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Investigation of a Portable Performance Measurement System for Neurologic Screening in Clinics

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***Abstract* –Motivated by the need for clinical screening for early detection of neurologic disease, a prototype portable instrument dubbed the Human Performance MultiMeter (HPMM) was developed. The HPMM is based on a set of lab-based performance capacity tests developed and evaluated over the last two decades. We attempted to integrate selected functionality of a set of modular lab-based instruments into a single, small package. In the present study, a 4th generation prototype was developed and evaluated for usability, measurement repeatability, and preliminary measurement validity. Five performance capacity tests (upper extremity coordination, isometric grip strength, simple response speed, rapid alternating movement, and steadiness/tremor) were administered to twenty healthy adult volunteers. Short-term reliability was investigated using a test-retest protocol. Most measures were found to possess good test-retest reliability (r>0.75). Preliminary validity was investigated by comparing results to those obtained with non-portable devices that served as models for the HPMM. Results were in good agreement with those instruments. It is concluded that measures of good fidelity can be obtained with this type of instrument.**

I. Introduction

There has been growing interest in early detection of neurologic diseases such as Parkinson's Disease and Alzheimer's Disease. While relatively low-cost screening tools suitable for widespread use exist for cardiovascular and other systems, the method currently in widespread use for neurologic screening is largely based on subjective observation and lacks sensitivity. This has motivated the use of more objective and quantitative performance tests [1]-[3]. Set-ups to do such performance tests generally require a separate lab room and the instruments would not be considered to be portable. To access the widest population base, we envision a small device that could be part of general practitioner's office and perhaps be used by a nurse or physician's assistant during routine check-ups or as an initial follow-up to patient reported concerns.

Given this context, a prototype portable instrument dubbed the Human Performance MultiMeter (HPMM) was developed. The tests performed with the HPMM are based on a set of lab-based performance capacity tests [3] developed and evaluated 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 a stand-alone mode (other modes incorporated in the design are not described here), the HPMM could be used to measure generic quantities such as force, speed, etc. Coupled with predefined procedures, specific measurements could be obtained that would represent strength of different muscle groups (from force), speed of movement about specific joints (from speed measurements), etc. The HPMM thus attempts to leverage advancements in sensor, microcontroller, and low-power instrumentation technology to integrate selected, proven aspects of measurement functionality from our modular lab-based instruments [3] into a small, easy-to-use package. In the present study, a 4th generation prototype was developed and evaluated [4] for usability, measurement repeatability, and preliminary measurement validity.

The HPMM was designed as a flexible hardware platform that could support the implementation of currently envisioned as well as future performance capacity measurements. The 4th generation platform (Fig. 1) consists of a main unit (20.5 cm x 13.5 cm x 3.8 cm) including: 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 (using Quantum QT310 and QT320 ICs), 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.

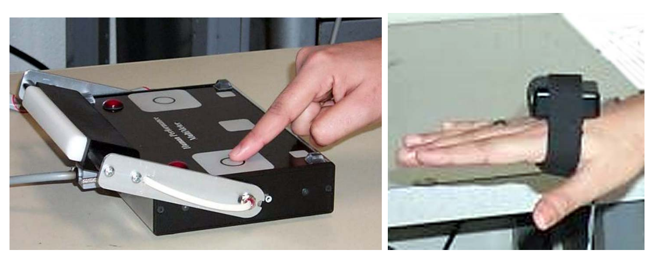

Fig. 1. HPMM Main Unit (left) with "LCD/touch screen side" facing the table and "touch sensor array side" facing subject. RSM affixed to the hand (right) for steadiness/tremor measurement.

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.

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Main components of software include user interface and a set of "generic test algorithms" (GTAs), one for each type of performance capacity test. Each of these is briefly described below. All measures are defined using concepts of General Systems Performance Theory, thereby producing results where a larger numerical value always represents a larger performance capacity (i.e., greater performance resource availability) [5].

II. Methodology

Subjects: Twenty subjects (10 male, 23-28 yrs; 10 female, 23-26 yrs), self-declared to be healthy and taking no medications, volunteered for the study which was reviewed and approved by the University of Texas at Arlington Institutional Review Board. Each subject was administered the five types of performance capacity tests twice, with a ten-minute break between sessions. Dominant (D) and non-dominant (N) sides were tested separately. A given "test" consisted of a predetermined number of trials, the results of which are subsequently processed to determine the final result.

Measures – General: The five GTAs studied collectively produce 13 different measures. These are categorized as primary, secondary and exploratory. Primary measures represent "the result"; i.e., that which is of most interest and possesses the characteristics, in the context of the respective test, of a true performance capacity measure [5]. This paper focuses on primary measures.

Isometric Strength: The generic isometric strength test measures the force production capacity of a muscle subsystem or group of subsystems. Depending on procedures, this can measure the amount of force resisted or generated by a subject. For the study, grip strength was measured. Here the seated subject is instructed to squeeze the grip sensor (i.e., the "handle" of main unit) after hearing a beep that signals the test start. Once the applied force exceeds given threshold (30N), the microcontroller samples the sensor output for 3 seconds. Thereafter, the subject is instructed to relax. Sampling continues until such time as the applied force falls below the same threshold. The result of a trial is the maximum force generated. The final result is the average of the best two of three trials. To test other muscle subsystems, the examiner holds the entire HPMM with the handle locked in position along the long edge of the housing, places the opposite edge (which is padded) against a body segment, and generates increasing force while the subject attempts to maximally resist.

Simple Visual Response Speed: This test utilizes the two LEDs and one sensor on the touch sensor array in a basic reaction time paradigm. The subject is instructed to place the index finger of the dominant hand on the "HOME" touch sensor. This is sensed and after a subsequent random delay (1-3 s), both LEDs are lighted. The time it takes the subject to lift his or her arm and remove the finger from the touch sensor is measured. The reciprocal of this time (responses per second) is computed as the trial result. The final result is the average of the best three of five trials. As the focus is on central information processing, only the dominant side hand is utilized in the test.

Rapid Alternating Movement: This type of motion is of general interest in neurology and has long been utilized to probe the integrity of neuromotor subsystems. Generically, a subject is instructed to produce reciprocal motion "as fast and as steadily as possible" about an isolated joint for a brief fixed time. Finger tapping performance is a specific instance of such a test and was used in this study.

Either the left or right touch sensor array groups can be utilized at the subject's discretion. Motion is restricted to flexion-extension about the metacarpophalangeal joint. After the examiner selects the test and positions the HPMM, a start alert beep is issued. A special filter algorithm is used to avoid false automated recognition of the start of the test due to any inadvertent touches. Upon passing this check (i.e., the characteristics of reciprocal motion are detected), touch sensor outputs are sampled at 100 Hz for 10 s and the times of touch sensor state transitions (i.e., touch start and touch end times) are logged. This data is analyzed immediately after the trial to compute three results: the tap speed (primary), tap duty-cycle mean (primary) and tap duty-cycle standard deviation (exploratory). The latter two are intended to address consistency of the motion. All three contribute to characterization of motion quality. Two trials are performed; the average of each measure across trials is used as the final result.

Neuromotor Channel Capacity (NMCC): This test has only one practical mode with the present platform; specifically, measurement of upper extremity NMCC associated with translational motion. NMCC (primary measure) is based on Fitts' Law and has been argued [6], [7] to be an objective measure of a coordination performance resource, reflecting the combination of speed and accuracy of movement (secondary measures) when both are stressed.

Utilizing the HPMM touch sensor array, the subject is asked to alternately tap the left and right circular touch sensor regions ("targets") "as fast and as accurately as possible" for 10 s. Data acquisition is essentially the same as that described for the rapid alternating movement test (e.g., continuous 10 ms interval samples of all the touch sensors are logged). This data is processed to count "hits" and "misses". From this data and knowledge of the test duration, speed and accuracy are computed. The primary measure is the obtained as:

$$\text{NMCC (bits/s)} = \text{Speed x Accuracy x} \log_2(A/W + 1)$$

Speed is in motions/s, accuracy is the fraction of attempts resulting in target "hits" (i.e., 0 – 1.0), and the third term is a version of Fitts' index of task difficulty [8] where A = center-to-center target separation and W = target width. This definition has been shown to produce results that are equivalent to the traditional statement of Fitts' Law [6]. Three trials are performed and the average of all trials is used as the final result.

Steadiness/Tremor: This test utilizes the RSM-1 (Fig. 1) and its MEMS-based accelerometer and angular rate sensor inertial technology. We have expanded our approach to include a combination of translational and rotational motion. While translational motion measurement is accelerationbased (g's), rotational motion measurement is rate-based (deg/s). Two degrees of freedom (DOFs) for each are utilized to obtain a result incorporating 4-DOFs of motion.

The RSM-1 can be applied to any body segment; the same generic algorithm is used to process data and determine results. Hand-arm steadiness (with the arm parallel to the floor) is used in the present study. The RSM-1 is mounted to the dorsum of the subject's hand and the subject is instructed to hold their outstretch arm "as steady as possible" for 10 s. Signal conditioned sensor outputs are sampled at a rate of 100 Hz. Calibrated sensor offsets are automatically subtracted from each sample and the results are time averaged. The result is inverted to obtain translational (X and Y RSM axes) and rotational (about the X and Y axes) steadiness measures with units of 1/g and s/deg respectively. This leads to four secondary measures. To obtain a single number composite result, we relied on concepts of General Systems Performance Theory [5], [6]. The four results were thus multiplied to obtain one single number result called the composite or 4-DOF steadiness.

Data Analyses: Descriptive statistics (mean, standard deviation, and coefficient of variation) were computed for each measure, treating dominant and non-dominant side data separately. In addition, the absolute value of the difference between Session 1 and Session 2 was computed for each subject's data and expressed as a percentage of the Session 1 measurement value. These values were averaged across subjects to provide a single number indicator of repeatability; e.g., mean of the absolute value of percent change (not reported here). Reliability measures were also computed between Session 1 and Session 2. Both intraclass correlation coefficients (ICC(3,1)) and Pearson product moment correlation coefficients were computed using SPSS version 12 and Microsoft Excel 2003, respectively.

III. Results

Table I contains selected descriptive statistics and reliability coefficients for primary measures.

TABLE I
DESCRIPTIVE STATISTICS AND RELIABILITY COEFFICIENTS (PEARSON'S r) FOR PRIMARY MEASURES

Measure	Side	Mean ± SD	r
Grip Strength (newtons)	D	311.9 ± 114.7	0.86
	N	321.3 ± 114.6	0.94
Visual-Hand Simple Response Speed (resp/s)	D	5.59 ± 0.53	0.83
Index Finger Rapid Alternating Movement: Speed (taps/s)	D	5.27 ± 0.57	0.87
	N	4.84 ± 0.52	0.83
Index Finger Rapid Alternating Movement: Mean Duty Cycle (%)	D	34.6 ± 7.7	0.80
	N	36.7 ± 6.7	0.78
Neuromotor Channel Capacity (NMCC) - Upper Extremity (bits/s)	D	8.2 ± 1.3	0.34
	N	6.3 ± 1.0	0.39
Hand-Arm 4-DOF Steadiness (s^2/deg^2g^2)	D	8302 ± 6279	0.63
	N	9007 ± 11482	0.95

Reliability as computed with the ICC(3,1) and the Pearson product moment correlation produced essentially equivalent results (typical for the sample size utilized here). Scatter plots further illustrating selected test-retest results are shown in Fig. 2 – 7.

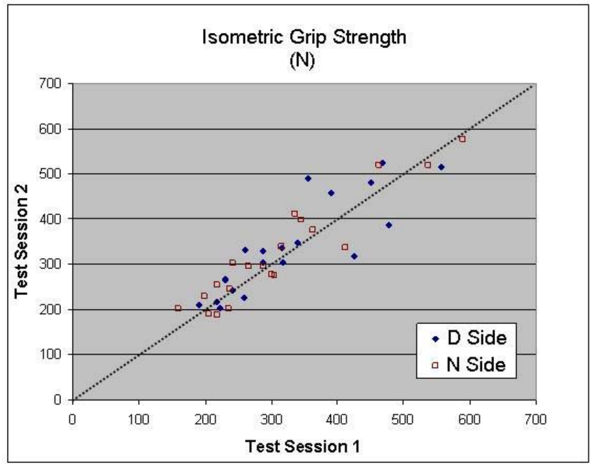

Fig. 2. Grip strength test-retest scatter plot.

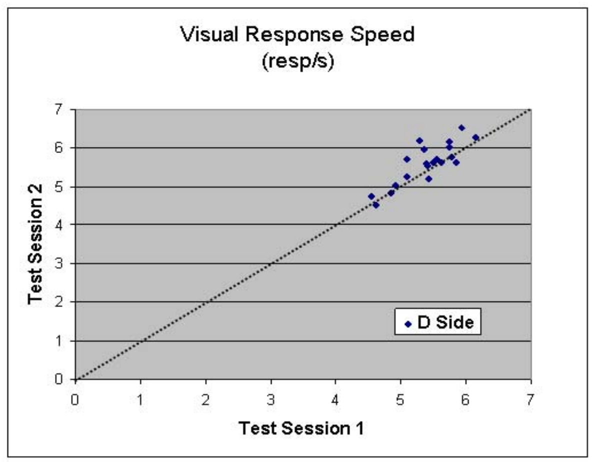

Fig 3. Simple visual-response speed scatter plot.

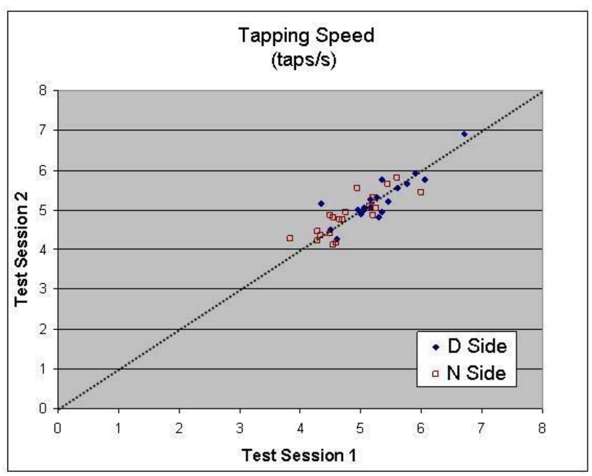

Fig. 4. Rapid alternating movement (index finger flexion-extension tapping) scatter plot.

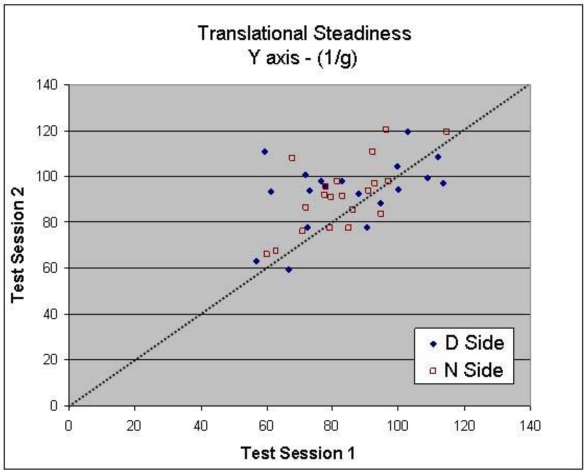

Fig. 5. Sample (Y axis) translational steadiness scatter plot.

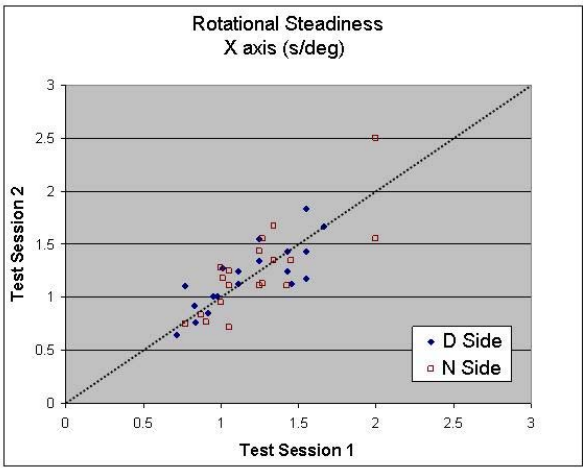

Fig. 6. Sample (about X axis) rotational steadiness scatter plot.

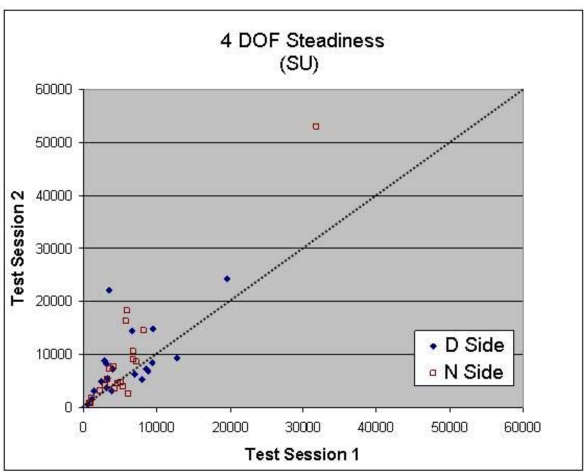

Fig. 7. Composite steadiness measure scatter plot (SU = "steadiness units" - see text).

IV. DISCUSSION

Given the healthy young adult subjects, which generally exhibit narrow inter-individual variability (and is therefore a "worst-case" test of repeatability), reliability was considered high for all primary measures except NMCC; we repeated the analysis by pooling D and N side data and the r value increased to 0.58 (as expected for the larger distribution). Behavior for this measure is marginal for early detection use and we anticipate further investigation (e.g., instrument positioning, difficulty interpreting instructions, etc.). The high reliability exhibited by the 4-DOF steadiness/tremor composite measure was particularly interesting and supports the unique method used to compute this composite score.

With regard to validity, measures demonstrated expected patterns of behavior (e.g., see Table I and Fig. 4, where D side values are larger than N side for coordination-oriented measures). Values obtained also agree well with lab-based measurements for subjects with similar characteristics. No comparable steadiness data was available.

No major usability problems were noted with the instrument or procedures for these five tests. Minor revisions to user-interface are planned based on new ideas resulting from the experience gained in this study.

V. CONCLUSION

The HPMM version studied has been shown to provide a simple means to obtain objective measures of encouraging fidelity. There are obviously tradeoffs to be made in the design of such a compact system that attempts to capture the functionality and level of performance obtained with more sophisticated systems that have "more natural" dimensions.

We envision a three-tiered approach to neurologic screening and assessment: 1) T1 (most accessible) - self-administered web-based performance capacity tests and questionnaires, 2) T2 - "general clinic" based (i.e., not staffed by a neurologist) with an instrument such as the HPMM serving as an objective measurement tool used under supervised conditions, and 3) T3 - "lab-based", incorporating the highest fidelity instruments, more sophisticated and perhaps more-lengthy procedures, and specialized expertise.

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