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
Percentage of Population Age 65+ in 2010
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

• **Dementia:** decline in mental ability severe enough to interfere with daily life
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
- 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)
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
Dementia Progression

- Normal
- Subjective Impairment
- Mild Cognitive Impairment
- Dementia

Decline over Time

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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.

**VASCULAR 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: Alzheimer’s.org.uk

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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
TREATMENTS
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, e.g.:
  - 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 **difficulties 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...
WHAT DO YOU CALL THIS AGAIN?
WHO AM I?
WHERE AM I?
WHO ARE YOU?!?

APRAXIA
Misuse of objects because of failure to identify them.
WHY DOESN'T THIS PEN WORK?!

AGONOSIA
Inability to recognize familiar objects, tastes, sounds, and other sensations...
WHAT IS THAT ON MY WHAT YA CALL IT?

APHASIA
Inability to express oneself through speech...
I CAN'T SAY THE WORDS I WANT.
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
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><em>What is the year? Season? Date? Day of the week? Month?</em></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td><em>Where are we now? State? County? Town/city? Hospital? Floor?</em></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><em>I would like you to count backward from 100 by sevens.</em> (93, 86, 79, 72, 65, ...) Stop after five answers. Alternative: <em>Spell WORLD backwards</em> (D-I-R-O-W)</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td><em>Earlier I told you the names of three things. Can you tell me what those were?</em></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: <em>No ifs, ands, or buts.</em></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td><em>Take the paper in your right hand, fold it in half, and put it on the floor.</em> (The examiner gives the patient a piece of blank paper.)</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td><em>Please read this and do what it says.</em> (Written instruction is <em>Close your eyes.</em>)</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td><em>Make up and write a sentence about anything.</em> (This sentence must contain a noun and a verb.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Please copy this picture.</em> (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
Screening Test: MINI-COG

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](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>Level of education</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Score</th>
<th>1. What day of the week is it?</th>
<th>2. What is the year?</th>
<th>3. What state are we in?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Apple</th>
<th>Pen</th>
<th>Tie</th>
<th>House</th>
<th>Car</th>
</tr>
</thead>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>How much did you spend?</th>
<th>How much do you have left?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>0-4 animals</th>
<th>5-9 animals</th>
<th>10-14 animals</th>
<th>15+ animals</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>87</th>
<th>649</th>
<th>8537</th>
</tr>
</thead>
</table>

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

<table>
<thead>
<tr>
<th>Hour markers okay</th>
<th>Time correct</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

10. Please place an X in the triangle.

<table>
<thead>
<tr>
<th>Triangle</th>
<th></th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th></th>
<th>11. I am going to tell you a story. Please listen carefully because afterwards, I’m going to ask you some questions about it.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>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.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>What was the female’s name?</th>
<th>What work did she do?</th>
<th>When did she go back to work?</th>
<th>What state did she live in?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### TOTAL SCORE

### SCORING

<table>
<thead>
<tr>
<th>High School Education</th>
<th>Less than High School Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>27-30</td>
<td>Normal</td>
</tr>
<tr>
<td>21-26</td>
<td>MNC*</td>
</tr>
<tr>
<td>1-20</td>
<td>Dementia</td>
</tr>
<tr>
<td>* Mild Neurocognitive Disorder</td>
<td></td>
</tr>
</tbody>
</table>


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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 neuropsychiatric 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

Functional measure

Change
Early detection
Memory changes

Baseline
3 years
6 years

Functional range
Volunteers… Living in many community settings…

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Measuring Walking Speed
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:

$$v_{12} = \frac{\{x_2 + e_2\} - \{x_1 + e_1\}}{t_2 - t_1}$$
Variability in walking speed increases as people develop dementia.

Slow walkers develop dementia earlier than fast walkers.

**Detect Cognitive Changes via Walking Speed**

Hayes, et al., Int. Conf. Alz. Disease 2006
Helping People to Remember

Context aware medication prompting
Context Aware Medication Prompting

Fall Detection: Buddiband

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

- Track user with GPS sensor (in shoe insole)
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>
Rates By Gender & Age

![Graph showing rates by gender and age]

*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
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)
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

![Symbol Matching Example]

Click on the number that corresponds to the following symbol:

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

![Design Memory Example]

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

![Color Matching Example]

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 SCAT3™:
The SCAT3™ is a standardized tool for evaluating injured athletes for concussion and can be used in athletes aged from 12 years and older. It is the updated version of the original SCAT and the SCAT2 published in 2006 and 2008, respectively. It is specifically designed for use in sports medicine and rehabilitation settings. The SCAT3™ is designed for use by trained professionals. If you are not qualified, please use the Sport Concussion Assessment Tool or similar tools recommended by your professional body.

What is a concussion:
A concussion is a disturbance in brain function caused by a direct or indirect blow to the head. It results in a variety of symptoms that can include headache, dizziness, confusion, memory loss, and changes in behavior. The SCAT3™ is designed to help identify and assess the symptoms of a concussion and provide guidance on when an athlete is safe to return to play.

SIDELINE ASSESSMENT
Indications for Emergency Management:
If an athlete shows any of the following signs, immediate medical attention is required:
- Glasgow Coma Scale (GCS) score less than 15
- Changes in mental status
- Persistent vomiting
- Persistent headaches
- Abnormal behavior (e.g., change in personality)

Potential signs of concussion:
Any of the following symptoms may indicate a concussion:
- Headache
- Nausea or vomiting
- Dizziness
- Changes in behavior (e.g., forgetfulness)
- Slurred speech
- Changes in alertness

Maddocks Test:
The Maddocks test is a simple test to check for a possible concussion. To perform the test, the athlete should be asked to:
1. Stand straight with their feet shoulder-width apart
2. Close their eyes and then open them

If the athlete becomes unsteady or tilted, the test is positive.

SCAT3™ Testing:
SCAT3™ is designed to help identify and assess the symptoms of a concussion and provide guidance on when an athlete is safe to return to play. It is important to consult a medical professional for any suspected concussions.

SAC Delayed Recall™:
SAC Delayed Recall™ is a test to assess memory function. It is used to determine if an athlete has a concussion or not.

Any athlete with a suspected concussion should be removed from play, medically assessed, monitored for deterioration, 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 the injury.
### Concussion Testing: SAC

**FIGURE 1**

**Standard Assessment of Concussion (SAC)**

**FORM A**

<table>
<thead>
<tr>
<th>Name:</th>
<th>Examiner:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date of Exam:</td>
<td>Time:</td>
</tr>
</tbody>
</table>

**Introductions:**
- I am going to ask you some questions. Please listen carefully and give your best effort.

**Concentration:**
- I am going to ask you some questions. Please listen carefully and give your best effort.

**Orientation Total Score**

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Trial 1</th>
<th>Trial 2</th>
<th>Trial 3</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Concentration VAR:**

<table>
<thead>
<tr>
<th>Concentration</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Concentration Total Score**

**Immediate Memory Total Score**

**Emotional Manuvers:**
- If you are not in a normal or controlled state, please follow the instructions carefully.
- These tests may be administered for baseline testing or at any other time.

- **External Manuvers:**
  - 5 Jumping Jumps
  - 5 Sit-Ups

- **Delayed Recall Total Score**

- **SAC Scoring Summary:**

- **Post Concussion Symptom Questionnaire**

**Instructions:**
- Please indicate which of the symptoms below are present on the date of the injury.

**Compared with before the injury, do you now (over the last 24 hours) suffer from:**

- **Headaches**
- **Feelings of dizziness**
- **Noise sensitivity**
- **Sleep disturbances**
- **Fatigue, tingling, and numbness**
- **Being irritable, easily angered**
- **Feeling depressed or tearful**
- **Feeling frustrated or impatient**
- **Forgetfulness, poor memory**
- **Poor Concentration**
- **Taking longer to think**
- **Blurred vision**
- **Light sensitivity**
- **Double vision**
- **Restlessness**

**Are you experiencing any other difficulties?**

*Please specify and rate as above:*
Concussion Testing: King-Devick

<table>
<thead>
<tr>
<th>DEMONSTRATION CARD</th>
<th>TEST I</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 7 5 9 0</td>
<td>5 4 1 8 5 0</td>
</tr>
<tr>
<td>2 5 7 4 6</td>
<td>6 3 2 4 9 4</td>
</tr>
<tr>
<td>1 4 7 6 3</td>
<td>5 9 2 3 1 3</td>
</tr>
<tr>
<td>7 9 3 9 0</td>
<td>4 5 8 7 5 4</td>
</tr>
<tr>
<td>4 5 2 1 7</td>
<td>3 4 6 8 3 1</td>
</tr>
<tr>
<td>5 3 7 4 8</td>
<td>2 1 5 6 3 7</td>
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<td>9 0 2 3 6 2</td>
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<tr>
<td>0 0 2 3 6</td>
<td>4 3 5 2 1 7</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>TEST II</th>
<th>TEST III</th>
</tr>
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<tbody>
<tr>
<td>5 6 4 1 3 8 5 0</td>
<td>9 7 4 3 1 5 8 3</td>
</tr>
<tr>
<td>4 6 5 9 2 4 1 3</td>
<td>5 1 8 4 3 7 2 1</td>
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<td>7 9 5 4 2 3 8 7</td>
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<tr>
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<td>4 3 5 2 1 7 8 3</td>
</tr>
</tbody>
</table>
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

https://www.youtube.com/watch?v=rB5Mb8KS5rE
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

• https://www.youtube.com/watch?v=ehjpG_0TobM
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

- [https://www.youtube.com/watch?v=HT1xe4JaV7w](https://www.youtube.com/watch?v=HT1xe4JaV7w)
Computerized Dynamic Posturography

Fixed Surface

1. Normal Vision
2. Eyes Closed

Sway-Referenced Surface

3. 1
4. 2
5. 3
6. 4
Eye Tracking

**Fig. 3.** Representative recordings 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 in a circle, and the semicircle pattern represents the eye position versus the target. Deviation from a target trajectory (dashed line) in both normal (A) and concussion (B) patients. A concussion signal is indicated by eye position 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
Concussion Detection

A. Instrumentation
   - Triaxial Accelerometer
   - Triaxial Gyroscope
   - Microcontroller

B. Mouthguard
   - Battery
   - Kinematic Sensors
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
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
- Linear Velocity
- Linear Position

Angular Velocities
- Angular Position
- Angular Velocity
- Angular Acceleration

Finding Peak Kinematic Vectors

Linear Direction Vector Corrected with Angular Motion

Peak Linear Motion Vector

Peak Angular Motion Vector

Orthogonal Cross Vector

Corrected Direction Vector
Video + Sensor Assessment

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

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
- Hours in Practice: 31.69
- Hours in Game: 18.50

<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>
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</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>
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<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>
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<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>
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<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>
Video/Sensor Assessment – Pros/Cons

• Low-cost of vision (e.g., two cameras); 1+ motion sensor per athlete
• Obstructed view for vision
• Difficulties estimating level of impact using vision (e.g., depending on angles)
• Motion sensors can detect impact and head motion
• Impact of sensors on athlete performance
• Generally difficulty determining impact count, severity, and location
• Possible to combine both
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)