Low-cost, quantitative motor assessment

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Abstract: Using custom software and an inexpensive novel motion capture sensor, we adapted and automated traditional subjective motor assessments in an integrated system to develop a quantitative motor assessment (QMA) that is quick, low-cost, and highly sensitive. We then established a normative database of unimpaired motor behavior with fifty young, healthy research participants (25 male and 25 female, 18-30 year-old subjects). We expect that the sensitivity, objectivity, low cost, portability, and ease of use make the QMA a useful and accessible tool to clinicians as well as researchers.

Introduction

There is a nationally recognized need for more sensitive motor assessments to evaluate and diagnose motor impairments following traumatic brain injury (TBI). Between 2001 and 2010 the incidence of emergency department visits and hospitalizations due to TBI increased by 70% (Centers for Disease Control and Prevention, 2014). Conventional neurological exams employed to assess TBI-induced motor deficits rely on subjective observations that often fail to detect subtle injuries. Correctly identifying movement impairments is critical for diagnosing movement disorders, determining prognosis, and prescribing an appropriate rehabilitation program. Emerging technology now makes it possible to easily, accurately (Weichert et al., 2013) and inexpensively capture finger and hand movements. The purpose of our research is to 1) exploit this technology to develop a quantitative motor assessment (QMA) that is clinically relevant, easy to administer, low-cost, and highly sensitive, and 2) establish a normative database to allow comparison of a patient's motor assessment relative to a healthy norm.

To this end, we developed a system based on traditional motor tests using low-cost markerless motion capture. Our system consists of an $80 Leap Motion sensor (Figure 1c) and custom software. This system automates traditional motor tests and measures the position of finger tips with a resolution of 0.01mm and a sampling frequency of 100Hz. We have seeded a normative database by administering this QMA to 50 control subjects.

Methods

Quantitative Motor Assessment

To develop the QMA, we first defined the assessments and their parameters, and then programmed tests to administer these assessments in an integrated system with a graphical user interface (GUI) and the Leap Motion sensor. We based the assessments in the QMA on conventional motor exams that have both significant utility to the clinician and adaptability to the motion capture modality. The tests and measures that comprise the QMA are shown in Table 1. To allow for comparison with traditional assessments, we included 3 traditional tests as well: Halstead-Reitan Finger Tapping Test, grip strength, and the Beery Visual Motor Integration Test.

Table 1

QMA Test	Behavioral Attributes	Measures
Balance	Postural stability	Mean path of the crown of the head Max A-P Sway Max M-L Sway
Finger Oscillation	Strength Movement efficiency	Number of taps Regularity (approximate entropy) of taps
Postural Tremor	Postural tremor	Power spectrum area
Reaction Time	Processing time	Reaction time
Visually Guided Movements	Visuomotor control Intention tremor	Dysmetria Power spectrum area

Administering the QMA and establishing a normative database

Participants

Fifty healthy subjects (age range 18-30 years; 23 females, 27 males) participated in this study. To be included, participants were required to be right-handed, free of any movement disorder or medications that interfere with movement or alertness, and not pregnant.

Participants were placed in front of a computer screen (Figure 1A) and presented with a GUI specific to the given QMA task. The user's fingertip (or hand, depending on the task) was represented by a ball-shaped cursor (or virtual hand) on the screen and moved as the user moved (Figure 2). The tasks were performed in random order. Positions and velocities of the finger tips and palm were recorded at 100 Hz. Movements were performed by both hands. The entire assessment required 1 hour 45 minutes.

Each subject performed the following QMA tests:

Balance

The sensor was mounted on a tripod and participants wore a helmet with two dowels attached. Participants stood with feet together and hands across the chest by the tripod so that the dowels extended over the sensor (Figure 1B). They held that position in each of five different conditions for 30s each while their sway was recorded. The five conditions were:

- Hard surface eyes open
- Hard surface eyes closed
- Soft surface eyes open
- Soft surface eyes closed
- Tandem stance, preferred foot in front

Figure 1 Test setup. for most tests (A), subjects pointed to objects on a screen while a Leap Motion sensor (C) captured their movements. In the balance test (B), subjects' head sway was extracted from the motion of dowels attached to a helmet.

Finger Oscillation Test

The GUI for the finger oscillation task (Figure 2A) contained two parallel lines, spaced 15mm apart, a black ball representing the user's finger, and a set of crosshairs marking the starting point. While viewing the GUI participants were instructed to "tap" their finger in the air as fast as possible so that the black ball on the screen moved below and then above the two parallel lines. Each trial lasted 10s, with 30-90s rest between trials. Our system tallied the number of taps during each trial. Movements in which the ball did not cross both the bottom and top lines were not included. The assessment was complete when the subject performed 5 trials within 5 oscillations of each other (10 trials max).

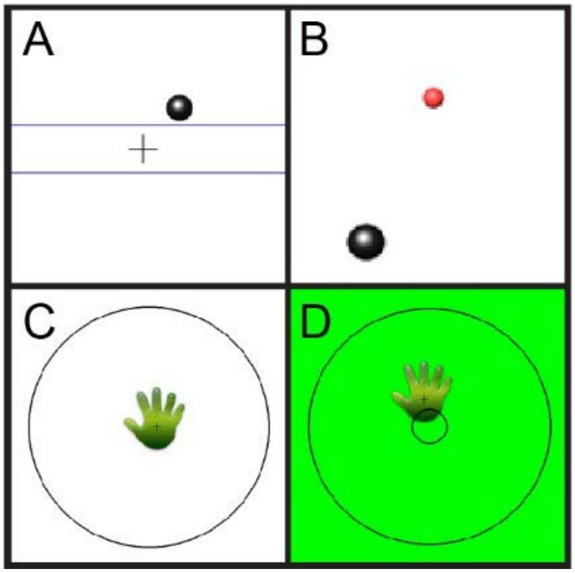

Figure 2 Graphical User Interface for QMA tests: finger oscillation (A), visually guided movements (B), postural tremor (C), and reaction time (C-D).

Postural Tremor

Participants were instructed to position their hand so that the corresponding virtual hand in the GUI was over a set of crosshairs in the center of a circle on the screen. (Figure 2C) In this location the hand was approximately 20cm over the motion capture sensor. They were to hold their hand at that location with the palm down and fingers spread for 30s. Two trials were performed with each hand to assess postural tremor.

Reaction Time

Participants set their hand over the sensor centering the hand on the screen in a circle as in the Tremor assessment (Figure 2C). At a random time between 0.5s-5s from the time the participants hand aligned with the crosshairs, a smaller 25mm circle appeared around the virtual hand and the background color on the screen changed from white to green. Participants were instructed to remove their hand out of the circle as quickly as possible when background color changed to green (Figure 2D). Ten trials were performed with each hand. The reaction time was defined as the average over the ten trials.

Visually Guided Movement

The GUI for the visually guided movement assessment (Figure 2B) consisted of a red ball that represented the user's finger and a black target that initially appeared in one of the corners of the screen. The participant was instructed to move their finger as fast as possible so that the red ball sat on top of the black target. They were to hold it there until they saw the next target appear in another corner, and then move to it as quickly as possible. The subsequent target appeared after the finger had rested on the target for 500ms. Sixty targets were presented randomly so that the 12 possible finger paths from corner to corner were performed and recorded five times in each of two trials.

Analysis

Using Matlab 2013b (Mathworks, Inc), we automated the extraction of test-specific measures (Table 1) from the raw position and time data captured by the motion sensor. The code included analyzing the data for motion tracking errors.

Careful thought and review of the literature were employed to calculate the measures. To assess balance, the normalized path for the crown of the head was calculated by:

$$Normalized\ Path = \frac{1}{t}\sum_{j=1}^{N-1}\left|p_{j+1} - p_j\right|$$

where t is time duration, N is the number of samples, and p is the three dimensional motion capture data at time sample j. Maximum sway in the anterior-posterior (A-P) and medial-lateral (M-L) planes were also calculated (Figure 3).

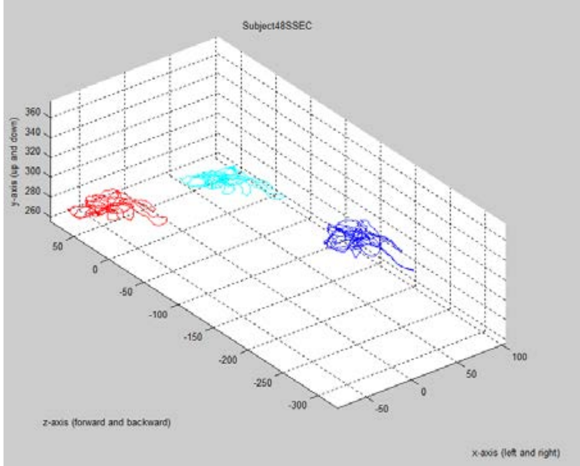

Figure 3 Path of Sway- Red: left tool; Cyan: Right tool; Blue: Crown of head

The finger oscillation assessment included an average number of finger taps for each hand, calculated for the number of valid taps over the five trials, or in the case where five trials within five taps of each other were not performed, the average was calculated for 10 trials. The regularity was determined by calculating approximate entropy, a statistical method to quantify the unpredictability of varying time-series data. High values of approximate entropy indicate greater irregularity.

Postural tremor was assessed by determining the area under the power spectrum curve between 4Hz -12Hz, the bandwidth for tremor (Deuschl et al., 1998).

Reaction time was defined as the time between the appearance of the visual stimulus (labeled by the program) and the exit of the palm of the hand outside of the 25mm circle, which was centered on the palm vector at the time of the visual stimulus.

Visual motor integration was assessed by a measure of dysmetria, the distance away from the target at the end of the movement, reported as a percent of the path from target to target. Kinetic tremor was also calculated, which was done in a manner similar to that of the postural tremor.

Results

Being normative data from young, healthy subjects, the QMA results were generally stereotyped (Figure 4), with no differences between men and women, except in the case of grip strength (p<.0001 for both the dominant and non-dominant hand) and the finger oscillation test (p=.023 for the dominant hand and p=.004 for the non-dominant hand.). There were significant differences between dominant and non-dominant hands on the finger oscillation test (p<.0001), tap regularity (p=.018), reaction time (p=.032), and dysmetria (p=.033).

When comparing the QMA to conventional tests, there was a correlation between the QMA finger oscillation test and the mechanical finger tap test for both the dominant and non-dominant hands (r=0.57 and r=0.73 respectively). There is a relationship between grip strength and both QMA finger oscillation and mechanical finger tap tests, however more so on the mechanical finger tap test.

In the balance assessment, there were significant differences in the path length in the eyes closed and eyes open conditions for each surface (p<.001 in both cases). There were significant differences in the path length between the hard surface and soft surface with eyes closed and eyes open (p<.001 in both cases). And there was a difference in the path length between the hard surface (feet together) and the hard surface tandem stance (eyes open in both) conditions (p=.001). The A-P sway was significantly greater than M-L sway in the soft surface eyes opened (p<.001), soft surface eyes closed (p=.036), and tandem stance conditions (p<.001).

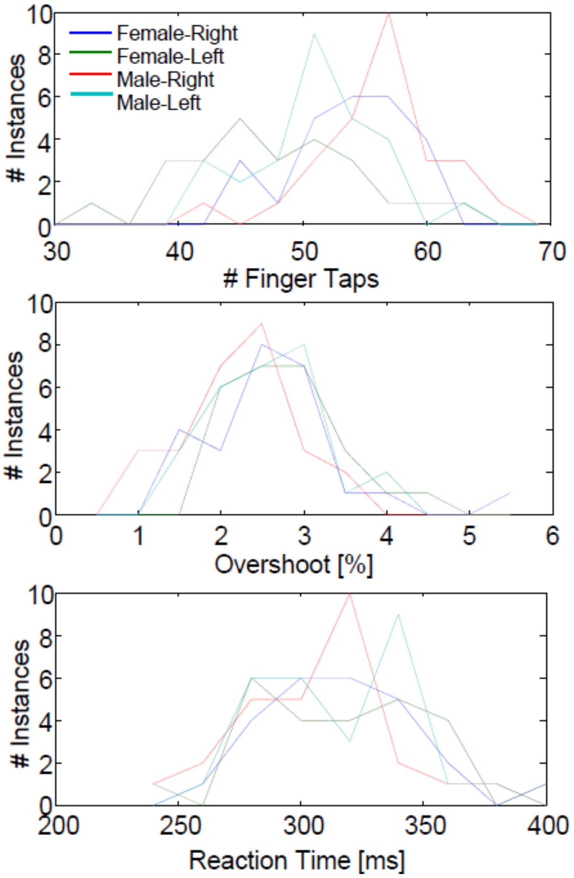

Figure 4 Histograms of QMA measures for the finger oscillation (top), visually guided movement (middle), and reaction time (bottom) tests.

Together these measures form a normative database against which patients' QMA results can be compared to evaluate the degree of their impairment.

Discussion

The difference between genders in the QMA finger oscillation test is consistent with results of both computer keyboard press and mechanical finger tap tests (Christianson and Leathem, 2004; Ruff and Parker, 1993). Likewise, the measures of differences in our balance measures also agree with posturography results (Kaufman et al., 2006; Pickett et al., 2007). That these results are consistent with similar assessments provides a level of confidence in the validity of the QMA. However, the QMA offers more affordability and ease-of-use over the exams referenced here.

Novel markerless motion capture technology allows for collection of an abundance of quantitative movement information. Using this technology and the associated normative databases will allow for quick, low-cost, and highly sensitive motor assessment in clinical settings, which we expect will result in improved diagnosis, prognosis, and rehabilitation following TBI. Because of the gaming industry, markerless technology is bound to continue to improve, creating more sensitive instruments.

This QMA and its normative database will be available on the BYU Neuromechanics Research Group website. We invite others to take advantage of it and contribute to the database.

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