Assessment of Gait and Gait-Related Mobility Following Traumatic Brain Injury

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Disclosures

• Active Grant Support
  • Avanir Pharmaceuticals – Industry-sponsored clinical trial

• Completed Grant Support
  • Foundation for Physical Medicine and Rehabilitation
  • Centers for Outcomes Research and Education (CORE) Faculty Support Award
  • Revance Therapeutics – Industry-sponsored clinical trial

• Employed by Atrium Health and receive salary
Learning Objectives

1. The learner will be able to describe how traumatic brain injury (TBI) impacts gait and gait-related mobility.
2. The learner will be able to identify traditional measures of mobility following TBI.
3. The learner will be able to describe the different tools that can be used to assess mobility.
4. The learner will be able to explain how body worn technology can be used in gait assessment in both the clinical and research settings following TBI.
Gait Changes Following TBI

- Decreased gait speed
- Decreased cadence
- Shorter stride length
- Increased time in stance phase
- Wider base of support
- Increased sway
- Decreased balance
- Leg asymmetry


Measure Mondays

- 10-Meter Walk Test
- 6-Minute Walk Test
- 5 Times Sit to Stand
- Berg Balance Scale
- Functional Gait Assessment
- Activities-Specific Balance Confidence Scale

10 Meter Walk Test (10MWT)

- Gait Speed
- Excellent test-retest reliability in adults with moderate to severe TBI
  - Self-selected pace
  - Fast pace
- Cut-off scores
  - < 0.4 m/s = household ambulator
  - 0.4 – 0.8 m/s = limited community ambulator
  - > 0.8 m/s = community ambulator

6 Minute Walk Test

- Submaximal aerobic capacity or endurance
- Excellent test-retest reliability after TBI

5 Times Sit to Stand (5TSTS)

- Functional lower extremity strength and transfer ability
- Excellent test-retest reliability in community-dwelling older adults
- Predictive of falls in older adults


Berg Balance Scale (BBS)

1. Sitting unsupported
2. Change of position: sitting to standing
3. Change of position” standing to sitting
4. Transfers
5. Standing unsupported
6. Standing with eyes closed
7. Standing with feet together
8. Tandem standing
9. Standing on one leg
10. Turning trunk (feet fixed)
11. Retrieving objects from floor
12. Turning 360 degrees
13. Stool stepping
14. Reaching forward while standing

- Static and dynamic sitting and standing balance
- Excellent test-retest reliability in TBI and stroke
- Excellent interrater reliability after stroke

Functional Gait Assessment (FGA)

6 m (20ft) long and 30.48 cm (12 in) wide walkway

1. Gait level surface
2. Change in gait speed
3. Gait with horizontal head turns
4. Gait with vertical head turns
5. Gait and pivot turn
6. Step over obstacle
7. Gait with narrow base of support
8. Gait with eyes closed
9. Ambulating backwards
10. Steps

• Walking balance
• Excellent test-retest reliability after stroke
• Excellent interrater reliability in vestibular disorders and stroke

Activities-Specific Balance Confidence (ABC) Scale

How confident are you that you will not lose your balance or become unsteady when you...

1. ...walk around the house? _____%
2. ...walk up or down stairs? _____%
3. ...bend over and pick up a slipper from the front of a closet floor? _____%
4. ...reach for a small can off a shelf at eye level? _____%
5. ...stand on your tip toes and reach for something above your head? _____%
6. ...stand on a chair and reach for something? _____%
7. ...sweep the floor? _____%
8. ...walk outside the house to a car parked in the driveway? _____%
9. ...get into or out of a car? _____%
10. ...walk across a parking lot to the mall? _____%
11. ...walk up or down a ramp? _____%
12. ...walk in a crowded mall where people rapidly walk past you? _____%
13. ...are bumped into by people as you walk through the mall? _____%
14. ...step onto or off of an escalator while you are holding onto a railing? _____%
15. ...step onto or off an escalator while holding onto parcels such that you cannot hold onto the railing? _____%
16. ...walk outside on icy sidewalks? _____%

- Self-reported measure of balance confidence
- Total score is average of all 16 items
- Only use if person has good insight into deficits

Timed “Up and Go” (TUG)

- Functional mobility
- Predictive of falls
- Excellent test-retest reliability
  - Children with TBI
  - Adults with stroke
  - Older adults


Importance of Attention During Gait
Dual Task

- Dual task = completion of a simultaneous task
- Dual task effect (DTE) = percent change in performance during dual task condition

\[
DTE(\%) = \left( \frac{\text{dual task gait speed} - \text{single task gait speed}}{\text{single task gait speed}} \right) \times 100\%
\]

\[
DTE = \frac{12 \text{ s} - 10 \text{ s}}{10 \text{ s}} = \frac{2 \text{ s}}{10 \text{ s}} = 20\%
\]
Dual Task Gait Speed Declines After Mild TBI


* p-value < 0.05 between TBI and control
Dual Task Effect is Greater After Mild TBI


* p-value < 0.05 between TBI and control
Dual Task Function After Sports-Related Mild TBI

- Dual task gait speed is slower for at least 2 months post-injury
  - Single task gait speed returns to normal by 2 weeks post-injury
- Increased dual task cost was associated with prolonged symptoms > 28 days
- Worsening dual task cost associated with increased likelihood of “time-loss” injury within 12 months post-concussion
Dual Task Impairments After Moderate to Severe TBI

- Two studies looked at obstacle walking while performing the visual Stroop test
- Individuals with moderate to severe TBI that could ambulate independently without AD
  - Normal visual acuity
- Individuals with TBI
  - Longer reaction time for Stroop task
  - Ambulated more slowly over obstacles


More to Gait Than Total Time or Speed

Patient A: Gait, Total Time = 12.01s

Patient B: Gait, Total Time = 11.2s
Gait Analysis Laboratories
Body Worn Technology is More Accessible

• Inertial Measurement Unit (IMU)
  - 3 accelerometers
  - 3 gyroscopes
  - 3 magnetometers
  - 1 temperature sensor

• Kinematic input
  - Upper torso
  - Ground impact accelerations

Inertial Measurement Unit (IMU)
- 3 accelerometers
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- 3 magnetometers
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Kinematic input
- Upper torso
- Ground impact accelerations
Validation of the IMU Compared with Vicon

- 10 subjects
  - 5 with prior lower extremity Orthopedic trauma
  - 5 age and sex-matched healthy controls

- Modified 10MWT

- Variables
  - Vertical acceleration
  - Pitch angular velocity
  - Roll angular velocity

Correlation Between IMU and Vicon

<table>
<thead>
<tr>
<th></th>
<th>Controls</th>
<th>Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Acceleration</td>
<td>$R = 0.992 \pm 0.010$</td>
<td>$R = 0.983 \pm 0.024$</td>
</tr>
<tr>
<td>Pitch Angular Velocity</td>
<td>$R = 0.920 \pm 0.059$</td>
<td>$R = 0.935 \pm 0.064$</td>
</tr>
<tr>
<td>Roll Angular Velocity</td>
<td>$R = 0.910 \pm 0.101$</td>
<td>$R = 0.977 \pm 0.018$</td>
</tr>
</tbody>
</table>

### Different Protocols Available

<table>
<thead>
<tr>
<th>10MWT</th>
<th>5TSTS</th>
<th>TUG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Each leg</td>
<td>Mean peak flexion angle</td>
<td>Maximum angular acceleration during sit-to-stand</td>
</tr>
<tr>
<td>Lift acceleration</td>
<td>Mean peak flexion angular velocity</td>
<td>Mean and peak angular velocities for the turn</td>
</tr>
<tr>
<td>Stance time</td>
<td>Mean peak extension angle</td>
<td>Segment times</td>
</tr>
<tr>
<td>Pitch magnitude</td>
<td>Mean peak extension velocity</td>
<td>• Sit-to-stand</td>
</tr>
<tr>
<td>Roll magnitude</td>
<td>Mean time</td>
<td>• Stand-to-sit</td>
</tr>
<tr>
<td></td>
<td>• Sit-to-stand</td>
<td>• Turn around</td>
</tr>
<tr>
<td></td>
<td>• Stand-to-sit</td>
<td></td>
</tr>
<tr>
<td></td>
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</tr>
</tbody>
</table>

Atrium Health
Carolinas Rehabilitation
Modified 10MWT – Patient A

Patient A Gait: Time = 12.01s
- Accel Asymmetry: 3.96%
- Stance Time Asymmetry: 0.70%
- Mean Pitch: 4.69 deg
- Mean Roll: 7.76 deg
Modified 10MWT – Patient B

Patient B Gait: Time = 11.82s
- Accel Asymmetry: 14.71%
- Stance Time Asymmetry: 17.98%
- Mean Pitch: 20.24 deg
- Mean Roll: 14.35 deg
Reliability of the Electronically Augmented TUG (EATUG) in Children with Moderate to Severe TBI

15 children with moderate to severe TBI

- Age 7 to 16-years-old
- Admitted to inpatient rehabilitation
- First TBI
- Best GCS 3-12 within 24 hours
- Out of post-traumatic amnesia
- Cognitively able to participate in the testing
- No weight bearing restrictions
- Able to ambulate 10 m without assistance
- English Speaking

15 healthy controls

- No prior TBI or Orthopedic trauma
- Age and sex matched to the participants with TBI
- Cognitively able to participate in the testing
- No weight bearing restrictions
- English speaking

## Participants

<table>
<thead>
<tr>
<th></th>
<th>TBI (n = 12)</th>
<th>TD (n = 10)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>10.5 ± 1.5</td>
<td>10.4 ± 1.3</td>
<td>0.87</td>
</tr>
<tr>
<td>Males</td>
<td>6</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Race (white)</td>
<td>9</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td>148.0 ± 15.4</td>
<td>147.9 ± 13.8</td>
<td>0.98</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>40.9 ± 10.3</td>
<td>41.1 ± 8.7</td>
<td>0.95</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>18.7 ± 4.5</td>
<td>18.9 ± 4.2</td>
<td>0.88</td>
</tr>
<tr>
<td>Education (years)</td>
<td>5.1 ± 1.4</td>
<td>5.2 ± 1.1</td>
<td>0.83</td>
</tr>
<tr>
<td>Leg length - right (cm)</td>
<td>75.1 ± 6.8</td>
<td>76.1 ± 4.8</td>
<td>0.71</td>
</tr>
<tr>
<td>Leg length - left (cm)</td>
<td>75.0 ± 6.7</td>
<td>76.1 ± 4.8</td>
<td>0.68</td>
</tr>
<tr>
<td>Orthotic use (yes)</td>
<td>2</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>GCS</td>
<td>5.3 ± 2.9</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>COAT</td>
<td>118.5 ± 3.0</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Wee-FIM®</td>
<td>5.8 ± 1.2</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td>Days from injury to clearing PTA</td>
<td>27.08 ± 11.89</td>
<td>–</td>
<td></td>
</tr>
</tbody>
</table>

EATUG Assessment
## EATUG Subcomponent Test-Retest Reliability


<table>
<thead>
<tr>
<th>TUG variable</th>
<th>Typically Developing Children (n = 10) ICC (95% CI)</th>
<th>Traumatic Brain Injury (n = 12) ICC (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total time</strong></td>
<td>0.97 (0.90–0.99)</td>
<td>0.94 (0.80–0.98)</td>
</tr>
<tr>
<td><strong>1st transition</strong></td>
<td><strong>Sit-to-stand component</strong></td>
<td></td>
</tr>
<tr>
<td>Max Torso Flx/Ext Angle (deg)</td>
<td>0.84 (0.36–0.96)</td>
<td>0.94 (0.81–0.98)</td>
</tr>
<tr>
<td>Pk Flx Ang Vel (deg/s)</td>
<td>0.89 (0.55–0.93)</td>
<td>0.91 (0.68–0.97)</td>
</tr>
<tr>
<td>Pk Ext Ang Vel (deg/s)</td>
<td>0.85 (0.41–0.96)</td>
<td>0.94 (0.80–0.98)</td>
</tr>
<tr>
<td>Pk Vert Accel (m/s²)</td>
<td>0.80 (0.20–0.95)</td>
<td>0.82 (0.38–0.94)</td>
</tr>
<tr>
<td><strong>1st turn</strong></td>
<td><strong>Turn around a mark</strong></td>
<td></td>
</tr>
<tr>
<td>Mean Turn Ang Vel (deg/s)</td>
<td>0.87 (0.47–0.96)</td>
<td>0.92 (0.74–0.97)</td>
</tr>
<tr>
<td>Peak Turn Ang Vel (deg/s)</td>
<td>0.89 (0.57–0.97)</td>
<td>0.93 (0.78–0.98)</td>
</tr>
<tr>
<td><strong>2nd transition</strong></td>
<td><strong>Stand-to-sit</strong></td>
<td></td>
</tr>
<tr>
<td>Max Torso Flx/Ext Angle (deg)</td>
<td>0.68 (–0.25–0.92) NS</td>
<td>0.96 (0.87–0.99)</td>
</tr>
<tr>
<td>Pk Flx Ang Vel (deg/s)</td>
<td>0.82 (0.28–0.95)</td>
<td>0.95 (0.82–0.98)</td>
</tr>
<tr>
<td>Pk Ext Ang Vel (deg/s)</td>
<td>0.79 (0.18–0.95)</td>
<td>0.96 (0.86–0.98)</td>
</tr>
</tbody>
</table>
## Differences Between TBI and Healthy Controls

<table>
<thead>
<tr>
<th>Total time variable (s)</th>
<th>TD (n = 10) Mean (SD)</th>
<th>TBI (n = 12) Mean (SD)</th>
<th>t</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st transition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sit-to-stand subcomponent</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Torso Flx/Ext Angle (deg)</td>
<td>49.15 (7.93)</td>
<td>38.11 (12.04)</td>
<td>2.479</td>
<td>0.022</td>
</tr>
<tr>
<td>Pk Flx Ang Vel (deg/s)</td>
<td>97.95 (16.87)</td>
<td>74.93 (23.81)</td>
<td>2.563</td>
<td>0.019</td>
</tr>
<tr>
<td>Pk Ext Ang Vel (deg/s)</td>
<td>100.72 (18.59)</td>
<td>84.56 (26.60)</td>
<td>1.617</td>
<td>0.122</td>
</tr>
<tr>
<td>Pk Vert Accel (m/s²)</td>
<td>4.13 (1.08)</td>
<td>3.22 (1.11)</td>
<td>1.940</td>
<td>0.067</td>
</tr>
<tr>
<td>1st turn</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turn around a cone</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Turn Ang Vel (deg/s)</td>
<td>93.18 (15.33)</td>
<td>78.96 (20.09)</td>
<td>1.834</td>
<td>0.082</td>
</tr>
<tr>
<td>Peak Turn Ang Vel (deg/s)</td>
<td>189.27 (38.21)</td>
<td>150.93 (39.43)</td>
<td>2.303</td>
<td>0.032</td>
</tr>
<tr>
<td>2nd transition</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stand-to-sit subcomponent</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Torso Flx/Ext Angle (deg)</td>
<td>45.07 (7.13)</td>
<td>38.17 (16.53)</td>
<td>1.306</td>
<td>0.211</td>
</tr>
<tr>
<td>Pk Flx Ang Vel (deg/s)</td>
<td>77.01 (18.40)</td>
<td>64.56 (27.01)</td>
<td>1.235</td>
<td>0.231</td>
</tr>
<tr>
<td>Pk Ext Ang Vel (deg/s)</td>
<td>99.60 (16.60)</td>
<td>89.69 (39.65)</td>
<td>0.787</td>
<td>0.443</td>
</tr>
</tbody>
</table>
Each participant listened to an array of 10 random numbers
3 practice tests were performed while sitting
Instructed to complete EATUG while focusing equally on the mobility and cognitive performance
Recall numbers when seated after TUG completion

## Impact of Cognitive Task on EATUG Performance

<table>
<thead>
<tr>
<th>TUG variable</th>
<th>Typically Developed Children (n = 10) Mean (SD)</th>
<th>Children with Traumatic Brain Injury (n = 12) Mean (SD)</th>
<th>F</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total time (sec)</strong></td>
<td>10.81 (1.34)</td>
<td>12.00 (2.33)</td>
<td>2.03</td>
<td>0.169</td>
</tr>
<tr>
<td><strong>1st transition</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Sit-to-stand subcomponent</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Torso Flx/Ext Angle (deg)</td>
<td>46.36 (11.37)</td>
<td>36.35 (10.72)</td>
<td>4.51</td>
<td>0.047</td>
</tr>
<tr>
<td>Pk Flx Ang Vel (deg/sec)</td>
<td>92.49 (20.82)</td>
<td>67.41 (26.06)</td>
<td>6.03</td>
<td>0.023</td>
</tr>
<tr>
<td>Pk Ext Ang Vel (deg/sec)</td>
<td>100.81 (18.94)</td>
<td>78.42 (23.88)</td>
<td>5.76</td>
<td>0.026</td>
</tr>
<tr>
<td>Pk Vert Accel (m/sec²)</td>
<td>3.84 (0.60)</td>
<td>2.99 (1.15)</td>
<td>4.45</td>
<td>0.048</td>
</tr>
<tr>
<td><strong>1st turn</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Turn-around-a-cone subcomponent</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean Turn Ang Vel (deg/sec)</td>
<td>88.47 (13.32)</td>
<td>70.88 (14.10)</td>
<td>8.93</td>
<td>0.007</td>
</tr>
<tr>
<td>Peak Turn Ang Vel (deg/sec)</td>
<td>185.98 (36.50)</td>
<td>139.37 (32.42)</td>
<td>10.06</td>
<td>0.005</td>
</tr>
<tr>
<td><strong>2nd transition</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Stand-to-sit subcomponent</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max Torso Flx/Ext Angle (deg)</td>
<td>41.91 (8.96)</td>
<td>33.29 (13.75)</td>
<td>2.89</td>
<td>0.105</td>
</tr>
<tr>
<td>Pk Flx Ang Vel (deg/sec)</td>
<td>75.42 (17.44)</td>
<td>57.50 (21.77)</td>
<td>4.41</td>
<td>0.049</td>
</tr>
<tr>
<td>Pk Ext Ang Vel (deg/sec)</td>
<td>86.88 (18.69)</td>
<td>72.70 (24.43)</td>
<td>2.26</td>
<td>0.149</td>
</tr>
</tbody>
</table>

Limitations of Wearable Technology

• Wearable technology is limited to research purposes only
• Need consensus on data analysis algorithms
  • Most are proprietary
  • Need minimum performance standards
• Location is important
  • Sufficient space needed
  • Some environments can impact sensors
• Population and diagnosis differences
  • Some are easier to test than others
  • Need to optimize algorithms to the populations
• What do the values mean in clinical practice?
Thank You!

- Department of PM&R
  - Dr. Newman
  - Kim Welsh
- Therapy Department
  - Katie Williams
  - Kelly Werts

- Department of Orthopedic surgery
  - Nahir Habet
  - Tamar Roomian
  - Dr. Stephen Sims
- Center for Outcomes and Research Excellence
  - William Anderson
Questions?