Selected Topics Communications and Mobile Computing (Smart Health)

TU Graz
University of Notre Dame
Percentage of Population Age 65+ in 2005
Percentage of Population Age 65+ in 2015
Percentage of Population Age 65+ in 2025
Potential Impairments of Aging Population

• **Memory performance:** difficulties remembering (long-term and short-term)

• **Cognitive performance:** difficulties acquiring knowledge and understanding through thought, experience, and the senses

• **Functional performance:** reduction of physical abilities
Abnormal Cognitive States

• Subjective memory complaints
  – Problems remembering
  – But no cognitive or functional deficits
• Mild cognitive impairment (MCI)
  – Memory complaints and some cognitive deficits
  – But no functional deficits
• Dementia
  – Cognitive and functional deficits
Types of Dementia

Dementia is a broad, “umbrella” term used to describe a range of neurological disorders. There are many different types of dementia, including these six:

- Alzheimer’s Disease
- Vascular Dementia
- Mixed Dementia
- Dementia with Lewy Bodies
- Frontotemporal Dementia
- Parkinson’s Dementia
Types of Dementia

The different kinds of dementia

Dementia is not one thing. There are several routes to similar symptoms

**ALZHEIMER’S 62%**
Causes problems with memory, language and reasoning. 5% of cases start before age 65

**VASCOULAR DEMENTIA 17%**
Impaired judgement, difficulty with motor skills and balance. Heart disease and strokes increase its likelihood

**MIXED DEMENTIA 10%**
Several types of dementia contribute to symptoms. Most common in people over 85

**OTHER 3%**
Conditions such as Creutzfeld-Jacob disease; depression; multiple sclerosis

**DEMENTIA WITH LEWY BODIES 4%**
Caused by Lewy body proteins. Symptoms can include hallucinations, disordered sleep

**FRONTOTEMPORAL DEMENTIA 2%**
Personality changes and language problems. Most common onset between the ages of 45 and 60

**PARKINSON’S DISEASE 2%**
Can give rise to dementia symptoms as the condition progresses

SOURCE: ALZHEIMERS.ORG.UK
Goals of Treatment

• What?
  – Improve or preserve ADL function
  – Reduce caregiver burden
  – Enhance quality of life

• How?
  – Improve or preserve cognitive function
  – Improve or preserve behavioral function
  – Slow down deterioration
  – Manage psychiatric and behavioral problems
Treatment

- Normal
- Subjective Impairment
- Mild Cognitive Impairment
- Dementia

Natural Course vs. Ideal

Time

With current treatments
BPSD

- Behavioral and Psychological Symptoms of Dementia (BPSD)
  - Disturbed perception, thought content, mood, or behavior; occur frequently in patients with dementia
  - Mood disorders (apathy, depression, dysphoria)
  - Sleep disorders: insomnia, hypersomnia, circadian rhythm disorders, obstructive sleep apnea
  - Psychotic symptoms: delusions, hallucinations
  - Agitation: pacing, wandering, aggression, anxiety

- Leads to increased suffering, early institutionalization, increased cost of care, and causes significant loss in the QoL for patient & caregivers

- About 2/3 of people with dementia experience some BPSD at some point (may rise to 70-80% among patients residing in nursing homes)
Memory Loss

• Many different types of memory, including:
  – Short-term (or working) memory (< 1 min)
  – Long-term (lifetime) memory
  – Sensor memory: visual (iconic), auditory (echoic), smell-based (olfactory), taste-based, or haptic (touch-based) memory

• Initial memory impairment occurs in short-term memory; long-term memory is often retained until late-stage dementia
Cognitive Function

• Cognitive function refers to how a person becomes aware of, perceives, or comprehends ideas; includes intellectual thinking, judgment, reasoning
• It declines gradually while young and more rapidly among older adults (>60s)
• Many other medical and psychological factors can influence cognitive function
Executive Function

• Executive function refers to a set of mental or cognitive skills believed to be controlled by the frontal lobe, anterior cingulate, prefrontal cortex, basal ganglia, and thalamus

• Two main types of executive functions:
  – Organization: attention, managing time, planning and organizing, remembering details, sequencing, and working memory
  – Regulation: self-control, emotional regulation, decision-making, and moral reasoning

• Impairments in executive function can lead to difficulty planning, difficulty to multitask, emotional swings and changes, loss of fine motor skills, apathy, and socially inappropriate behaviors
Behavioral and Psychological Symptoms of Dementia (BPSD)

• Disturbed perception, thought content, mood, or behavior; occur frequently in patients with dementia
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• Leads to increased suffering, early institutionalization, increased cost of care, and causes significant loss in the QoL for patient & caregivers
• About 2/3 of people with dementia experience some BPSD at some point (may rise to 70-80% among patients residing in nursing homes)
Diagnosis of Dementia

• Significant deterioration in two or more areas of cognitive function that is severe enough to interfere with a person’s ability to perform everyday activities

• Diagnosis requires impairment of two or more core mental functions:
  – Memory
  – Language skills
  – Visual perception
  – Ability to focus and pay attention
  – Ability to reason and solve problems

• The loss of brain function is severe enough that a person has difficulty performing normal everyday tasks
Alzheimer’s: 3 Stages

• Progressive neurodegeneration with increasing impairments

• Three stages:
  – Early or mild stage, during which the clinical symptoms include mild cognitive decline and functional impairments
  – Middle or moderate stage, during which there are moderate impairments
  – Late stage or severe (or end-stage), with severe manifestations
Alzheimer’s: 7 Stages

- No impairment
- Very mild decline (minor memory issues)
- Mild decline (others may notice memory issues)
- Moderate decline (simple math; short-term memory; managing finances/bills; details about life history)
- Moderately severe (dressing, recalling simple details, significant confusion)
- Severe (confusion, unawareness of environment, recognizing others, bowel and bladder control, personality changes, wandering, needing assistance)
- Very severe (nearing death; communication, swallowing)
Alzheimer’s: Risk Factors

- Age
- Gender
- Race
- Genetics (ApoE4)
- Parental History
- Stress / inflammation
- Midlife hypertension
- Midlife hypercholesterolemia
- Obesity
- Diabetes
- Sleep disturbances
- Healthcare neglect (nutrition, exercise, ...)


Common Symptoms in Dementia

5 As to Alzheimer Diagnosis

Anomia
Inability to remember names of things...

Amnesia
Memory loss...

Agnosia
Inability to recognize familiar objects, tastes, sounds, and other sensations...

Apraxia
Misuse of objects because of failure to identify them...

Aphasias
Inability to express oneself through speech...
Aphasia

- Problems with language, comprehension
- Initially characterized by fluent aphasia (reading/writing impaired)
- Able to initiate and maintain conversations
- Syntax and grammar intact, but speech is vague with nonspecific phrases like “the thing”
- Later language can be severely impaired with mutism, echolalia
Apraxia

- Inability to carry out motor activities previously able to do despite intact motor function
- Contributes to loss of ADLs
Agnosia

• The inability to recognize or identify objects despite intact sensory function
  – Typically occurs later in the course of illness
  – Can be visual or tactile
Testing

• Thorough history (medical, psychiatric, neurological)
• Are ADL/IADLs affected?
• Physical and neurological exam
• Cognitive testing (initial screening, then more detailed if needed)
• Labs and imaging (rule out reversible causes)
• Consider neuropsychological testing or referral to psychiatry or neurology
• Determine the etiology/establish the diagnosis
• Treat or refer
Cognitive Screening Tests

• Mini-Mental Status Exam (MMSE)
• Montreal Cognitive Assessment (MoCA)
• Mini-Cog – combines clock drawing and three item memory test
• Saint Louis University Mental Status (SLUMS)
Screening Test: MMSE

- Useful to have at **baseline**
- Can track changes over time
- In Alzheimer’s, patients lose 3 points/year
- Careful of false positives in those with little education
- Careful of false negatives in those with high premorbid intellectual functioning
Mini-Mental State Examination (MMSE)

Instructions: Ask the questions in the order listed. Score one point for each correct response within each question or activity.

<table>
<thead>
<tr>
<th>Maximum Score</th>
<th>Patient’s Score</th>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td></td>
<td>“What is the year? Season? Date? Day of the week? Month?”</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>“Where are we now? State? County? Town/city? Hospital? Floor?”</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>The examiner names three unrelated objects clearly and slowly, then asks the patient to name all three of them. The patient’s response is used for scoring. The examiner repeats them until patient learns all of them, if possible. Number of trials:</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>“I would like you to count backward from 100 by sevens.” (93, 86, 79, 72, 65, …) Stop after five answers. Alternative: “Spell WORLD backwards.” (D-I-R-O-W)</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>“Earlier I told you the names of three things. Can you tell me what those were?”</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>Show the patient two simple objects, such as a wristwatch and a pencil, and ask the patient to name them.</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>“Repeat the phrase: “No ifs, ands, or buts.””</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>“Take the paper in your right hand, fold it in half, and put it on the floor.” (The examiner gives the patient a piece of blank paper.)</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>“Please read this and do what it says.” (Written instruction is “Close your eyes.”)</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>“Make up and write a sentence about anything.” (This sentence must contain a noun and a verb.)</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>“Please copy this picture.” (The examiner gives the patient a blank piece of paper and asks him/her to draw the symbol below. All 10 angles must be present and two must intersect.)</td>
</tr>
<tr>
<td>30</td>
<td>TOTAL</td>
<td></td>
</tr>
</tbody>
</table>
Screening Test: MoCA

- Comprehensive, not easy!
- Catches those with higher premorbid functioning levels
- Is free unlike MMSE
- Mocatest.org
**Montreal Cognitive Assessment (MOCA)**

### Visuospatial / Executive
- **Copy Cube**: Points
- **Draw Clock**: Points

### Naming
- Rhinoceros
- Lion
- Camel

### Memory
- Read list of words, subject must repeat them. Do 3 trials. Do a recall after 5 minutes.
- ** FACE ** | ** VELVET ** | ** CHURCH ** | ** DAISY ** | ** RED **:
  - 1st trial:
  - 2nd trial:

### Attention
- Read list of digits (rdig/sex). Subject has to repeat them in the forward order:
  - 2 1 8 5 4
- Subject has to repeat them in the backward order:
  - 7 4 2
- Read list of letters. The subject must tap with his hand at each letter A. No points if 2 or more:

### Serial 7 Subtraction Starting at 100
- 93
- 86
- 79
- 72
- 65

### Language
- Repeat: I only know that John is the one to help today:
- The cat always hid under the couch when dogs were in the room:

### Abstraction
- Similarity between e.g. banana - orange - fruit
- Train - bicycle
- Watch - ruler

### Delayed Recall
- Mix to recall words with no cue:
  - ** FACE ** | ** VELVET ** | ** CHURCH ** | ** DAISY ** | ** RED **:
- Points for uncued recall only

### Orientation
- Category cue:
- Multiple choice cue:

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© Z. Hounsett MD  Version November 7, 2004

Visit www.mocatest.org
1. Instruct the patient to listen carefully to and remember these 3 words: banana-sunrise-chair
2. Instruct the patient to draw the face of a clock, after the numbers are placed, ask them to draw the hands of the clock to read “one ten”
3. Ask the patient to repeat the 3 previously stated words
Clock Drawing Test - Abnormal

Figure 2
Brief Screening Exams
Clock Drawing Test
Mildly Impaired Sample

Figure 3
Brief Screening Exams
Clock Drawing Test
Moderately/Severely Impaired Sample
Screening Test: SLUMS

• Better psychometric properties than MMSE, with scoring normed to educational level

• http://medschool.slu.edu/agingsuccessfully/pdfsurveys/slumsexam_05.pdf
## Screening Test: SLUMS

### VAMC SLUMS Examination

**Questions about this assessment tool? E-mail aging@slu.edu**

<table>
<thead>
<tr>
<th>Name</th>
<th>Age</th>
<th>Is patient alert?</th>
<th>Level of education</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| 1. What day of the week is it? | 0-1 |
| 2. What is the year? | 0-1 |
| 3. What state are we in? | 0-1 |

4. Please remember these five objects. I will ask you what they are later.

- Apple
- Pen
- Tie
- House
- Car

5. You have $100 and you go to the store and buy a dozen apples for $3 and a tricycle for $20.

- How much did you spend? 0-3
- How much do you have left? 0-3

6. Please name as many animals as you can in one minute.

- 0-4 animals
- 5-9 animals
- 10-14 animals
- 15+ animals

7. What were the five objects I asked you to remember? 1 point for each one correct.

8. I am going to give you a series of numbers and I would like you to give them to me backwards. For example, if I say 42, you would say 24.

- 87
- 649
- 8537

9. This is a clock face. Please put in the hour markers and the time at ten minutes to eleven o’clock.

- Hour markers okay
- Time correct

10. Please place an X in the triangle.

- Which of the above figures is largest?

11. I am going to tell you a story. Please listen carefully because afterwards, I’m going to ask you some questions about it.

   Jill was a very successful stockbroker. She made a lot of money on the stock market. She then met Jack, a devastatingly handsome man. She married him and had three children. They lived in Chicago. She then stopped work and stayed at home to bring up her children. When they were teenagers, she went back to work. She and Jack lived happily ever after.

- What was the female’s name?
- What work did she do?
- When did she go back to work?
- What state did she live in?

**TOTAL SCORE**

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Course of Alzheimer’s Disease

**Mild** (MMSE 20-24) – primarily memory and visuospatial deficits, mild executive functioning impairment

**Moderate** (MMSE 11-20) – more pronounced aphasia, apraxia, loss of IADLs, may need increased assistance with ADLs, often exhibiting neuropsychiatric symptoms

**Severe** (MMSE 0-10) – severe language disturbances, pronounced neuropsych manifestations, neurological symptoms (rigidity, incontinence, dysphagia, gait disturbance)

**Death** 8-12 years after the diagnosis

**Institutionalization** common with increasing neuropsychiatric issues, loss of ADLs, caregiver stress
Identify meaningful change in real-time, by changing both the timing and place for assessments

• Bring the **locus of assessment** into the daily life of the home and community
• Record events in **real-time** as they occur
• Be **minimally obtrusive** or in the background of daily activity – “ambient assessment”
• Record **continuously**
Approach: Detecting Early Changes

Early detection of memory changes in a functional measure over time:

- Baseline
- 3 years
- 6 years

Change and early detection over the functional range.
Volunteers…
Living in many community settings…
Measuring Walking Speed
Approach

\( \tilde{x}_i \) : physical location of sensor \( i \)

\( x_i \) : Location at which sensor \( i \) detects motion

Location of movement triggering sensor \( i \) is at \( \{x_i + e_i\} \)

Velocity of movement between sensor 1 and sensor 2 is then calculated as:

\[
v_{12} = \frac{\{x_2 + e_2\} - \{x_1 + e_1\}}{t_2 - t_1}
\]
Detect Cognitive Changes via Walking Speed

Variability in walking speed increases as people develop dementia.

Hayes, et al., Int. Conf. Alz. Disease 2006

Slow walkers develop dementia earlier than fast walkers.
Helping People to Remember

Context aware medication prompting
Wandering: Buddiband

• Detects changes in typical activity levels; if a user's activity levels significantly diminish, contact is made with the user or carer

• Fall detection
Eating Reminder

- A fragrance-release system designed to stimulate appetite among people with dementia. The mains-powered unit releases three food fragrances a day, adjustable to coincide with the user's mealtimes.
Concussions

- Complex pathophysiological process that affects the brain, induced by traumatic biomechanical forces

1.2 Million Youth Concussions Per Year
50% FB Players Have Sustained A Concussion
35% Suffered Multiple Concussions
80% Symptoms Worsen Over Weeks
50% Return To Play Too Soon
70% Would RTP Concussed
41% Would Not Leave A Game
50 H.S. Football Players Have Died Since 97
What Happens During a Concussion?

- Brain hits the skull
- Impact results in bruising and possible nerve damage
- Trauma damages astroglial cells, which release S-100B (calcium-binding protein)
Signs and Symptoms

• Somatic (e.g., headache)
• Cognitive (e.g., feeling like in a fog, slowed reaction time)
• Emotional and behavioral (e.g. lability, irritability)
• Physical (e.g., loss of consciousness, amnesia)
• Sleep disturbance (e.g., drowsiness, insomnia)
### Signs and Symptoms

<table>
<thead>
<tr>
<th>Category</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain</td>
<td>Headache, Neck pain, Pressure in head</td>
</tr>
<tr>
<td>Senses</td>
<td>Sensitive to noise, Sensitive to light, Blurred vision, Balance problems, Dizziness</td>
</tr>
<tr>
<td>Physical discomfort</td>
<td>Fatigue, Feeling like fog, Not feeling right, Drowsy, Nausea</td>
</tr>
<tr>
<td>Emotional</td>
<td>Irritable, Nervous, Sad, Feeling emotional, Feeling down</td>
</tr>
<tr>
<td>Cognitive</td>
<td>Difficulty remembering, Difficulty concentrating</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>Union of Frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain</td>
<td>110</td>
</tr>
<tr>
<td>Senses</td>
<td>100</td>
</tr>
<tr>
<td>Physical Discomfort</td>
<td>90</td>
</tr>
<tr>
<td>Emotional</td>
<td>60</td>
</tr>
<tr>
<td>Cognitive</td>
<td>50</td>
</tr>
</tbody>
</table>
Signs and Symptoms

- Headache
- Pressure in Head
- Neck Pain
- Dizziness
- Sensitive to Light
- Balance Problems
- Sensitive to Noise
- Blurred Vision
- Not Feeling Right
- Feel Like Fog
- Fatigued
- Nausea

Participants
Rates By Gender & Age

Rate per 100,000

- Males
- Females

Age group (years)

Source: Table A4.
Figure 1: Convenience Sample Injury Rates per 1,000 Athletic Exposures by Sport and Type of Athletic Exposure, High School Sports-Related Injury Surveillance Study, US, 2012-13

Injury Rate per 1,000 Athletic Exposures
Long Term Consequences

- Temporary or permanent (lifelong physical, emotional or cognitive disabilities)
- Personality can be altered (usually for the worse); depression; suicide
- Ability to work or maintain relationships or care for oneself can be reduced or destroyed
- Abuse of alcohol and drugs is common
- Can devastate the survivor’s family (divorce rate is above 75%, high bankruptcy rate)
- Loss of motor control; seizures
- Dementia; Alzheimer’s (earlier onset, higher risk); Parkinson’s
- Second-impact syndrome (often deadly)
- Shortened sports career; inability to work
- Law suits
- Financial burden of TBI (estimated to exceed $400 billion in 2014)
Concussion Testing: ImPACT

Sample questions from ImPACT test

The ImPACT test is administered at the start of a sports season to determine an athlete's baseline results, and again following a concussion to determine if his or her brain has recovered from the trauma. The memory and recognition tests, samples shown below, are conducted in conjunction with a general healthy history questionnaire and a survey of recent symptoms.

SYMBOL MATCHING
Evaluates visual processing speed, learning and memory
Click on the number that corresponds to the following symbol:

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
</table>

Symbols are shown with corresponding numbers. As a symbol is displayed below, the subject must click on the matching number above. After 27 matches, the subject must remember the correct symbol-number pairing.

DESIGN MEMORY
Evaluates attentional processes and visual recognition memory
Was this one of the designs displayed?

Yes  No

Twelve designs are presented for 750 milliseconds, twice to facilitate learning. The subject is then shown a series of correct and incorrect designs and asked if each was displayed previously.

COLOR MATCH
Evaluates reaction time, impulse control/response inhibition

RED
BLUE
GREEN

Some words are displayed in their matching color (e.g. RED appears in a red color) and some do not (e.g. BLUE appears in a green color). The subject is instructed to quickly click on the word box only if the word and color match.

SOURCE: ImPACT

LAURA SPARKS - State Journal
Concussion Testing: SCAT

**SCAT3™**
Sport Concussion Assessment Tool – 3rd Edition
For use by medical professionals only

**What is the SCAT?**
The SCAT is a standardized tool for evaluating injured athletes for concussion and can be used in athletes aged from 13 years and older. It comprises the original SCAT and the SCAT 2 published in 2008 and 2009, respectively. For younger ages (12 and under), please use the Child SCAT 3. The SCAT 3 is designed for use by medical professionals. If you are not qualified, please use the Sport Concussion Assessment Tool (SCAT) to complete the SCAT 2 test for the first time and for subsequent post-injury test. Specific instructions for use of the SCAT 3 are provided on page 8. If you are not familiar with the SCAT, please read through these instructions carefully. This test may be used in a random or non-random fashion to determine individual, team, group, or organizational memory. Any mention of reproduction in a digital format is approved by the Concussion in Sport Group.

**What is a concussion?**
A concussion is a disturbance in brain function caused by a direct or indirect blow to the head. Results in a variety of symptoms associated with the impact, and many do not have any associated symptoms. The recovery process should not be delayed, and any athlete with a concussion should return to play only when cleared by a medical professional.

**SIDELINE ASSESSMENT**
Indications for Emergency Management
- Not to be used as a substitute for a medical exam and should not be used in place of medical advice.
- This assessment tool should be used in conjunction with other medical professionals.

**Potential signs of concussion?**
- Any of the following signs are observed after a direct or indirect blow to the head, the athlete should be evaluated by a medical professional.
- Glasgow Coma Scale score less than 15
- Subjective symptoms
- Vomiting
- Amnesia
- History of head injury

**What should you do if you suspect a concussion?**
- Remove the player from play immediately.
- Provide care and follow the guidelines outlined in the SCAT 3.
- Follow up with a medical professional.

**SCAT3™**
Sport Concussion Assessment Tool – 3rd Edition
For use by medical professionals only

**BACKGROUND**
Name: [Name]
Date: [Date]
Examiner: [Examiner]

**Cognitive & Physical Evaluation**
1. **Cognitive Assessment**
   - Standardized Assessment of Concussion (SAC)
   - Orientation (1 point for each correct answer)
   - What month is it? [1]
   - What is the date today? [1]
   - What is the day of the week? [1]
   - What year is it? [1]
   - What time is it (in correct time)? [1]

2. **Immediate Memory**
   - List 4 objects: [1 point each]
   - [Object 1] [1], [Object 2] [2], [Object 3] [3], [Object 4] [4]
   - [Object 1] [1], [Object 2] [2], [Object 3] [3], [Object 4] [4]

3. **Glasgow Coma Scale (GCS)**
   - Motor response (M): [1 point each]
   - Motor response: [1 point each]
   - Verbal response (V): [1 point each]
   - Verbal response: [1 point each]
   - Glasgow Coma Scale score (E = V + M): [1 point each]

4. **Maddocks Test**
   - Maddocks Test score: [1 point each]

5. **Neck Examination**
   - Range of motion: [1 point each]
   - Tenderness: [1 point each]

6. **Balance Examination**
   - Score: [1 point each]
   - Score: [1 point each]

7. **Coordination Examination**
   - Coordinate: [1 point each]
   - Coordinate: [1 point each]

8. **SAC Delayed Recall**
   - Delayed recall score: [1 point each]

Any athlete with a suspected concussion should be REMOVED FROM PLAY, medically assessed, monitored for deterioration (i.e., should not be left alone) and should not drive a motor vehicle until cleared to do so by a medical professional. No athlete diagnosed with concussion should be returned to sports participation on the day of injury.
Concussion Testing: King-Devick
Balance Error Scoring System (BESS)
Balance Error Scoring System (BESS)

1. Hands lifted off of iliac crests
2. Opening eyes
3. Step, stumble, or fall
4. Moving hip into more than 30 degrees of flexion or abduction
5. Lifting forefoot or heel
6. Remaining out of testing position for more than 5 sec

- Errors are 1 point each & totaled across all test conditions

Double  Single  Tandem

- Three stances on firm surface for 20 seconds each
- Maximum 10 points for each stance
- Scored out of 30
Timed Tandem Gait

• Baseline heel-toe walk along a straight line 4 times with highest number as a “baseline”
• Repeat at times of injury for comparison
• More consistent compared to BESS however fatigability can play a role in performance
Computerized Dynamic Posturography

- Sensory Organization Test (SOT)
  - Assesses functional balance focusing on the visual, vestibular, and somatosensory systems
  - Age related normative data
  - Helps with functional goal setting and treatment planning
Computerized Dynamic Posturography

1. Fixed Surface (Normal Vision)
2. Fixed Surface (Eyes Closed)
3. Sway-Referenced Surface
4. Sway-Referenced Surface
5. Sway-Referenced Surface
6. Sway-Referenced Surface
## Computerized Dynamic Posturography

<table>
<thead>
<tr>
<th>Ratio</th>
<th>Conds.</th>
<th>Functional Relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Somatosensory</td>
<td>2/1</td>
<td>Pt’s ability to use input from the somatosensory system to maintain balance.</td>
</tr>
<tr>
<td>(SOM)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visual</td>
<td>4/1</td>
<td>Pt’s ability to use input from the visual system to maintain balance.</td>
</tr>
<tr>
<td>(VIS)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vestibular</td>
<td>5/1</td>
<td>Pt’s ability to use input to the vestibular system to maintain balance.</td>
</tr>
<tr>
<td>(VEST)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preference</td>
<td>3+6/2+5</td>
<td>The degree to which pt relies on visual info to maintain balance, even when the info is incorrect.</td>
</tr>
<tr>
<td>(PREF)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Eye Tracking

![Image of eye tracking equipment and data graphs]

**Figure 3.** Representative recordings of gaze positions (blue indicates left eye, red indicates right eye) relative to the target. Gaze positions were gathered at a frequency of 500 Hz. Circular patterns represent the path of the eye following a dot moving in a circle, and the semi-circle pattern represents the eye position versus the target. Deviation from a target trajectory (dashed line) in both normal (A) and post-concussion (C) patients. A concussion signal is indicated by eye position jumping ahead of the dot shown in B and C. From left to right (C), subject data at baseline, immediately post-concussion, and 2 days post-concussion.
FIG. 3. Representative scattergrams of gaze positions (blue indicates left eye, and red indicates right eye) relative to the target; gaze positions were gathered at a frequency of 500 Hz. Circular patterns represent the path of the eye following a dot moving in a circle, and the semicircular pattern represents the eye position versus the target. Deviation from a target trajectory (dashed line) in both normal (A) and postconcussive (B) patients. A concussion signal is indicated by eye positions jumping ahead of the dot shown in B and C. From left to right (C), patient data at baseline, immediately postconcussion, and 2 days postconcussion.
Concussion Detection

• Measure G-Force impact to the head in order to determine risk of concussion

![Gauging G-force chart](chart.png)
Concussion Detection

A  Instrumentation

- Triaxial Accelerometer
- Triaxial Gyroscope
- Microcontroller

B  Mouthguard

- Battery
- Kinematic Sensors

Dimensions:
- 24.4mm
- 10.1mm
Concussion Detection
Concussion Detection

Direction, Location and Magnitude for all Impacts in Boxing, American Football

Impact counts
Impact locations
Impact severity
Rotational forces
Video Assessment

A. Raw Event Video

B. Video Trimmed

C. First Round Classification

D. Second Round Classification

- Endzone Camera
- Sideline Camera

Multiple Angle Video

Play Footage

Non-Play Footage

Possible Head Contact Events

Confirmed Head Contact Event

Other Events

Non-Head Impact
Video Assessment

A. Helmet Contact
B. Body Contact
C. No Contact
D. Obstructed View
E. Idle
F. Not in Video
Video Assessment

A  Multi-View Confirmed Head Contact

Endzone View Possible Contact  Sideline View Confirmed Contact

B  Multi-View False Positive Head Contact

Endzone View Possible Contact  Sideline View No Head Contact
Video + Sensor Assessment

A. Impact Location Vectors

B. Processing Instrumented Mouthguard Kinematics

- Integrating and Differentiating Sensor Signals

  - Linear Acceleration \( \int dt \)
  - Linear Velocity \( \int dt \)
  - Linear Position

  - Angular Velocity \( \int dt \)
  - Angular Position
  - Angular Acceleration \( \frac{d}{dt} \)

Finding Peak Kinematic Vectors

Linear Direction Vector Corrected with Angular Motion

Peak Linear Motion Vector

Peak Angular Motion Vector x Peak Angular Motion Vector

Orthogonal Cross Vector

Corrected Direction Vector
Video + Sensor Assessment

**A** Video-Based Helmet Contact Periods
- First Round Video Assessment: 1,004 HC Periods
- Second Round Video Assessment: 271 HC Periods
- Hours of Video: 160

**B** Sensor-Based Head Impacts
- Total Recorded: 13,034 Impacts
- With High IR: 2,032 Impacts
- Recorded During Practice or Game: 10,949 Impacts
- Cross-Verified: 193 Video HC Periods
  217 Sensor Impacts

**C** Exposure per Player-Hour

<table>
<thead>
<tr>
<th>Exposure Data</th>
<th>Practice Exposure (95% Confidence)</th>
<th>Game Exposure (95% Confidence)</th>
<th>Total Exposure (95% Confidence)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Second Round Video Assessment</td>
<td>6.12 (5.29 - 7.05)</td>
<td>4.16 (3.28 - 5.20)</td>
<td>5.40 (4.78 - 6.08)</td>
</tr>
<tr>
<td>High IR Mouthguard</td>
<td>29.3 (27.5 - 31.3)</td>
<td>59.0 (55.5 - 62.6)</td>
<td>40.5 (38.7 - 42.3)</td>
</tr>
<tr>
<td>Cross-Verified Video</td>
<td>4.17 (3.49 - 4.94)</td>
<td>3.30 (2.52 - 4.24)</td>
<td>3.85 (3.32 - 4.43)</td>
</tr>
<tr>
<td>Cross-Verified Mouthguard</td>
<td>4.70 (3.98 - 5.52)</td>
<td>3.68 (2.85 - 4.66)</td>
<td>4.32 (3.77 - 4.94)</td>
</tr>
</tbody>
</table>

Hours in Practice: 31.69
Hours in Game: 18.50
Video/Sensor Assessment – Pros/Cons

- Low-cost of vision (e.g., two cameras); 1+ sensor per athlete
- Obstructed view for vision
- Difficulties estimating level of impact using vision
- Wrong use of sensors
- Impact of sensors on athlete performance
- Generally difficulty determining impact count, severity, and location
Video/Sensor Assessment – Pros/Cons

- Sub-concussive hits!
  - Hits below concussion threshold
  - Repetitive hits have similar effect as one large impact
  - Also linked to CTE (chronic traumatic encephalopathy)