP I platform are quite comparable to those obtained for the HPMM.

To further investigate the possible contribution of training (i.e., the subject's "knowledge of proper test procedures") to the unusual findings for the BEP I dominant side case, an additional set of analyses was carried out. Now VMMPC data sets were constructed based on the order in which subjects encountered and executed tests. Each of the four resulting data sets contained an equal mix of BEP I and HPMM derived VMMPC values. From this, it was found that the lowest test-retest reliability occurred for the data set representing "the first encounter" with the VMMPC test. Reliabilities increased for the second and third encounters and then fell back slightly for the fourth encounter (see Fig 4.3). This pattern suggests that training was not adequate prior to collection of data that is supposed to be "meaningful". This, along with the small sample size argument presented above, supports the notion that subject training and practice are the most likely cause of the unusual findings for the BEP I dominant body side case.

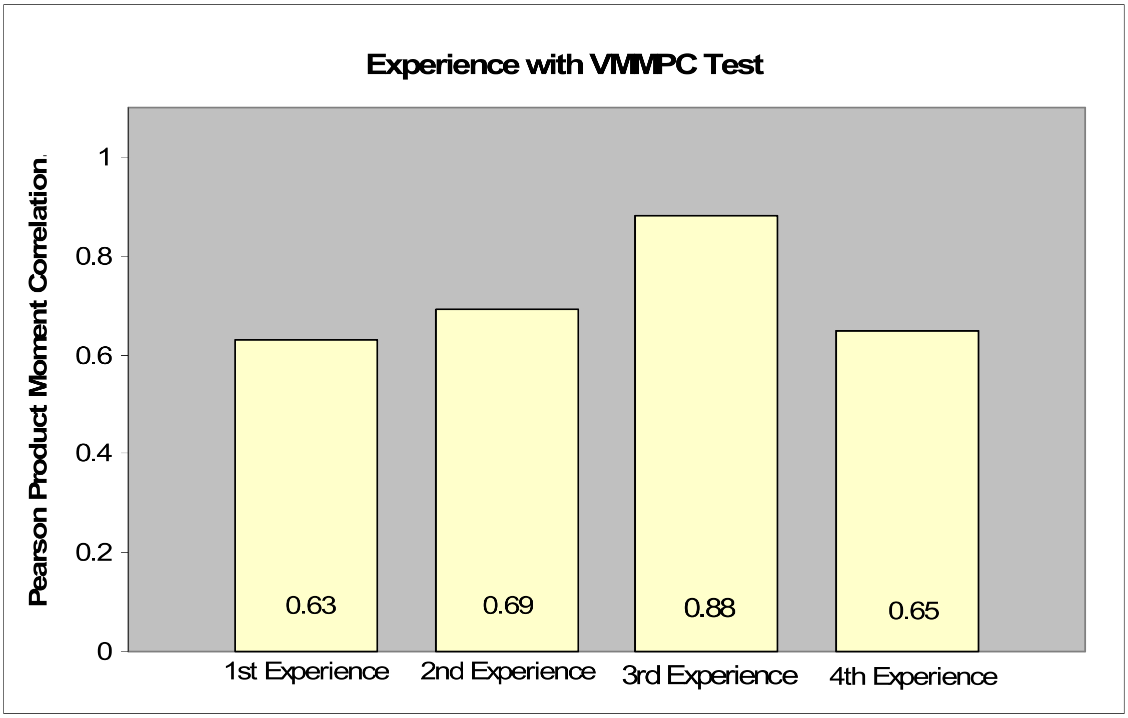

Figure 4.3 Bar graph showing the change in repeatability as a function of subject experience with the VMMPC test

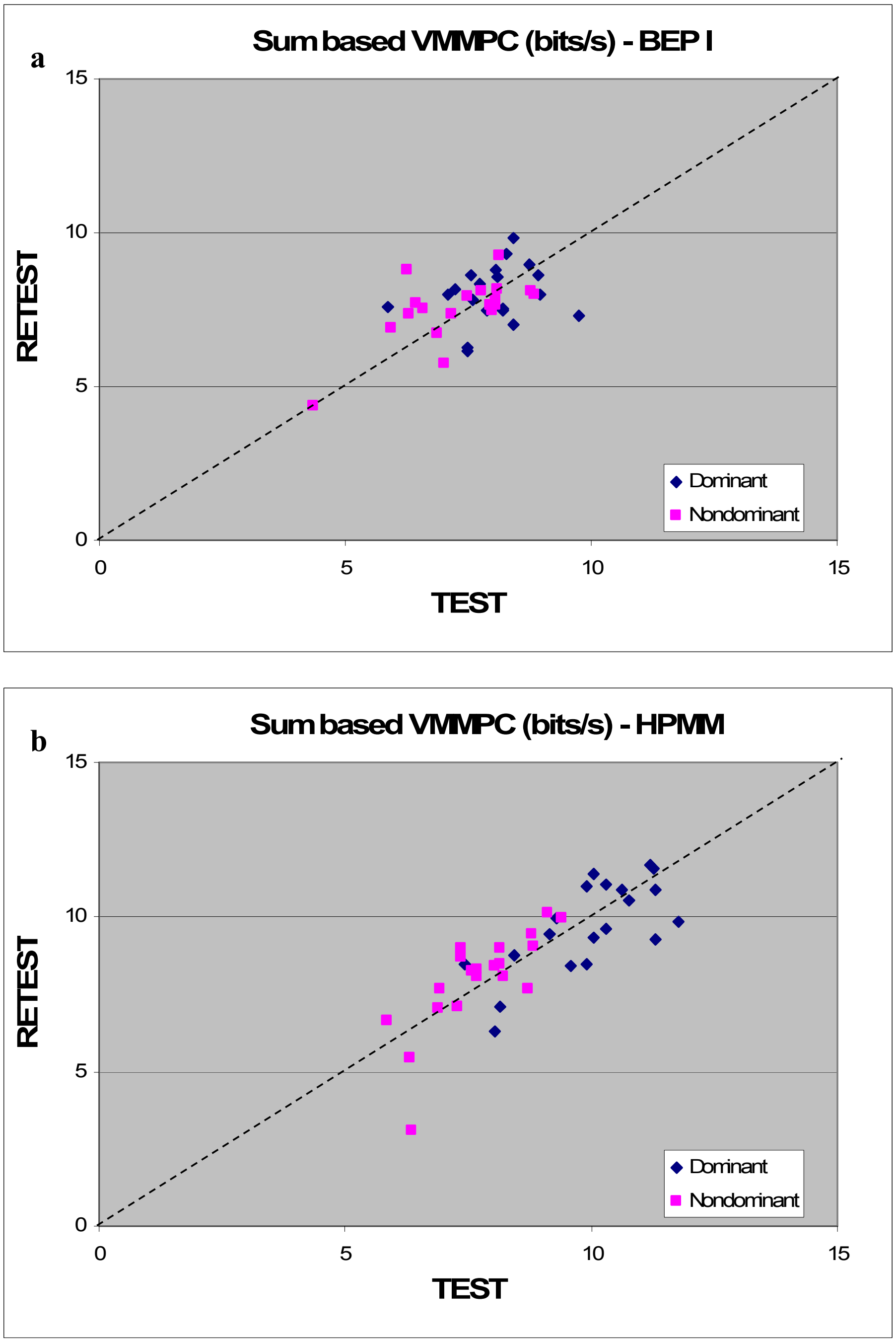

Figure 4.4 Test-retest scatter plot for VMMPC from (a) BEP I, including dominant and nondominant side scores; (b) the HPMM, including dominant and nondominant side scores

A similar evaluation was carried out for the VAIPD test, with Pearson product moment correlation coefficients and average percent change values shown in Table 4.2. This test is considerably simpler than the VMMPC test since it is not a dual-task test and thus there are no separate primary and secondary task scores to consider.

Table 4.2 Test-retest reliability results for Visual Auditory Information Processing Dexterity (VAIPD) tests and for different rules used to compute final measures

Platform: Measure Name (units)	**Rule Used to Compute Candidate Final Measure**									
	Avg of All (3) Trials		**Avg Best 2 of 3 Trials**		**Avg 1st 2 Trials**		**Best of 1st of 2 Trials**		**1st Trial**	
	r *	**Δ (%)****	**r ***	**Δ (%)****	**r ***	**Δ (%)****	**r ***	**Δ (%)****	**r ***	**Δ (%)****
BEP I Platform VAIPD (bits/s)	0.80	6.4	0.79	6.9	0.77	7.27	0.72	7.9	0.61	9.6
HPMM Platform VAIPD (bits/s)	0.75	8.1	0.74	8.3	0.61	9.36	0.43	10.5	0.23	15.5

r *= Pearson product moment correlation coefficient, the measure of reliability employed
Δ (%) **= average (across subjects) of | ((retest value-test value)/test value)*100|

From Table 4.2, the following observations are made:

- Pearson's r values are moderately high (0.75 – 0.80) for both platforms for measures based on the "average of all 3 trials" rule.
- There is a small decrease in reliability for both platforms when "the average of the best 2 of 3 trials" rule is used. Note that this would still require execution of three trials in order to compute this measure.

- There is a more substantial decrease in reliability for the case where the "average of the first 2 trials" rule is used. This case refers to the possibility of acquiring data from only two trials in the future and thus saving test administration time. The decrease in reliability (relative to the average of all 3 trials) is more substantial for the HPMM than for the BEP I.
- For remaining cases, reliability continues to the decline at a substantial rate for the HPMM, but less significantly for the BEP I.

Based on these observations, it was decided to select the "average of all 3 trials" as the rule for determining the final computation of VAIPD. One factor is the desire to use the same rule for both the BEP I and HPMM platforms. Another factor is that this rule produced the most reliable results, and the time savings associated with final results based on only two trials was not considered significant relative to the reduction in reliability (especially for the HPMM). All subsequent references to the measure "VAIPD" in this document will refer to this definition.

To further investigate and summarize VAIPD repeatability graphically, Figures 4.5a and 4.5b show test-retest scatter plots, with separate plots for BEP I and HPMM measures. These plots are quite similar for both platforms, showing a fairly tight distribution of points about the dashed line representing ideal test-retest agreement.

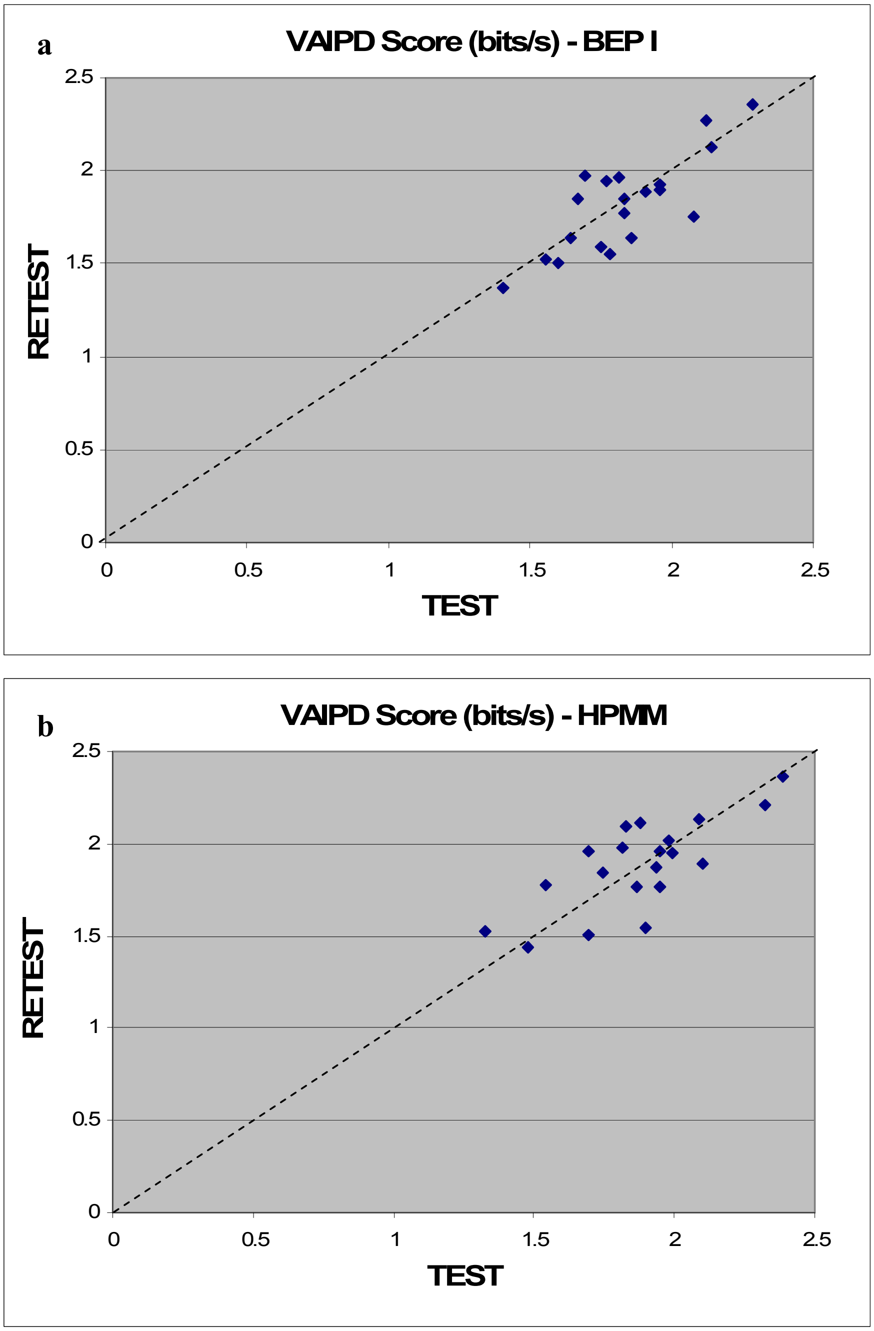

Figure 4.5 Test-retest scatter plot for VAIPD from (a) the BEP I; (b) the HPMM

4.3.2 Descriptive Statistics for Selected Final Performance Capacity Measures

Given that decisions have been reached regarding the rule to be used for computing the final test result (processing data across multiple trials), descriptive statistics can now be computed for the various measures. Tables 4.3 and 4.4 provide means, standard deviations, and coefficients of variation (CV) for measures derived from the VMMPC and VAIPD tests, respectively.

Table 4.3 Descriptive statistics for VMMPC test measures

	Test			**Retest**		
Platform: Measure Name (units)	**Mean**	**S.D.**	**C.V.(%)**	**Mean**	**S.D.**	**C.V.(%**
BEP I Platform						
VMMPC – Sum Composite (bits/s)						
- Dominant Side	08.0	0.82	10.3	08.0	0.93	11.7
- Nondominant Side	07.3	1.09	14.9	07.5	1.04	13.8
Primary Task – NMCC (bits/s)						
- Dominant Side	06.6	0.83	12.7	06.5	0.94	14.4
- Nondominant Side	05.9	1.05	17.8	06.1	1.04	16.9
Secondary Task – VIPC (bits/s)						
- Dominant Side	01.4	0.18	12.4	01.5	0.16	10.9
- Nondominant Side	01.4	0.17	12.1	01.4	0.19	14.1
HPMM Platform						
VMMPC – Sum Composite (bits/s)						
- Dominant Side	09.9	1.22	12.3	09.7	1.48	15.3
- Nondominant Side	07.7	0.98	12.6	08.0	1.60	20.1
Primary Task – NMCC (bits/s)						
- Dominant Side	08.3	1.21	14.5	08.1	1.44	17.8
- Nondominant Side	06.2	1.00	15.9	06.5	1.48	22.9
Secondary Task – VIPC (bits/s)						
- Dominant Side	01.6	0.14	08.9	01.6	0.15	09.3
- Nondominant Side	01.5	0.15	09.9	01.5	0.20	13.2

The most notable result from Table 4.3 is the range of VMMPC values (dominant vs. non-dominant) for the BEP I as compared to the HPMM. The HPMM shows an expected type of result, where dominant side scores are substantially greater than non-dominant side score for both the "test" and "retest" components of the experiment. For the BEP I, however, the difference between dominant and non-dominant side data is substantially less. Further examination of Table 4.3 shows that the VMMPC values obtained for the non-dominant side for the BEP I and HPMM platform are within 0.5 bits/s of each other, whereas the difference is much greater (approximately 1.8 bits/s) for the dominant side comparison, with BEP I results being substantially less. These observations further support the discussion regarding the impact of subject training on the results for the VMMPC test.

It is also useful to note that the numerical values obtained for the primary task (i.e., neuromotor channel capacity) and the secondary task (i.e., visual information processing capacity) are in expected ranges, based on previous studies (Mulukutla, 2005) in which these tasks were executed alone; i.e., not in a dual-task scenario.

For the descriptive data for the VAIPD test (Table 4.4), the similarity of results obtained on the BEP I and HPMM platforms is striking. Coefficients of variation are all typical for these types of measures. Given the level of complexity associated with the task, the coefficient of variation for the overall VAIPD measure was considered to be rather low for the group, representing a relatively narrow range of performance.

Table 4.4 Descriptive statistics for VAIPD test measures

Measure [units]	Test			Retest		
	Mean	**S.D.**	**C.V.(%)**	**Mean**	**S.D.**	**C.V.(%)**
BEP I Platform						
• VAIPD Score (bits/s)	1.83	0.22	11.8	1.82	0.26	14.1
• Processing Accuracy (%)	98.5	2.22	2.25	98.4	1.77	1.80
• Processing Speed (bits/s)	1.86	0.24	12.6	1.85	0.28	15.1
• Movement Speed (cm/s)	83.2	12.8	15.4	84.6	13.1	15.4
HPMM Platform						
• VAIPD Score (bits/s)	1.87	0.26	13.7	1.89	0.25	13.12
• Processing Accuracy (%)	98.1	1.44	1.47	98.5	1.85	1.88
• Processing Speed (bits/s)	1.91	0.27	13.9	1.92	0.27	13.9
• Movement Speed (cm/s)	42.5	9.79	23.0	44.5	7.19	16.2

4.3.3 Comparison of HPMM to BEP I measures

The BEP I is considered a "lab-based" instrument. The HPMM is a device which attempts to approximate certain aspects of the BEP I, as well as other lab-based instruments. Ideally, it would be desirable to think that the same performance capacities (e.g., VMMPC and VAIPD) are being measured whether using the HPMM or BEP I platform. However, it is recognized that the BEP I represents more of an "established reference", while the HPMM represents an approximate to the BEP I. Therefore, several basic comparisons of the measures obtained from each platform have been prepared in which results from the BEP I represent the standard of comparison.

Table 4.5 allows comparison of descriptive statistics (means, standard deviations, and coefficients of variation) for each platform for the VMMPC test. In addition, Figure 4.6 shows HPMM vs. BEP I scatter plots for VMMPC measures. Figures 4.7 and 4.8 allow comparison of performance on primary and secondary task components across the two platforms.

Table 4.5 Comparison of VMMPC measures obtained with the BEP I to those obtained with the HPMM. Only values from the "test" (not "retest") components are used

Measure [units]	**BEP I**			**HPMM**		
	Mean	**S.D.**	**C.V.(%)**	**Mean**	**S.D.**	**C.V.(%**
VMMPC – Sum Composite (bits/s)						
• Dominant Side	08.0	0.82	10.3	09.9	1.22	12.3
• Nondominant Side	07.3	1.09	14.9	07.7	0.98	12.6
Primary Task – NMCC (bits/s)						
• Dominant Side	06.6	0.83	12.7	08.3	1.21	14.5
• Nondominant Side	05.9	1.05	17.8	06.2	1.00	15.9
Secondary Task – VIPC (bits/s)						
• Dominant Side	01.4	0.18	12.7	01.6	0.14	08.9
• Nondominant Side	01.4	0.17	12.1	01.5	0.15	09.9

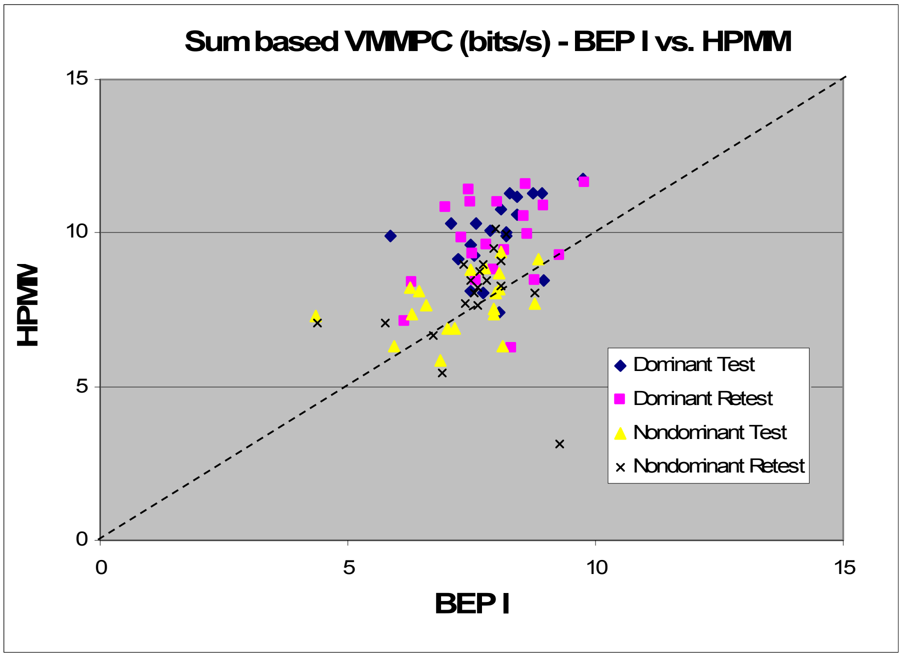

Figure 4.6 BEP I vs. HPMM scatter plot for VMMPC (bits/s)

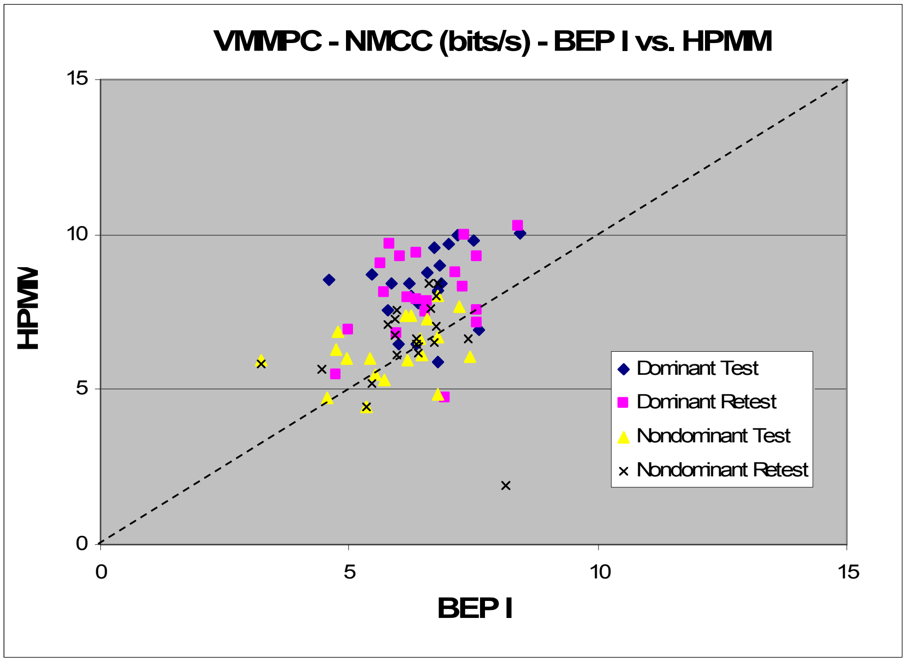

Figure 4.7 BEP I vs. HPMM scatter plot for VMMPC primary task score, neuromotor channel capacity (bits/s)

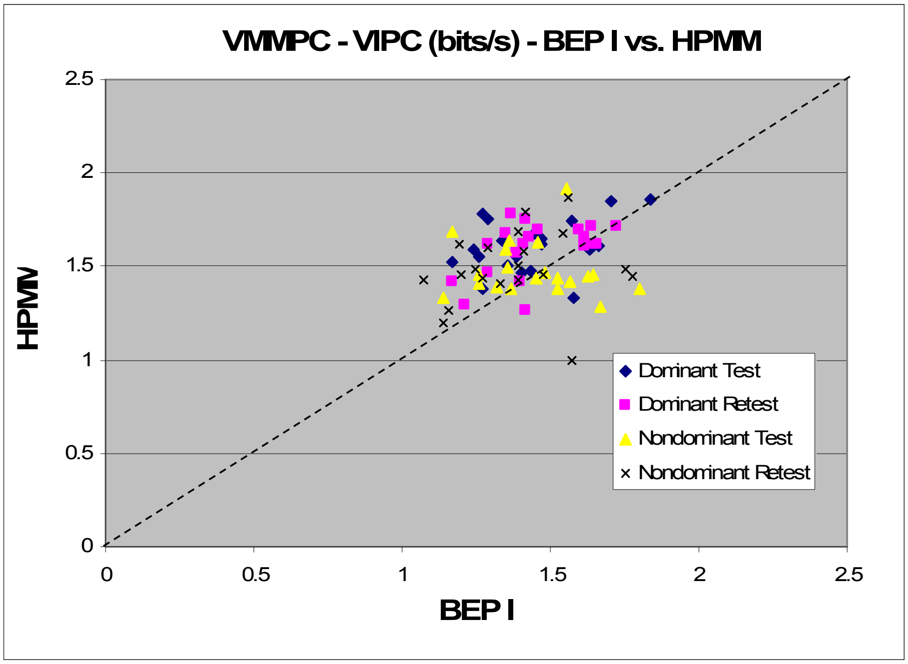

Figure 4.8 BEP I vs. HPMM scatter plot for VMMPC secondary task score, visual information processing capacity (bits/s)

Given the major physical differences between the BEP I and HPMM platform, the numerical values obtained for the VMMPC measures compare quite favorably. The most notable difference is the distance between primary task targets as well as the average distance between the primary task pathway and secondary task targets. One would expect that the primary task scores should be comparable, because Fitts' law takes into account the physical distances involved. It is clear, however from Table 4.5 and Figure 4.7 that neuromotor channel capacity values are slightly higher for the HPMM. This would tend to make the VMMPC values obtained with the HPMM also slightly higher. There is no good, simple reason to explain why the neuromotor channel capacity values would be higher on the HPMM at present.

It can also be observed that the secondary task measure (visual information processing capacity) is also slightly greater on the HPMM compared to the BEP I platform. This can be accounted for based on physical distances. The secondary task basically involves a reaction time paradigm. However, the subject’s hand can be located in a variety of different positions when a visual stimulus is presented. Reaction time is estimated as the time from when the stimulus is presented until the subject completes a response (as opposed to initiating a response). This unavoidably must include a contribution from movement time (i.e., not only reaction time). The average movement time component is longer on the BEP I because of the greater distances involved. This would tend to overestimate the reaction time values, resulting in visual information processing speed scores that are lower than they should be; i.e., artificially lower.

Table 4.6 allows comparison of descriptive statistics (means, standard deviations, and coefficients of variation) for each platform for the VAIPD test. In addition, Figure 4.9 shows the BEP I vs. HPMM scatter plot for VAIPD. Figures 4.10 and 4.11 allow comparison of performance on primary and secondary task components of VAIPD across the two platforms.

Table 4.6 Comparison of VAIPD measures obtained with the HPMM to those obtained with the BEP I. Only values from the "test" (not "retest") component of the test session are used

Measure [units]	**BEP I**			**HPMM**		
	Mean	**S.D.**	**C.V.(%)**	**Mean**	**S.D.**	**C.V.(%)**
VAIPD Score (bits/s)	1.83	0.22	11.8	1.87	0.26	13.7
• Processing Accuracy (%)	98.5	2.22	2.26	98.1	1.44	1.47
• Processing Speed (bits/s)	1.86	0.24	12.6	1.91	0.27	13.9
• Movement Speed (cm/s)	83.2	12.8	15.4	42.5	13.9	23.0

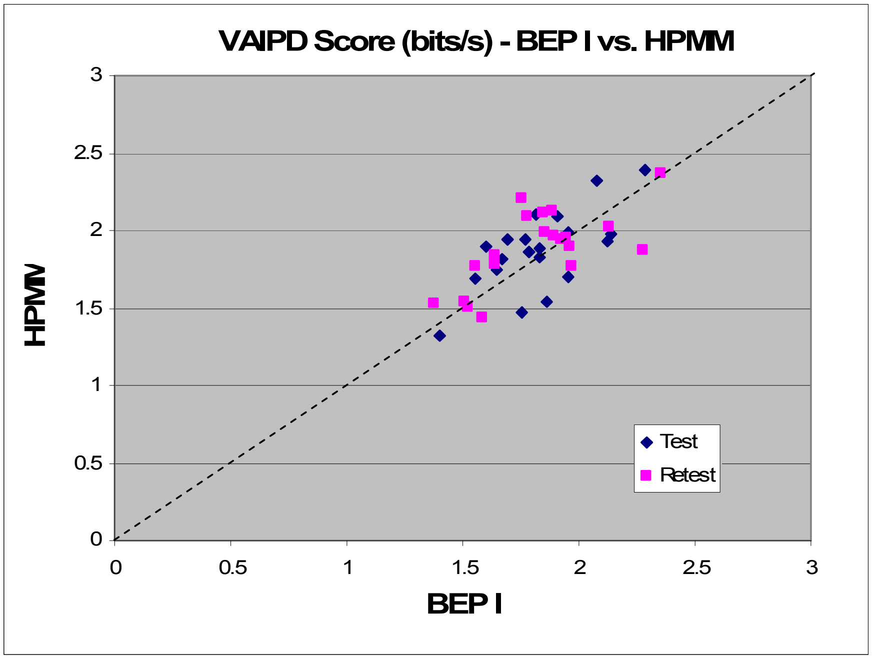

Figure 4.9 BEP I vs. HPMM scatter plot for VAIPD (bits/s)

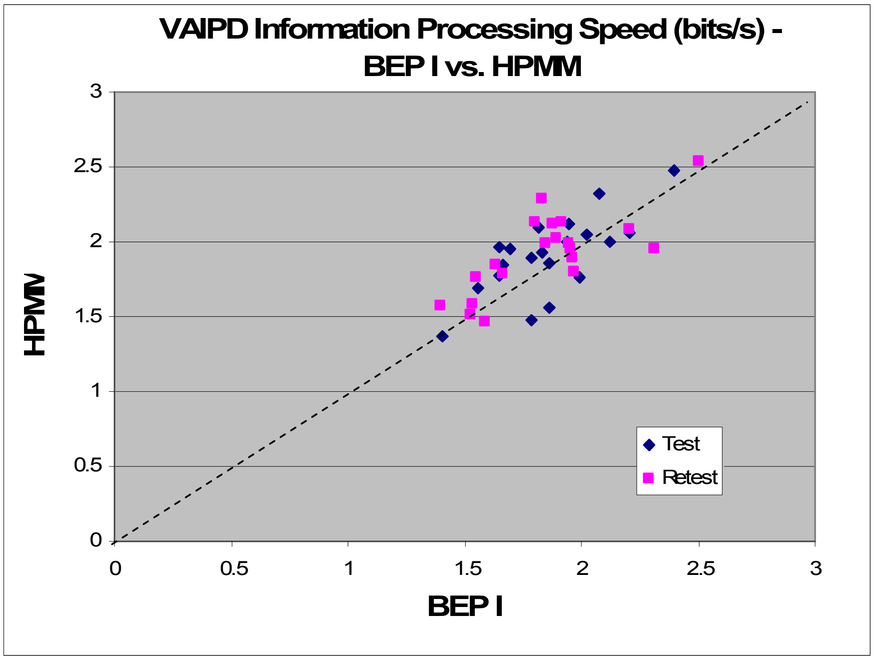

Figure 4.10 BEP I vs. HPMM scatter plot for VAIPD information processing speed measure (bits/s)

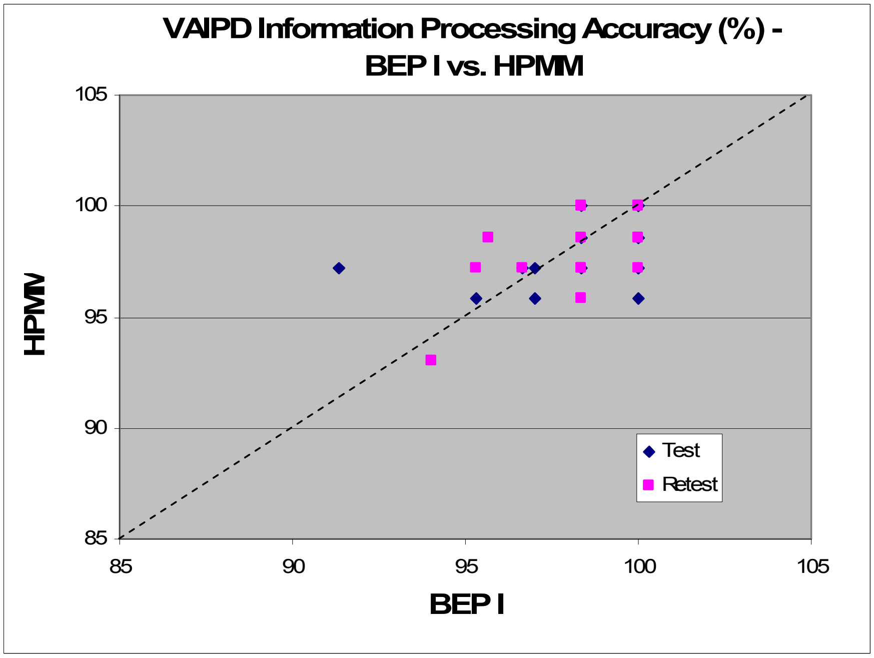

Figure 4.11 BEP I vs. HPMM scatter plot for VAIPD information processing accuracy measure (%)

For the VAIPD test, the agreement between the scores obtained with the HPMM and the BEP I is striking. Physical differences between the two platforms are less likely to be influential, because reaction time is measured from the time a stimulus is presented until the subject removes his or her hand from the HOME touch sensor. Thus, the distance between the HOME and other touch sensors involved do not enter into the computation of the major measures.

The movement speed measure is substantially different between the two platforms with it being slower on the HPMM (83.2 cm/s vs. 42.5 cm/s). This measure is not considered a primary measure of the test; it is simply a parameter that is measured. It is not “the” performance capacity that is maximally stressed during this task. Nonetheless, this difference is interesting. Subjects do travel a shorter distance on the HPMM. It is possible that they do not have time to reach as high of a peak movement speed because of this. The measure obtained, which is reflective of the average movement speed, is thus less.

To investigate the relation between the VMMPC and VAIPD tests, the dominant values of the test component from both the VMMPC and the VAIPD tests on the HPMM were compared. Pearson’s r was found to be -0.03 which implies that the tests are very much independent of each other. This is an excellent result since it shows that the two tests characterize different capacities. Given other construct aspects, this suggests that they represent difference capacities that are drawn upon in higher level situational awareness tasks.

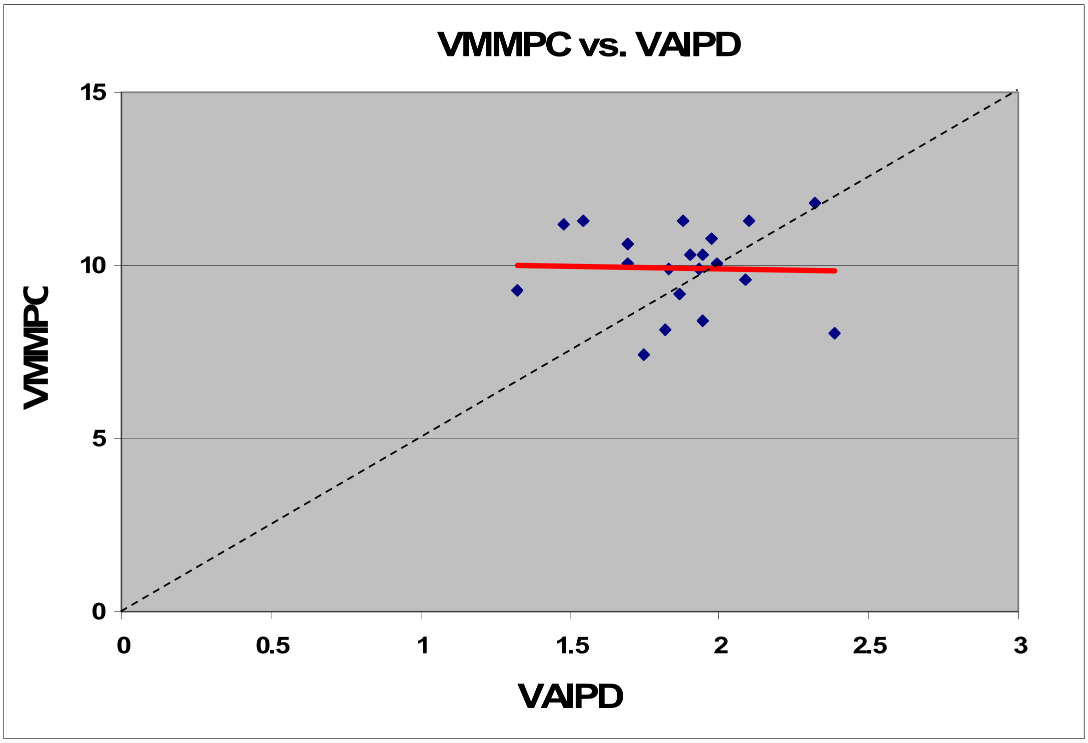

Figure 4.12 VMMPC vs. VAIPD scatterplot for independence

4.4 Discussion of Results

Cicchetti, (Cicchetti, 1994) has suggested the following reliability (r) guidelines for clinical significance: $r < 0.70$ – unacceptable ; $0.70 \leq r < 0.80$ – fair; $0.80 \leq r < 0.90$ – good; $r \geq 0.90$ – excellent. According to Cicchetti's guidelines, the test-retest reliability of the VMMPC measures are "unacceptable" for the BEP I, with the nondominant side case very close to the threshold for "acceptable". For the HPMM platform, the test-retest reliability is characterized as "fair". Given the previous discussion regarding the most likely cause of the somewhat "different" and unusual test-retest result obtained for just the BEP I dominant side case, the collective test-retest reliability of the VMMPC test is considered to be at least “acceptable”.

For the VAIPD measures, the test-retest reliabilities are interpreted at the high end of “fair” under the Cicchetti guidelines for both platforms.

All of the test-retest reliability results reported here must be considered in light of the population used in the study, which consisted primarily of healthy young adult subjects. This type of group characteristically exhibits low inter-individual variability (which is confirmed by the coefficients of variations obtained here). In effect, this “exercises” the measurements only over a relatively small portion of the range for which they are intended to measure (Kondraske, 2006c). In such cases where the distribution of data represents only a portion of the overall range of measurement, the computed Pearson product moment correlation coefficients will be lower than they would be if the subjects participating exhibited a wider range of performance. Thus, this represents a worst-case and rather conservative estimate of repeatability. Given the values of Pearson’s r obtained under the present conditions, it is very likely that all measures would move up at least one bracket on Cicchetti’s scale if the study simply included subjects exhibiting a larger inter-individual variability. Typically, this is not done in test-retest reliability studies since it is difficult to find and recruit subjects who exhibit “low performance” that is also stable over time. One must take care, however, not to incorrectly judge a measure as “not reliable” and perhaps take steps that would appear to improve reliability in healthy young adults but actually might reduce reliability and validity in the population of intended use.

For example, if additional trials were included, the test-retest reliability may improve in healthy young adults. However, in patients, fatigue may begin to play a larger role and the test may lose both validity and reliability.

The pattern of results in which dominant side performance is generally greater than non-dominant side performance, as well as the fact that values obtained for primary and secondary task scores are within expected ranges, provide a contribution to a basic level of validity for the VMMPC test.

CHAPTER 5

CONCLUSIONS AND FUTURE RESEARCH

This thesis addresses the measurement of two performance capacities that are argued to be lower level components of situational awareness. The following objectives have been achieved:

1. The design and implementation of the VMMPC and VAIPD tests on the BEP I were reviewed and documentation was enhanced as necessary.
2. Implementations of the VMMPC and VAIPD tests on the HPMM platform were defined, with results that closely mimic the respective lab-based implementations on the HPCMS's BEP I module.
3. Software was developed for the HPMM platform that implements the VMMPC and VAIPD tests, yielding a new version (version 4.1) of the HPMM.
4. The test-retest repeatability of the VMMPC and VAIPD measures were evaluated experimentally on both the HPCMS (BEP I) and HPMM platforms.
5. The results obtained for the VMMPC and VAIPD tests with the HPMM were compared to those obtained with the HPCMS (BEP I).

In this chapter, conclusions regarding the investigation of these two new performance capacity tests are summarized. In addition, recommendations for future research and development are provided.

5.1 Conclusions

Based on the experimental results and discussion in Chapter 4, conclusions have been formulated separately for each of the two tests on each of the two platforms. In addition, more general conclusions regarding each of the two tests are also presented.

For the VMMPC test on the BEP I platform, it is concluded that:

- A test should be based on three trials and the final result should be computed as the average of all three trials.
- By strict application of the rather conservative Cicchetti guidelines (Cicchetti, 1994), test-retest reliability is “unacceptable”. However, caution in this interpretation is warranted. The non-dominant side result, which was argued to be less likely impacted by subject training issues, is on the threshold of “acceptable”. Reasonable explanations exist for the low Pearson obtained for the dominant side. Especially in light of the reliability obtained for the HPMM implementation and the high similarity of BEP I and HPMM implementations, there is nothing to suggest an intrinsic flaw in this test. It is expected that closer attention to subject training procedures or use with subjects exhibiting larger inter-individual variability may alone remedy this result. If not, the use of additional trials (four or five) may be necessary.
- Basic evidence of validity exists. Dominant side results are generally better than non-dominant side results. Primary task scores are similar to those obtained in previous studies in which the primary task was executed alone. Secondary task

scores compare reasonably with two choice visual information processing speed test scores from previous studies when it was measured in a single-task scenario.

- Other than the unusual finding for dominant side test-retest reliability, overall results were generally positive. Continued use and development of this test on the BEP I platform is warranted.

For the VMMPC test on the HPMM platform, it is concluded that:

- A test should be based on three trials and the final result should be computed as the average of all three trials.
- According to the Cicchetti guidelines, test-retest reliability is interpreted to be “fair”.
- Agreement of values obtained to those obtained with the BEP I was modestly good. Perfect agreement is not expected due to physical device differences. A statistical model may be used to transform values obtained with the HPMM to be in better agreement with those obtained with the BEP I.
- Basic evidence of validity exists. Dominant side results are generally better than non-dominant side results. Primary task scores are similar to those obtained in previous studies in which the primary task was executed alone. Secondary task scores compare reasonably with two choice visual information processing speed test scores from previous studies when it was measured in a single-task scenario.

For the VMMPC test in general, it is concluded that:

- The dual-task scenario utilized is reasonable and can be executed by all healthy subjects with out major sources of confusion or other problems. The test has strong construct validity for measurement of a factor that relates in a meaningful way to situational awareness.
- The method by which subjects are instructed to do the test requires care so as not to mislead subjects regarding whether one aspect of the test is emphasized over another aspect.
- The test is challenging for healthy subjects, but appears to have a level of difficulty that would allow for execution by individuals with moderate impairments.
- The basic test appears to be adaptable to implementation on multiple platforms, with “acceptable” levels of test-retest reliability attainable.

For the VAIPD test on the BEP I platform, it is concluded that:

- A test should be based on three trials and the final result should be computed as the average of all three trials.
- According to the Cicchetti guidelines, test-retest reliability is found to be “good”.
- Basic evidence of validity exists. The VAIPD scores obtained were reasonable and reliable considering the fact that the subject is allowed to execute the task with his dominant hand for all test trials and the task itself is not complex.

For the VAIPD test on the HPMM platform, it is concluded that:

- A test should be based on three trials and the final result should be computed as the average of all three trials.
- According to the Cicchetti guidelines, test-retest reliability is found to be “fair”.
- Agreement of values obtained to those obtained with the BEP I was found to be very good except for the movement speed values. The movement speed values on the HPMM were low compared to the values on the BEP I because of the differences in physical dimensions of the two instruments. It is emphasized that “movement speed” is merely an ancillary measure of this test, however. The BEP I can capture the normal range of motions in a subject whereas the HPMM cannot do the same because of its smaller size.
- Basic evidence of validity exists. The VAIPD scores are found to be reasonable and reliable considering the fact that the subject is allowed to execute the task with his dominant hand for all test trials and the task itself is not complex.

For the VAIPD test in general, it is concluded that:

- The task methodology is good and can be executed by all healthy subjects with out confusion except for a minor issue with the BEP I, specifically situation 4, where at times the subject might get confused with the variety of different LEDs that may randomly be lighted. The test has strong construct validity for measurement of a factor that relates in a meaningful way to situational awareness.

The present conceptualization and approach to implementation method is deemed "sufficient" and requires no further improvements. The VMMPC and the VAIPD test results have been shown to be not correlated in this population of healthy subjects. Therefore, it is concluded that each test measures something different. Since, 1) each test itself has strong content and construct validity with regard to the relevance to situational awareness and 2) each test is shown to measure "something different", it is concluded that the combination of these two tests should be able to characterize two performance capacities that may go a long way toward characterizing the fundamental capacities that support situational awareness tasks.

5.2 Recommendations for Future Work

It is recommended that additional experimental work, aimed again at the study of test-retest reliability be carried out. The most basic additional work would simply involve adding subjects (e.g., doubling the number of subjects) to the current study, leaving all procedures the same. This was provided for in the protocol that was approved by the UTA Institutional Review Board. This would increase the sample size for both the VMMPC and VAIPD tests, although the primary interest here would be the VMMPC test. Procedures involving instructions to subjects for the VMMPC test should first be reviewed. Deviation from the scripts provided in the Appendix, which are sometimes motivated by subject questions, should be strictly avoided as this can introduce sources of variability.

Depending on the outcome of a new analysis with increased sample size, a new study may be warranted that focuses on the VMMPC. Procedures would be identical to the present study, except that five test trials should be performed for each body side. Current results suggest that the currently used three trials is perhaps "on the threshold" of producing good test-retest reliability. This will allow investigation of the impact of including a larger number of trials in the computation of "final" measures of the test on test-retest reliability. In addition, instructions to the subject should be reviewed and possibly revised, placing more emphasis on demonstration – and less on verbal descriptions. For words that remain part of the instructions, care should be taken to maximize unambiguous meaning. This perhaps could be investigated by careful study of questions asked by subjects after receiving instructions. It is therefore recommended that tests executed in a new study be videotaped to permit a systematic study of the examiner-test subject interactions.

For the VMMPC test, the orientation of the touch sensor-side of the HPMM was inverted. This clearly is not an ideal circumstance. As noted, the VMMPC test was conceived around the capabilities of the BEP I. The HPMM touch sensor array was designed prior to the existence of the VMMPC test as a concept. Given these circumstances, improvements to the touch sensor side of the HPMM are suggested. Specifically, two additional touch sensors should be incorporated. These should be clearly "associated" with the visual stimuli. Therefore, it is preferable that these touch sensors be located just to the inside of the LEDs (i.e., one just to the right of the left-side

LED and one just to the left of the right-side LED). The size of the touch sensors are tentatively planned to be 1.71 x 1.71 cm, which is about 1.5 times the size of the control touch sensor region (which were used as part of the secondary task in the present study). Larger targets should allow for faster response since the demand on accuracy is not as great. This will make the implementation of the VMMPC test on the HPMM more similar to that on the BEP I.

It is noted that the error region on the HPMM is divided into four regions namely, anterior, posterior, medial, and lateral regions. The current generation of hardware ties together anterior and posterior regions as well as medial and lateral regions, thus resulting in the ability to know if errors were “anterior-posterior” or “medial-lateral”. The execution of additional studies proposed above could include a study of the nature of error distribution during the VMMPC test. This may ultimately lead to revised performance scoring methods.

No specific recommendations are offered for the VAIPD test for either of the two platforms on which it was implemented and evaluated.

Another type of study is also warranted that addresses issues with both the VMMPC and VAIPD tests. In this study, the VMMPC test should be administered to subjects as well as the single task NMCC tests (i.e., the primary task component of the VMMPC test) and a two-choice visual information processing speed test (i.e., the secondary task component of the VMMPC test). The focus of the analysis would then be to explain and reconcile the results obtained. In addition, it is recommended that a single-task eight-choice visual information processing speed test and the VAIPD test be administered as part of this new study. Using the latter, the results from the two-choice visual information processing speed test, and the results from the VAIPD tests, it may be possible to infer the information processing loads associated with at least situations 1,2, and 3 employed in the VAIPD test.

APPENDIX A

INSTRUCTIONS TO TEST SUBJECTS AND EXAMINERS

VISUAL MOTOR MULTI-TASK PERFORMANCE CAPACITY (VMMPC) TEST

AND

VISUAL AUDITORY INFORMATION PROCESSING DEXTERITY (VAIPD) TEST

1.0. VISUAL MOTOR MULTI-TASK PERFORMANCE CAPACITY (VMMPC) TEST (GTA10 – HPMM Platform)

1.1. INSTRUCTIONS TO THE SUBJECT:

- The purpose of this test is to measure your response in tasks performed with your hand and arm in situations that stress coordination and which require that you focus on two tasks simultaneously.
- We will use this device (point out the device). There are two touch sensor regions (point out to subject). Each of these has a target and an error region (show these regions). Below each of these two touch sensor regions are two additional touch sensors (point out). There are also two lights, one to the left and the other to the right (point these out).
- In this test, you are asked to tap the target portion of the two large touch sensor regions alternately, from right to left or from left to right continuously while working as fast and as accurately as possible. Your finger should hit the small circle that serves as the target (Demonstrate the motion to the subject). Use the pad of your index finger to tap.
- While you are doing the fast alternating motion one of the lights will come on. You must be alert for this. When it happens you must tap the smaller square touch sensor on the same side as the light as quickly as possible and return to the alternating tapping task (Demonstrate).
- You must work to do the alternating motion as fast and as accurately as possible while also watching for the light and touching the appropriate small square touch sensor as quickly as possible when the light comes on.
- The test starts with a beep and lasts for 15 seconds. The end of the test will be signaled with a double beep.
- Work to do your best.

1.2. INSTRUCTIONS TO THE EXAMINER:

- Turn the HPMM over and show the subject the side with the target and error regions.
- Position the subject's chair and test module so that the shoulder of the arm involved is centered on the HPMM.
- Thus, when the right arm is used, the HPMM center will be slightly to the right of the body center, and vice-versa with the left arm.
- After selecting READY, you should position the device as described above. A single beep will occur and you may ask the subject to start performing the test whenever they are ready. The HPMM will start sampling only when the subject starts executing the primary movement (i.e. taps the left sensor then the right sensor and back to the left sensor consecutively, he/she can start with either the right or the left sensor).
- Since this test involves a trade-off between speed and accuracy, the best score is obtained when the subject is moving fast enough to make a few errors. Therefore, the subject's final score should show somewhere between 5-25% error factor (75-95% accuracy).
- Some impaired subjects may not be able to obtain accuracy rates this high. You should watch the subject and scores from early trials and try to achieve the best score by encouraging a slow subject to speed up and by reminding a subject with low accuracy on the primary task to be "more careful".

2.0. VISUAL AUDITORY INFORMATION PROCESSING DEXTERITY (VAIPD) TEST (GTA 11 – HPMM Platform)

2.1. INSTRUCTIONS TO THE SUBJECT:

- The purpose of this test is to measure your ability to recognize and process visual and sound information and respond to different patterns presented in an appropriate manner.
- In this test, we will use the two lights on this device, one to the left and the other to the right (point out). Below each of the lights, there are two large touch sensor regions of the HPMM. At the center of the panel is another touch sensor called the HOME touch sensor. In addition, the device can also generate "beep" sounds.
- The test is divided into four different situations, each of which has a correct response. You will start with your hand on the HOME sensor and then wait for one of four situations, determined by a combination of lights and beep sounds, to be presented:

  - If the left light comes on with no beep, you should respond by moving from the HOME sensor to the left touch sensor region as quickly as possible.
  - If the right light comes on with no beep, you should respond by moving from the HOME sensor to the right touch sensor region as quickly as possible.
  - If either the left or the right light comes on with a brief beep, you should always respond by moving from the HOME sensor to the left touch sensor region as quickly as possible.
  - If both lights come on with or without a beep sound, you must keep your hand on the HOME touch sensor.

- A tap on any other region other than that specified will count as an error. Use the pad of the index finger to touch the sensors. For this test, touching anywhere inside the large square touch sensor region will be OK. You do not need to aim for the small circle.
- A total of 24 situations will be presented one after another. After each one, put your finger back on the HOME sensor and stay alert for the next one. The whole test starts with a beep. It is over when you hear a double beep.
- Remember that the goal of this test is to perform as fast as possible when each situation is presented and to provide the correct response.

2.2. INSTRUCTIONS TO THE EXAMINER:

- After selecting the test and the READY option, orient the HPMM so that the touch sensor side is facing up and show the subject the parts of the device used in this test (e.g. lights, left and right touch sensors, and HOME sensor regions).
- Position the subject's chair and test module so that the shoulder of the arm involved is centered on the module.
- Thus, when the right arm is used, the module center will be slightly to the right of the body center, and vice-versa with the left arm.
- After selecting READY, the HPMM will start sampling only after it makes sure the subject is touching the HOME sensor continuously for a few seconds. A single beep signals the start of the test, a double beep ends the test.
- Be sure that the subject understands the instructions. The best way to achieve this is to run a practice trial.

3.0. VISUAL MOTOR MULTI-TASK PERFORMANCE CAPACITY (VMMPC) TEST (BEP I Platform)

3.1. INSTRUCTIONS TO THE SUBJECT:

- The purpose of this test is to measure your response in tasks performed with your hand and arm in situations that stress coordination and which require that you focus on two tasks simultaneously.
- We will use this device (point out the device). We will be using these two lights (point out light 4 and 5) and the two touch sensitive plates associated with these lights (point them out). In addition, we will also use these six touch sensitive regions (point out the touch sensors nearest to the test subject). The three plates on each side are termed as the target and error regions, the target region being the plate in the middle and the error regions the plates at the sides of the target (point it out). The narrow strip touch sensitive region on each side serves as a target.
- In this test you are asked to tap the target touch sensitive metal plates situated at the left and right sides of the device alternately, from right to left or from left to right continuously while working as fast and as accurately as possible. Use the pad of the index finger to tap.
- While you are doing the fast alternating motion, one of the lights will come on, one of the two lights that I pointed . You must be alert for this and when it happens you must tap the touch sensor in front of the light that came on as quickly as possible and then immediately return to the alternating tapping task (Demonstrate).
- You must work to do the alternating motion as fast and as accurately as possible while also watching for the light and touching the appropriate touch sensitive metal plate as quickly as possible when the light comes on.
- The test starts with a beep. The test lasts for 15 seconds and it ends with a flash of all the lights twice and a double beep.
- Work to do your best.

3.2. INSTRUCTIONS TO THE EXAMINER:

- Familiarize the subject with the parts of the BEP I that will be used during the course of the test (point out the left and right target and error regions, the plates corresponding to lights 4 and 5).
- Orient the BEP I so that the touch plates are easily accessible to the subject (not too close or too far).
- Position the subject’s chair and the BEP I so that the shoulder of the arm involved is centered on the module.
- Thus, when the right arm is used, the module center will be slightly to the right of the body center, and vice-versa with the left arm.
- Since this test involves a trade-off between speed and accuracy, the best score is obtained when the subject is moving fast enough to make a few errors. Therefore, the subject’s final score should show somewhere between 5-25% error factor (75-95% accuracy).
- Some impaired subjects may not be able to obtain accuracy rates this high. You should watch the subject and scores from early trials and try to achieve the best score by encouraging a slow subject to speed up and by reminding a subject with low accuracy on the primary task to be “more careful”.
- After selecting the test from the host computer, the BEP I will beep once to indicate the start of the test. A double beep and flash of all the lights twice indicates the end of the test. A test trial lasts for 15 seconds.

4.0. VISUAL AUDITORY INFORMATION PROCESSING DEXTERITY (VAIPD) TEST (BEP I Platform)

4.1. INSTRUCTIONS TO THE SUBJECT:

- The purpose of this test is to measure your ability to recognize and process visual and sound information and respond to different patterns presented in an appropriate manner.
- In this test, we will use these four lights (point out lights 3 to 6). The touch sensitive plates you tap for the test will be the plates associated with lights 4 and 5 and the HOME touch sensor (point out these features). The device will also generate "beep" sounds.
- The test is divided into four different situations, each of which has a correct response. You will start with your hand on the Home plate and then wait for one of four situations, determined by a combination of lights and beep sounds, to be presented:

    - If the fourth light comes on (point it out) with no beep, you should respond by moving from the HOME touch sensor (point it out) to the touch sensor in front of the fourth light (point it out).
    - If the fifth light comes on (point it out) with no beep, you should respond by moving from the HOME touch sensor (point it out) to the touch sensor in front of the fifth light (point it out).
    - If either the left or the right light comes on with a brief beep, you should always respond by moving from the HOME touch sensor to the touch sensor in front of the fourth light.
    - If any two of the four lights come on with or without a beep sound, you should respond by keeping your hand on the HOME touch sensor.

- A tap on any other region other than that specified will count as an error. Use the pad of the index finger to contact the touch plates.
- A total of 24 situations will be presented one after another. After each one, put your finger back on the home plate and stay alert for the next one. The whole test starts with a beep. It is over when you hear a double beep along with all the lights flashing twice.
- Remember the goal of this test is to perform as accurately and as fast as possible when each situation is presented.

4.2. INSTRUCTIONS TO THE EXAMINER:

- Familiarize the subject with the parts of the BEP I that will be used during the course of the test (point out the HOME touch sensor, the touch sensors associated with the fourth and fifth lights, and lights 3 through 6).
- Orient the BEP I so that the touch plates are easily accessible to the subject (not too close or too far).
- Position the subject's chair and the BEP I so that the shoulder of the arm involved is centered on the module.
- Thus, when the right arm is used, the module center will be slightly to the right of the body center, and vice-versa with the left arm.
- After selecting the test from the host computer, the BEP I will beep once to indicate the start of the test. A double beep and flash of all the lights twice indicates the end of the test.
- Be sure that the subject understands the instructions. The best way to achieve this is to run a practice trial.

APPENDIX B

COMPUTATION OF RESULTS OBTAINED WHEN EXECUTING

VISUAL MOTOR MULTI-TASK PERFORMANCE CAPACITY (VMMPC) TEST

AND

VISUAL AUDITORY INFORMATION PROCESSING DEXTERITY (VAIPD) TEST

1.0. VISUAL MOTOR MULTI-TASK PERFORMANCE CAPACITY (VMMPC) TEST (GTA10 – HPMM Platform)

1.1.0. Primary Task Measures

1.1.1. Movement Accuracy (%)

Movement Accuracy is measured in percent. The expected range is from 15% to 95%. It is desired to know and report this to the nearest hundredth of one percent; i.e., xxx.xx. The formula used is:

$$\text{Movement Accuracy (\%)} = \frac{\textit{Number of Accurate Responses} * 100{,}000}{\textit{Total Contacts}}$$

The *Number of Accurate Responses* will always be less than or equal to the *Total Contacts*. Both of these variables are integers. Assume that "99%" would be represented as the integer 99 (and not 0.99). To obtain the desired resolution while using just integer math routines, the result of the calculation shown above was designed to have units of:

"Movement Accuracy (%) x 1000"

For example, if the *Number of Accurate Responses* equaled the *Total Contacts* (100% accuracy), the formula above would yield the integer 100,000 as the result.

When implemented, the *Number of Accurate Responses* is an 8 bit variable. It is multiplied by a 24 bit variable containing the value 100,000. The multiplication routine produces a 32 bit integer result. Over the course of a 15 s test trial, the *Total Contacts* could certainly not exceed 100 (as limited by human movement speeds). This is perhaps an overly conservative estimate. Thus, the largest result possible from this multiplication is 100 contacts x 100,000 = 10,000,000. As the largest decimal number that can be represented with 3 bytes is $2^{24}-1 = 16{,}777{,}215$ (which is > 10,000,000), only the lower 3 bytes (24 bits) of the 32 bit result are relevant. The upper byte is discarded. The 24 bit value is then divided by a 16 bit variable containing the *Total Contacts*, providing a 24 bit result.

Consider an example where the *Number of Accurate Responses* = 25 and the *Total Contacts* = 30, then the computation will be as follows:

$$= \frac{25 * 100000}{30} = 83333 \text{ (integer).}$$

This corresponds to a Movement Accuracy of 83.33%.

The 24 bit binary number obtained as the result is converted to binary coded decimal form for display. A decimal point is inserted in the appropriate place to communicate the proper scaling. It is noted that only integers which conform to the format xxx.xx with desired resolution are extracted and displayed, for example if the binary result is 83333 then the Movement Accuracy is displayed as 083.33%.

1.1.2. Movement Speed (cm/s)

Movement Speed is measured in cm/s. The expected range is from about 10 cm/s to 100 cm/s. It is desired to calculate and represent this to the nearest hundredth of a centimeter; i.e., xxx.xx. The formula used is:

$$\text{Movement Speed (cm/s)} = \frac{\mathit{Total\ Contacts} * 1524000}{\mathit{Test\ Duration}}$$

where *Test Duration* has units of “sec x 1000” (i.e., it is the number of ms representing the *Test Duration*). To obtain the desired resolution while using just integer math routines (i.e., both the *Total Contacts* and the *Test Duration* variables contain only integers), the result of the calculation shown above was designed to have units of:

“Movement Speed (cm/s) x 100”

When implemented, a 24 bit variable is used to represent the target-to-target distance (15.24 cm) multiplied by 100,000. This yields the integer constant shown above in the numerator (1,524,000). An 8 bit variable is used to represent *Total Contacts.* The 8 bit *Total Contacts* and the 24 bit integer constant are multiplied to obtain a 32 bit result. The 32 bit product obtained is divided by a 16 bit variable containing the *Test Duration* (in ms) to produce a result that is represented in 32 bits. Here again, the upper byte is discarded and the rightmost 24 bits are considered as the answer, the result is limited to 24 bits because of physiological boundaries. Thus, if the *Total Contacts* = 30 and the *Test Duration* = 15 s, then the computation will be as follows:

$$= \frac{30 * 1524000}{15000} = 3048 \text{ (integer).}$$

This corresponds to a Movement Speed of 30.48 cm/s.

The 24 bit binary number obtained as the result is converted to binary coded decimal form for display. A decimal point is inserted in the appropriate place to communicate the proper scaling. A point of note here is that only integers which conform to the xxx.xx format with desired resolution are extracted and displayed, for example if the binary result is 3048 then the Movement Speed is displayed as 030.48 cm/s.

1.1.3. Neuromotor Channel Capacity (bits/s)

Neuromotor Channel Capacity (NMCC) is measured in bits/s. The expected range is from 1.0 bit/s to about 12.0 bit/s. It is calculated to the nearest hundredth of a bit/s; i.e., xx.xx. The formula used is:

$$\text{Neuromotor Channel Capacity (bits/s)} = \text{NMCC (bits/s)}$$

$$= \mathit{Index\ of\ Task\ Difficulty} * \mathit{Movement\ Accuracy} * \mathit{Movement\ Speed}$$

where the *Index of Task Difficulty* for the HPMM is 3.41 bits, *Movement Accuracy* (as used in this formula is in percent and 100% = 1.00), and *Movement Speed* is in motions per second. One motion consists of either a left-to-right or right-to-left movement.

$$\text{Movement Accuracy (\%)} = \frac{\mathit{Number\ of\ \ Accurate\ Responses} * 100{,}000}{\mathit{Total\ Contacts}}$$

and

$$\text{Movement Speed (motions/s)} = \frac{\mathit{Total\ Contacts}}{\mathit{Test\ Duration}}$$

To obtain the desired resolution while using just integer math routines, the formula and algorithm are designed to produce a result with units of:

"Neuromotor Channel Capacity (bits/s) x 100"

The formula used for NMCC is as follows:

$$= \frac{Total\ Contacts * 10 * Number\ of\ \ Accurate\ Responses * 341 * 100}{Test\ Duration * Total\ Contacts}$$

The scaling of x10 and x100 in the numerator account for the fact that *Test Duration* is expressed as an integer number of ms in the software. The constant 341 represents "100x" the *Index of Task Difficulty* (3.41 bits).

When implemented, the *Total Contacts* is represented by an 8 bit variable. This is multiplied by 10 to yield a result that is represented as a 16 bit product. The 16 bit product is multiplied with a 16 bit variable containing the *Index of Task Difficulty* multiplied by 100, 341 (3.41 * 100). This operation yields a 32 bit product. The upper byte is discarded, the logic of which follows. For example, assume that the *Total Contacts* = 70 and the *Number of Accurate Responses* = 50, then the computation thus far will be 70*10*50*341 = 11935000 in decimal (B61D18 in hexadecimal). As can be seen, the upper byte of the 32 bit product contains no value. Hence, after discarding the upper byte, the 24 bit product is multiplied by 100 to yield a 32 bit result. Note that the intermediate values obtained from each computation were scaled by multiples of 10 (x10, x100) so that even after division the required resolution is obtained using just integers (no floating point). The 32 bit product is divided by a 16 bit variable containing the *Test Duration* in ms (15000 ms). The 32 bit quotient obtained from the above operation is divided by a 16 bit variable containing the *Total Contacts*. The resulting quotient is represented as a 32 bit integer, of which the upper byte is discarded. This is because the result obtained is contained within the rightmost 24 bits due to physiological boundaries. Hence, the Neuromotor Channel Capacity * 100 is represented as a 24 bit integer. The 24 bit integer is converted to binary coded decimal form for display.

To elucidate better, let the *Total Contacts* = 70, the *Number of Accurate Responses* = 50 and the *Test Duration* = 15000 ms, then the computation will be as follows:

$$= \frac{70 * 10 * 50 * 341 * 100}{70 * 15000}$$

$$= \frac{1193500000}{1050000} = 1136 \text{ (integer).}$$

This corresponds to a NMCC of 11.36 bits/s.

The 24 bit binary number obtained as the result is converted to binary coded decimal form for display. A decimal point is inserted in the appropriate place to communicate the proper scaling. It is to be noted that only integers which conform to the format xx.xx with desired resolution are extracted and displayed, for example if the binary result is 1136 then the NMCC is displayed as 11.36 bits/s.

1.2.0. Secondary Task Measures

1.2.1. Response Accuracy (%)

Response Accuracy is measured in percent. The expected range is from 0% to 100%. It is calculated to the nearest hundredth of one percent; i.e., xxx.xx. To obtain the desired resolution while using just integer math routines, the formula used is:

$$\text{Response Accuracy (\%)} = \frac{\textit{Number of Correct Responses to Secondary Task} * 10{,}000}{\textit{Total Secondary Task Trials}}$$

As implemented now and for the foreseeable future, the maximum *Number of Secondary Task Trials* is about 10. The *Number of Correct Responses to Secondary Task* will always be less than or equal to the *Total Secondary Task Trials.* Both of these variables are integers. Assume that “99%” would be represented as the integer 99 (and not 0.99). To obtain the desired resolution while using integer math routines, the result of the calculation shown above was designated to have units of:

“Response Accuracy (%) x 100”

For example, if the *Number of Correct Responses to Secondary Task* equaled the *Total Secondary Task Trials* (100% accuracy), the formula above would yield the integer 10,000 as the result.

When implemented, the 8 bit variable containing the *Number of Correct Responses to Secondary Task* is multiplied with a 16 bit variable containing 10,000. The multiplication routine results in a 24 bit product which is divided by a 16 bit variable containing the *Total Secondary Task Trials*, resulting in a 24 bit Response Accuracy.

As an example, let the *Number of Correct Responses to Secondary Task* = 4 and the *Total Secondary Task Trials* = 6, then the computation will be as follows:

$$= \frac{4 * 10000}{6} = 6666 \text{ (integer).}$$

This corresponds to a Response Accuracy of 66.66%.

The 24 bit binary number obtained as the result is converted to binary coded decimal form for display. A decimal point is inserted in the appropriate place to communicate the proper scaling. It is to be noted that only integers which conform to the format xxx.xx with desired resolution are extracted and displayed, for example if the binary result is 6666 then the Response Accuracy is displayed as 066.66%.

1.2.2. Processing Speed (bits/s)

Processing Speed is measured in bits/s. The expected range is from about 0.50 bits/s to about 4.0 bits/s. It is calculated to the nearest hundredth of a bit/s; i.e., xx.xx. The formula used is:

$$\text{Processing Speed (bits/s)} = \text{Average of} \left[\frac{\mathit{1\ bit}}{\mathit{Reaction\ Time\ \ for\ each\ Secondary\ Task\ Trial}} \right]$$

where *Reaction time* here for each Secondary Task has units of “seconds”.

To facilitate the use of integer math, the above equation is expanded and modified as follows:

$$\text{Processing Speed (bits/s)} = \frac{\left[\frac{100000}{RT_1} + \frac{100000}{RT_2} + \ldots\ldots + \frac{100000}{RT_n} \right]}{N}$$

RT_n – *Reaction Time* associated with Secondary Task Trial “n”.
N – *Total Secondary Task Trials.*

The “1 bit” is replaced by 100000 since the *Reaction Time* is represented in its equivalent ms range (i.e., in integer format), this is so that the result obtained after division will be of required resolution using just integers and no floating point values. To obtain the desired resolution while using just integer math routines, the result of the calculation shown above was designed to have units of:

“Processing Speed (bits/s) x 100”

When implemented, the 24 bit variable containing 100,000 is divided by the 16 bit variable containing the *Reaction Time* obtained for each secondary task. The resultant 24 bit quotient is summed across all N trials and stored. This stored resultant 24 bit sum (*Sum of Processing Speeds*) is also utilized later when calculating the Visual Information Processing Capacity. The 24 bit sum is divided by a 16 bit variable containing the *Total Secondary Task Trials*. The resulting Processing Speed is represented as a 24 bit integer. Thus, for example, consider there are two reaction times recorded for two secondary tasks (3000 ms and 500 ms respectively), then the computation will be as follows:

$$= \frac{\frac{100000}{3000} + \frac{100000}{500}}{2} = \frac{33 + 200}{2} = \frac{233}{2} = 116 \text{ (integer).}$$

This corresponds to a Processing Speed of 1.16 bits/s.

The 24 bit binary number obtained as the result is converted to binary coded decimal form for display. A decimal point is inserted in the appropriate place to communicate the proper scaling. It is to be noted that only integers which conform to the format xxx.xx with desired resolution are extracted and displayed, for example if the binary result is 116 then the Processing Speed is displayed as 01.16 bits/s.

1.2.3. Visual Information Processing Capacity (bits/s)

Visual Information Processing Capacity is measured in bits/s. The expected range is from about 0.50 bits/s to 2.50 bits/s. It is calculated to the nearest hundredth of a bit/s; i.e., xx.xx. The formula used is:

Visual Information Processing Capacity (bits/s) = *Response Accuracy* * *Processing Speed*

$$= \frac{\textit{Number of Correct Responses to Secondary Task}}{\textit{Total Secondary Task Trials}} * \frac{\textit{Sum of Processing Speeds}}{\textit{Total Secondary Task Trials}}$$

When implemented, the 8 bit variable containing the *Number of Correct Responses to Secondary Task* is multiplied with the 24 bit variable containing the *Sum of Processing Speeds*, saved earlier when computing the Processing Speed. The upper 8 bits are discarded from the 32 bit result obtained. This is because the result obtained is contained within the rightmost 24 bits due to the range limits of the measure. The overall denominator value is obtained by multiplying the 8 bit variable containing the *Total*

Secondary Task Trials by itself yielding a 16 bit result. The 24 bit numerator is divided by the 16 bit denominator to yield a 24 bit Visual Information Processing Capacity.

To elucidate better, let the *Number of Correct Responses to Secondary Task* = 4, *Sum of Processing Speeds* = 700, *Total Secondary Task Trials* = 6, then the computation will be as follows:

$$= \frac{4 * 700}{6 * 6} = \frac{2800}{36} = 77 \text{ (integer).}$$

This corresponds to a Visual Information Processing Capacity of 0.77 bits/s.

The 24 bit binary number obtained as the result is converted to binary coded decimal form for display. A decimal point is inserted in the appropriate place to communicate the proper scaling. It is to be noted that only integers which conform to the format xx.xx with desired resolution are extracted and displayed, for example if the binary result is 77 then the Visual Information Processing Capacity is displayed as 00.77 bits/s.

2.0. VISUAL AUDITORY INFORMATION PROCESSING DEXTERITY (VAIPD) TEST (GTA11 -HPMM Platform)

2.1. Accuracy (%)

Accuracy is measured in percent. The expected range is from 85% to 100%. It is desired to know and report this to the nearest hundredth of a percent; i.e., xxx.xx. (range). The formula used is:

$$\text{Accuracy (\%)} = \frac{Number\ \ of\ \ Correct\ \ Responses\ \ *\ 10000}{Total\ \ Situation\ Trials}$$

The *Number of Correct Responses* will always be less than or equal to the *Total Situation Trials*. Both these variables are integers. Assume that “99%” would be represented as the integer 99 (and not 0.99). To obtain the desired resolution while using just integer math routines, the result of the calculation shown above was designed to have units of:

“Accuracy (%) x 100”

For example, if the *Number of Correct Responses* equaled the *Total Situation Trials* (100% accuracy), the formula above would yield the integer 10,000 as the result.

When implemented, an 8 bit variable containing the *Number of Correct Responses* is multiplied with a 16 bit variable containing 10,000. The resultant 24 bit variable is divided by the 16 bit variable containing the *Total Situation Trials* to yield accuracy of 24 bits.

As an illustration, let the *Number of Correct Responses* = 22 and *Total Situation Trials* = 24, then the computation will be as follows:

$$= \frac{22 * 10000}{24} = \frac{220000}{24} = 9166 \text{ (integer).}$$

This corresponds to an Accuracy of 91.66 %.

The 24 bit binary number obtained as the result is converted to binary coded decimal form for display. A decimal point is inserted in the appropriate place to communicate the proper scaling. It is to be noted that only integers which conform to the format xxx.xx with desired resolution are extracted and displayed, for example if the binary result is 9166 then the Accuracy is displayed as 091.66%.

2.2. Processing Speed (bits/s)

Processing Speed is measured in bits/s. The expected range is from about 1.2 bits/s to 3.0 bits/s. It is desired to know and report this to the nearest hundredth of a bit/s; i.e., xx.xx. The formula used is:

$$\text{Processing Speed (bits/s)} = \text{Average of}\left[\frac{\mathit{1\ bit}}{\mathit{Situation\ \ Reaction\ Time}}\right]$$

where, in the above, *Reaction Time* for each situation has units of "seconds".

To facilitate the use of integer math, the above equation is expanded and modified as follows:

$$\text{Processing Speed (bits/s)} = \frac{\left[\frac{100000}{RT_1}+\frac{100000}{RT_2}+\cdots\cdots+\frac{100000}{RT_n}\right]}{N}$$

RT_n – *Reaction Time* associated with situation trial "n".

N – *Number of Situation Trials* for situations 1, 2 and 3 = 18 (There are four types of situations, numbered 1 –4. It is not possible to compute a *Reaction Time* for Situation 4 (See main text for details).

In the equation above, 1 bit is scaled by 100000 since the *Reaction Time* is now considered in its equivalent ms range and it is desired that the result obtained after division has the required resolution using just integer math and no floating points. To achieve this, the result of the calculation shown above was designed to have units of:

"Processing Speed (bits/s) x 100"

When implemented, the 24 bit variable containing 100,000 is divided by a 16 bit variable containing the *Reaction Time* obtained for each situation trial (excluding trials for situation 4). The 16 bit quotient, discarding the upper 8 bits since the result obtained is contained within the rightmost 16 bits due to measurement range limits, is iterated for each situation trial (18 times) and saved. The resultant 16 bit sum obtained is divided by the 16 bit variable containing the *Number of Situation Trials (18)*, yielding a 16 bit result. Here the result is 16 bits for which an empty (containing zeroes) upper byte is added to make it 24 bits, so that it is compatible when computing the conversion from 24 bit binary to 4 byte BCD.

To elucidate the computation, consider the *Sum of Processing Speeds* for each of the 18 situations = 8612 and the *Number of Situation Trials* = 18, then the computation will be as follows:

$$= \frac{8612}{18} = 478 \text{ (integer).}$$

This corresponds to a Processing Speed of 4.78 bits/s.

The 24 bit binary number obtained as the result is converted to binary coded decimal form for display. A decimal point is inserted in the appropriate place to communicate the proper scaling. It is to be noted that only integers which conform to the format xx.xx with desired resolution are extracted and displayed, for example if the binary result is 478 then the Processing Speed is displayed as 04.78 bits/s.

2.3. Movement Speed (cm/s)

Movement Speed is measured in cm/s. The expected range is from 10 cm/s to 120 cm/s. It is calculated to the nearest hundredth of a cm/s; i.e., xxx.xx. The formula used is:

$$\text{Movement Speed (cm/s)} = \frac{8.255\, cm}{\textit{Average of Movement Times for 18 Trials}\ (\textit{Sit 1, 2, and 3})}$$

$$= \frac{8.255 * N}{\left[MT_1 + MT_2 + \cdots\cdots + MT_n\right]}$$

MT_n – *Movement Time* associated with situation trial “n”.
N – *Number of Situation Trials* associated with situations 1, 2 and 3 = 18.

$$= \frac{8255 * 1800}{\left[MT_1 + MT_2 + \cdots\cdots + MT_n\right]}$$

Here the numerator constant is sufficiently scaled and the *Movement Times* have been converted to their equivalent ms range. This is so that even after dividing the numerator constant by the *Sum of Movement Times* the required resolution is obtained in just integers and not floating point.

$$= \frac{14859000}{\left[MT_1 + MT_2 + \cdots\cdots + MT_n\right]}$$

To obtain the desired resolution while using integer math routines, the result of the calculation shown above was designed to have units of:

“Movement Speed (cm/s) x 100”

When implemented, the numerator contains the constant 14859000 which is the product obtained after multiplying the distance between the home sensor and the left/right target sensor (8.255 cm) by the *Number of Situation Trials* (comprising situations 1,2 and 3 = 18). It is multiplied by 100000 to yield a 24 bit numerator. The numerator is divided by a 16 bit variable containing the *Sum of Movement Times* for all the 18 situations, the quotient is 24 bits. The resulting Movement Speed obtained is of 24 bits. As an example, let us consider the *Sum of Movement Times* for all 18 situations = 2500 ms, then the computation will be as follows:

$$= \frac{14859000}{2500} = 5943 \text{ (integer).}$$

This corresponds to a Movement Speed of 59.43 cm/s.

The 24 bit binary number obtained as the result is converted to binary coded decimal form for display. A decimal point is inserted in the appropriate place to communicate the proper scaling. It is to be noted that only integers which conform to the format xxx.xx with desired resolution are extracted and displayed, for example if the binary result is 5943 then the Movement Speed is displayed as 059.43 cm/s.

2.4. Visual Auditory Information Processing Dexterity Score (bits/s)

Visual Auditory Information Processing Dexterity Score is measured in bits/s. The expected range is from 0.5 bits/s to 3.5 bits/s. It is desired to know and report this to the nearest hundredth of a bit/s; i.e., xx.xx. The formula used is:

$$\text{Visual Auditory Information Processing Dexterity Score (bits/s)} = \mathit{Accuracy} * \mathit{Processing\ Speed}$$

$$= \mathit{Accuracy} * \mathit{Average\ of} \left[\frac{1\, \mathit{bit}}{\mathit{Situation\ Reaction\ Time}} \right]$$

$$= \frac{Accuracy * Sum\ of\ \ Processing\ Speeds}{Number\ of\ \ Situation\ Trials\ (Sit1,2,and3)}$$

When implemented, the 16 bit variable containing the *Sum of Processing Speeds* is multiplied with the 16 bit variable containing the *Accuracy*, previously obtained. The 32 bit product is divided by the *Number of Situation Trials* (18), yielding a 32 bit score. The upper byte is discarded because the result obtained is contained within the rightmost 24 bits due to physiological boundaries to yield Visual Auditory Information Processing Dexterity Score in 24 bits. As an example, let *Accuracy* obtained previously, prior to fixed point scaling = 9167, *Sum of Processing Speeds* = 8608 and the *Number of Situation Trials* = 18, then the computation will be as follows:

$$= \frac{9167 * 8608}{18} = \frac{78909536}{18} = 4383863 \text{ (integer)}$$

This corresponds to a Visual Auditory Information Processing Dexterity Score of 4.38 bits/s.

The 24 bit binary number obtained as the result is converted to binary coded decimal form for display. A decimal point is inserted in the appropriate place to communicate the proper scaling. It is to be noted that only integers which conform to the format xx.xx with desired resolution are extracted and displayed, for example if the binary result is 4383863 then the Visual Auditory Information Processing Dexterity Score is displayed as 04.38 bits/s.

3.0. INTEGER RESULT TO BCD CONVERSION (GTA 10 and 11)

Each of the computations described above produces a binary result. The result contains an appropriate scaling (e.g., x 100, x1000, etc.) to allow representation of a measure with a desired resolution using an integer format. For proper display, the binary number is converted to binary coded decimal (BCD) format (i.e., a series of BCD values) and a decimal point is inserted in the proper location to "account for" the scaling incorporated to allow all calculations to be performed in integer (vs. floating point) form.

For every measure the final computation is tailored such that it gives a 24 bit result. As previously noted, the 24 bit result is then converted to a BCD format. For all measures, this is always a 4 byte BCD format, thus providing eight BCDs. This means that an integer of up to 8 digits having a value less than 16,777,216 can be represented. These eight BCDs are numbered "1" through "8", with "1" being the right-most digit:

Location	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**
Example Value	0	0	8	0	0	0	0	0

From this eight digit result, it is necessary to: 1) select the location of what will be the most significant digit in the displayed result, 2) specify the number of digits to be extracted for use in the final result, and 3) specify the location of the decimal point in the displayed result. As currently implemented, if a given measure has a value that is less than the maximum allowed by the number of digits specified, leading zeroes are displayed. For example, 80.00% will be displayed as 080.00%. The table below provides the required information for each of the measures.

After the appropriate BCDs have been extracted from the initial four byte BCD result, each of the BCD values is then converted to its equivalent character code as given in the LCD datasheet (T6963C).

Parameters	**MSD Start**	**No. of Digits**	**No. of Places to the Right of the Decimal Point**
VMMPC Primary Task: Movement Accuracy (%)	6	5	2
Primary Task: Movement Speed (cm/s)	5	5	2
Primary Task Main Score: Neuromotor Channel Capacity (bits/s)	4	4	2
Secondary Task: Response Accuracy (%)	5	5	2
Secondary Task: Processing Speed (bits/s)	4	4	2
Secondary Task: Visual Information Processing Capacity (bits/s)	4	4	2
VAIPD Accuracy (%)	5	5	2
Processing Speed (bits/s)	4	4	2
Movement Speed (cm/s)	5	5	2
Visual Auditory Information Processing Dexterity Score (bits/s)	8	4	2

APPENDIX C

INSTITUTIONAL REVIEW BOARD DOCUMENTS

THE UNIVERSITY OF TEXAS
AT ARLINGTON

INFORMED CONSENT

PRINCIPAL INVESTIGATOR: George V. Kondraske, Ph.D.

TITLE OF PROJECT: Investigation of Information Processing and Cognitive Performance Capacities with Different Stimulus-Response Configurations

This Informed Consent will explain about being a research subject in an experiment. It is important that you read this material carefully and then decide if you wish to be a volunteer.

PURPOSE

The purpose of this research study is to evaluate two tests related to the ability of humans to process information and recognize situations. Two different physical configurations of the tests are being studied to determine if there are major differences in the results obtained with each set-up and to gain insight into the performance scores of healthy subjects. The results obtained will help in the development of tests that may be useful in vocational and rehabilitation applications, as well as in the evaluation of neurologic diseases.

DURATION

You are being asked to participate in one session lasting approximately 30 minutes. Up to 40 subjects are expected to participate. Data collection will take place in Room 241 Nedderman Hall, the main lab of the Human Performance Institute at the University of Texas at Arlington.

PROCEDURES

You will undergo a series of brief tests in order to measure selected “performance resource capacities” associated with information processing and simple hand-eye coordination tasks. There are two types of tests in two different experimental set-ups. Each test involves making simple motions of the fingers and arms as rapidly as you can in response to visual and auditory signals. You will be asked to perform the tests to the best of your ability. The series of tests will be repeated twice during the session, with a five minute break in between.

POSSIBLE RISKS/DISCOMFORTS

There are few potential risks involved in this study. During the testing, you may experience some fatigue or possibly some frustration with your ability to perform the tasks.

POSSIBLE BENEFITS

By participating in this study, you will be assisting in the evaluation of a new measurements that may benefit many others in the future. This study is expected to lay the groundwork for future work that may prove to be valuable for the early diagnosis of neurologic diseases, the evaluation of the effectiveness of new therapies, and in decision-making such as fitness for driving. In addition, you may also learn about some aspects of human information processing and performance.

ALTERNATIVE PROCEDURES/TREATMENTS

There are no alternative procedures for this study. However, you may choose not to participate.

CONFIDENTIALITY

Every attempt will be made to see that your study results are kept confidential. A copy of the records from this study will be stored in Nedderman Hall Room 215 for at least three (3) years after the end of this research. The results of this study may be published and/or presented at meetings without naming you as a subject. Although your rights and privacy will be maintained, the Secretary of the Department of Health and Human Services, the UTA IRB, the FDA (if applicable), and personnel particular to this research (individual or department) have access to the study records. Your (e.g., student, medical) records will be kept completely confidential according to current legal requirements. They will not be revealed unless required by law, or as noted above.

CONTACT FOR QUESTIONS

If you have any questions, problems or research-related medical problems at any time, you may call Dr. George Kondraske at 817/272-2335 or Mr. Saju Mathew at 817/272-3454. You may call the Chairman of the Institutional Review Board at 817/272-1235 for any questions you may have about your rights as a research subject.

VOLUNTARY PARTICIPATION

Participation in this research experiment is voluntary. You may refuse to participate or quit at any time. If you quit or refuse to participate, the benefits (or treatment) to which you are otherwise entitled will not be affected. You may quit by notifying Dr. Kondraske or Mr. Mathew at any time either in person or by calling 817/272-2335. You will be told immediately if any of the results of the study should reasonably be expected to make you change your mind about staying in the study.

By signing below, you confirm that you have read or had this document read to you. You will be given a signed copy of this informed consent document. You have been and will continue to be given the chance to ask questions and to discuss your participation with the investigator.

You freely and voluntarily choose to be in this research project.

INVESTIGATOR APPROVED TO ADMINISTER CONSENT DATE

SIGNATURE OF VOLUNTEER DATE

REFERENCES

Callaghan, J.T., Cerimele, B.J., Kassahun, K., Nyhart, E.H., Hoyes-Beehler, P.J., Kondraske, G.V. (1997). Olanzapine: interaction study with imipramine. J. Clinical Pharmacology, October, 971-978.

Charter, R.A. (2003). A breakdown of reliability coefficients by test type and reliability method, and the clinical implications of low reliability. The Journal of General Psychology, July, v130 i3, 290(15).

Cicchetti, D.V. (1994). Guidelines, Criteria, and Rules of Thumb for Evaluating Normed and Standardized Assessment Instruments in Psychology. Psychological Assessment, vol. 6, No.4, 284-290.

Endsley, M. R. (1995). "Toward a theory of situation awareness in dynamic systems". Human Factors, 37(1), 32–64.

Endsley, M. R. (1988). Situation awareness global assessment technique (SAGAT). Proceedings of the National Aerospace and Electronics Conference (NAECON). New York: IEEE, 789-795.

Fitts, P.M. (1954). The information capacity of the human motor system in controlling the amplitude of movement, J. Exp. Psychol., vol. 47, 381-391.

Fleishman, E. A. & Quaintance, M. K. (1984). Taxonomies of Human Performance. The Description of Human Tasks, Orlando, FL: Academic Press, Inc.

W. E. Hick. (1952). On the rate of gain of information. Quarterly Journal of Experimental Psychology, 4, 11-26.

Kauranen, K. and Vanharanta, H.(1996). Influences of aging, gender, and handedness on motor performance of upper and lower extremities, Perceptual and Motor Skills, vol. 82, 515-525.

Kondraske, G.V. (1982). Design, Construction, and Evaluation of an Automated Computer-Based System for Quantification of Neurologic Function. Doctoral Dissertation, Arlington, TX: The University of Texas at Arlington.

Kondraske, G.V., Potvin, A. R., Tourtellotte, W. W., & Syndulko, K. (1984). A computer-based system for automated quantification of neurologic function. IEEE Trans Biomed Eng, 31(5), 401-414.

Kondraske, G.V. (1987a). Looking at a young science: The study of human performance. SOMA: Engineering for the Human Body, American Society of Mechanical Engineering, 50-53.

Kondraske, G.V. (1987b). Human performance: Science or art? Thirteenth Northeast Bioengineering Conference. Philadelphia: Proceedings, 44-47.

Kondraske, G. V. (1990). A PC-based performance measurement laboratory system. J of Clin Engr, 15(6), 467-478.

Kondraske, G.V. (1992). Palmtop Size Human Performance Multi-Meter (HPMM) for Crew Monitoring. NASA SBIR Proposal.

Kondraske, G. V. (1995). An elemental resource model for the human-task interface. International Journal of Technology Assessment in Health Care, 11(2), 153-173.

Kondraske, G.V. (1999). Determination of Fitts' index of performance using constructs of General Systems Performance Theory and implications for motor control performance capacity measurement. Abstracts, 17th Annual Houston Conference on Biomedical Engineering Research, A. M. Sherwood, (Ed.), Houston, 86.

Kondraske, G.V. (2000). Performance theory: implications for performance measurement, task analysis, and performance prediction. CD-ROM Proceedings of the World Congress on Medical Physics and Biomedical Engineering, July 23-28, (4 pgs).

Kondraske, G.V. and Vijai, J. (2004). Human information processing: measurement of performance resources supporting situational awareness (HPI Technical Report TR2004-002R, Version 1.0), Arlington, TX: University of Texas at Arlington Human Performance Institute.

Kondraske, G.V. Vijai, J., and Mathew, S.J. (2006). Human information processing: measurement of performance resources supporting situational awareness (HPI Technical Report TR2004-002R, Version 2.0), Arlington, TX: University of Texas at Arlington Human Performance Institute

Kondraske, G.V., Mathew, S.J., Mulukutla, R., and Sriwatanapongse, W. (2006). Appendix A: Design and Implementation Support Materials for Specific HPMM Performance Capacity Tests, Human Performance Multimeter (HPMM): Conceptualization and Design Evolution. HPI Technical Report TR2000.005R, Version 3.3, Arlington, TX: The University of Texas at Arlington Human Performance Institute.

Kondraske, G. V. (2006a). The Elemental Resource Model for Human Performance. In J. Bronzino (Ed.), The Biomedical Engineering Handbook 3rd Edition: Biomedical Engineering Fundamentals, 75.1-75.19, Boca Raton: CRC Press, Taylor & Francis.

Kondraske, G.V. (2006b). Personal communication. September 12, 2006.

Kondraske, G.V. (2006c). Human performance engineering: Challenges and prospects for the future. In J Bronzino (Ed), The Biomedical Engineering Handbook 3rd Edition: Biomedical Engineering Fundamentals, 85.1-85.10, Boca Raton: CRC Press, Taylor & Francis.

Kondraske, G.V., & Vasta, P. J. (2006). Measurement of information processing subsystem performance capacities. In J. Bronzino (Ed.), The Biomedical Engineering Handbook 3rd Edition: Biomedical Engineering Fundamentals, 78.1-78.14, Boca Raton: CRC Press, Taylor & Francis.

Kondraske, G.V., Mulukutla, R. and Stewart, R.M. (2006). Investigation of a Portable Performance Measurement System for Neurologic Screening in Clinics. CD-ROM Proceedings of the 28th Int. Conf. of the IEEE Engineering in Medicine and Biology Society, New York, Aug 30 – Sept 3, 3962-3965.

Parasuraman, R. and Davies, D.R., eds. (1984). Varieties of Attention, Orlando, FL: Academic Press, Inc.

Potvin, A.R., Tourtellotte, W.W., Potvin, J.H., Kondraske, G.V., and Syndulko, K. (1985). The Quantitative Examination of Neurologic Function, Boca Raton, FL: CRC Press.

Sarter, N. B. & Woods, D. D. (1991). How in the world did I ever get into that mode: Mode error and awareness in supervisory control. Human Factors, 37(1), 5-19.

Schneider, W. and Shiffrin, R.M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. Psychological Review, 84, 1-66.

Shannon, C.E. (1948). A mathematical theory of communication. The Bell System Technical Journal. 27(3), 379-423.

Shiffrin, R.M. and Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. Psychological Review, 84, 127-90.

Smith, S.S. and Kondraske, G.V. (1987). A computerized system for quantitative measurement of sensorimotor aspects of human performance. Physical Therapy, 67(12), 1860-1867.

Swaine, B.R. and Sullivan, S.J. (1992). Relation between clinical and instrumented measures of motor coordination in traumatically brain injured persons. Arch Phys Med Rehabil, vol. 73(1), 55-59.

Swaine, B.R. and Sullivan, S.J. (1993). Reliability of the scores for the finger-to-nose test in adults with traumatic brain injury, Physical Therapy, vol. 73(2), 71-78.

Walker, G.H., Stanton, N.A., Young, M.S. (2006). The ironies of vehicle feedback in car design, Ergonomics, 49(2), 161 – 179.

Wickens, C.D. (1984). Engineering psychology and human performance,
Columbus, OH: Charles E. Merrill Publishing Co.

Wickelgren, W.A. (1977). Speed-accuracy tradeoff and information processing dynamics. Acta Psychologica (North-Holland), 41, 67-85.

Wikipedia (2006) Situational awareness.

http://en.wikipedia.org/wiki/Situational_awareness.

BIOGRAPHICAL INFORMATION

The author was born in Fahaheel, Kuwait in the year 1977. He received his Bachelor of Engineering degree in Instrumentation and Applied Electronics from M.S.Ramaiah Institute of Technology at Bangalore, India in the year 2000. He received his Master of Science degree in Biomedical Engineering from the University of Texas at Arlington in the year 2007.