INTRODUCTION

There is a nationally recognized need for more sensitive motor assessments to evaluate and diagnose motor impairments following traumatic brain injury (TBI). Conventional motor assessments rely on subjective observations and often fail to detect subtle impairments common in TBI. The purpose of our research is to 1) develop a quantitative motor assessment (QMA) that is quick, 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 to administer traditional motor tests using low-cost markerless motion capture. Our system consists of an $80 Leap Motion sensor and custom software (Figure 1). 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

Fifty healthy, right-handed subjects (age range 18-30 years; 23 females, 27 males) completed five QMA tests (described below). 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. Tests 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:

**Finger Oscillation Test**
- Participants were instructed to make oscillatory finger movements as fast as possible for 10s
- Subjects received visual feedback of their finger location on a graphical user interface (GUI) (Figure 2A) and needed to oscillate their finger above and below a band to achieve a tap
- Subjects needed 5 trials within 5 oscillations of each other (10 trials max)
- 30-90s rests between trials

**Visually Guided Movement**
- Subjects moved the tip of their index finger, represented as a red dot, as quickly as possible to targets appearing in random order (Figure 2B)
- The next target appeared after the finger had rested on the target for 500ms.

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.

Figure 2: Graphical User Interface for QMA tests: finger oscillation (A), visually guided movements (B), postural tremor (C), and reaction time (C-D).
Two trials, each with 12 paths executed 5 times in random order were completed.

**Postural Tremor**
- Participants were instructed to hold their hand over the motion capture sensor with palm down and fingers spread (Figure 2C).
- Two trials of 30s each for each hand.

**Reaction Time**
- Participants held their hand over the sensor (Figure 2C).
- Subjects were instructed to remove their hand as quickly as possible as soon as the background color changed from white to green (Figure 2D).

**Balance**
- Participants stood with feet together and hands across the chest for 30s (Figure 1B).
- Five different trials were completed, each in a different pose:
  - Hard surface eyes open
  - Hard surface eyes closed
  - Soft surface eyes open
  - Soft surface eyes closed
  - Tandem stance, preferred foot in front

The data from each test were analyzed to extract test-specific measures (Table 1). Together these measures form a normative database against which patients’ QMA results can be compared to evaluate the degree of their impairment.

**RESULTS AND DISCUSSION**

Being normative data from young, healthy subjects, the QMA results were generally stereotyped, with few differences between men and women or dominant and non-dominant hands (Figure 3). 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. We invite others to take advantage of it and contribute to the database.

**ACKNOWLEDGEMENTS**

Utah NASA Space Grant Consortium and EPSCoR

![Figure 3](image-url)

Figure 3: Histograms of QMA measures for the finger oscillation (top), visually guided movement (middle), and reaction time (bottom) tests.

<table>
<thead>
<tr>
<th>QMA Test</th>
<th>Behavioral Attributes</th>
<th>Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finger Oscillation</td>
<td>Strength, movement efficiency</td>
<td>Number and regularity (approximate entropy) of taps</td>
</tr>
<tr>
<td>Visually Guided Movements</td>
<td>Visuomotor control, kinetic tremor</td>
<td>Dysmetria, duration, smoothness, power spectrum area</td>
</tr>
<tr>
<td>Postural Tremor</td>
<td>Tremor, chorea, strength, impersistence</td>
<td>Area under power spectrum between 4 and 12 Hz</td>
</tr>
<tr>
<td>Reaction Time</td>
<td>Processing time</td>
<td>Reaction time</td>
</tr>
<tr>
<td>Balance</td>
<td>Postural stability</td>
<td>Mean path, max. excursion of the crown of the head</td>
</tr>
</tbody>
</table>

Table 1: Each QMA test was designed to assess particular behavioral attributes that were defined and quantified as measures.