

Safety and Performance  
18-738 Sports Technology

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# Overview

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- Evolution of technologies for performance and safety
- Concussion and sideline testing
- Riddell's smart helmet
- Reebok's Checklight system
- Smart mouthguards
- Other efforts
- Research at Carnegie Mellon

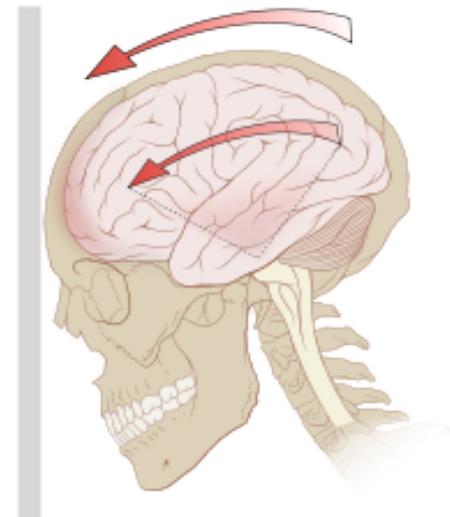


Technology for Player Safety

# Concussions (1)

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- Most common type of **mild traumatic brain injury (MTBI)**
  - Head injury with temporary cognitive impairment, loss of brain function
  - Latin **concutere** = **“to shake violently”**
  - Latin **concussus** = **“action of striking together”**
- Causes
  - The fluid and membrane in brain is jotted.  
The brain is jostled in the fluid. The brain has trauma in it.
  - Blow to the head
  - Sports injuries
  - Car/bicycle accidents
  - Falls
  - Acceleration forces without direct impact (explosion nearby)

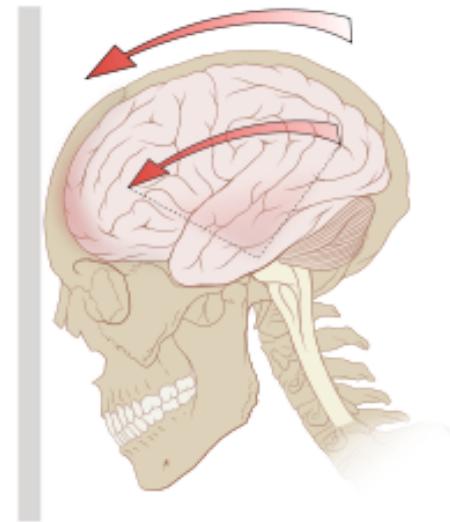


Explosion might give you a concussion. You can have concussion without impact.

# Concussions (2)

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- **Grades of concussion**
  - Whether post-traumatic **amnesia** exists *they forgot who they are*
  - Whether there is loss of consciousness
  - Whether subject exhibits confusion
  - Whether symptoms are exhibited  
*may not be able to walk balanced.*
  - Duration of the concussion (5 minutes, > 24 hours)
- **Symptoms** *There might not be visible symptoms.*
  - Headache, dizziness, vomiting, nausea
  - Lack of motor coordination, issues of balance
  - Light sensitivity, double vision, blurred vision
  - Convulsions, seizures



# Concussions (3)

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- Reported to be about 6 in 1,000 people
- Repeated incidents
  - Those who have had one concussion typically susceptible to another
  - Smaller impacts may trigger same severity The next impact can be more severe.  
It's the repeated one being scary.
  - Increase risk for dementia, Parkinson's disease, depression
- Recovery
  - Treatment involves physical and mental rest
  - Recovery typically within 3 weeks, but symptoms may persist Treatment : rest up -- 3 weeks.

# Diagnosis

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- Lack of highly-noticeable symptoms makes diagnosis hard
  - Concussion shares symptoms with so many other simpler injuries
  - Athletes may minimize their injuries to remain in the competition
  - 2005 study suggested that more than 88% of injuries go undiagnosed
  - Diagnostics
    - Sports Concussion Assessment Tool (SCAT2) card
    - Brain-imaging scans
    - Check for unequal pupil-size
    - Neurophysiological tests
    - In sports, these are used to make the **Return-to-Play (RTP) decision**
- There's no ways to diagnose trauma in brain with cencertanty. There's no way to diagnoise concession with certainty.
- Sport Players:
1. They have contract -- they want to stady in the game
  2. They don't realize that they have symptoms.

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  - These are used to make the Return-to-Play (RTP) decision

# Sideline Evaluation

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## **Consensus Statement on Concussion in Sport: The 3rd International Conference on Concussion in Sport Held in Zurich, November 2008**

**Paul McCrory, MBBS, PhD\*; Willem Meeuwisse, MD, PhD†; Karen Johnston, MD, PhD‡; Jiri Dvorak, MD§; Mark Aubry, MD||; Mick Molloy, MD¶; Robert Cantu, MD††#**

\*University of Melbourne, Parkville, Australia; †University of Calgary, Calgary, Alberta, Canada; ‡Toronto Rehabilitation Institute, Toronto, Ontario, Canada; §FIFA Medical Assessment and Research Center and Schulthess Clinic, Zurich, Switzerland; ||International Ice Hockey Federation, Hockey Canada, and Ottawa Sport Medicine Centre, Ottawa, Ontario, Canada; ¶International Rugby Board, Dublin, Ireland; #Emerson Hospital, Concord, MA

A bunch of sport doctors held the conference.

### **2.2 On-Field or Sideline Evaluation of Acute Concussion**

When a player shows ANY features of a concussion

- (a) The player should be medically evaluated onsite using standard emergency management principles, and particular attention should be given to excluding a cervical spine injury.
- (b) The appropriate disposition of the player must be determined by the treating health care provider in a timely manner. If no health care provider is available, the player should be safely removed from practice or play and urgent referral to a physician arranged.
- (c) Once the first aid issues are addressed, then an assessment of the concussive injury should be made using the SCAT2 or other similar tool.
- (d) The player should not be left alone following the injury, and serial monitoring for deterioration is essential over the initial few hours following injury.
- (e) A player with diagnosed concussion should not be allowed to RTP on the day of injury.  
Occasionally, in adult athletes, there may be RTP on the same day as the injury. See section 4.2.

The player has to be evaluated by a doctor,  
, it cannot be the parent, not player  
himself, not the coach.

If there's no doctors nearby, the  
player must not return to field.

The player should not be left alone.

# SCAT2 Cards

## Pocket SCAT2



FIFA®



Concussion should be suspected in the presence of **any one or more** of the following: symptoms (such as headache), or physical signs (such as unsteadiness), or impaired brain function (e.g. confusion) or abnormal behaviour.

### 1. Symptoms

Presence of any of the following signs & symptoms may suggest a concussion.

- Loss of consciousness
- Seizure or convulsion
- Amnesia
- Headache
- "Pressure in head"
- Neck Pain
- Nausea or vomiting
- Dizziness
- Blurred vision
- Balance problems
- Sensitivity to light
- Sensitivity to noise
- Feeling slowed down
- Feeling like "in a fog"
- "Don't feel right"
- Difficulty concentrating
- Difficulty remembering
- Fatigue or low energy
- Confusion
- Drowsiness
- More emotional
- Irritability
- Sadness
- Nervous or anxious

### 2. Memory function

Failure to answer all questions correctly may suggest a concussion.

"At what venue are we at today?"

"Which half is it now?"

"Who scored last in this game?"

"What team did you play last week/game?"

"Did your team win the last game?"

### 3. Balance testing

#### Instructions for tandem stance

"Now stand heel-to-toe with your **non-dominant** foot in back. Your weight should be evenly distributed across both feet. You should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."

Observe the athlete for 20 seconds. If they make more than 5 errors (such as lift their hands off their hips; open their eyes; lift their forefoot or heel; step, stumble, or fall; or remain out of the start position for more than 5 seconds) then this may suggest a concussion.

Any athlete with a suspected concussion should be **IMMEDIATELY REMOVED FROM PLAY**, urgently assessed medically, should not be left alone and should not drive a motor vehicle.

Many of these are questions that the doctor asks, and they are very subjective questions.

What's scary is that some of them the athlete can fake through, some muscle memory will game through.

# SCAT2 Cards



**SCAT2**  
Sport Concussion Assessment Tool 2

Name \_\_\_\_\_

Sport/team \_\_\_\_\_

Date/time of injury \_\_\_\_\_

Date/time of assessment \_\_\_\_\_

Age \_\_\_\_\_ Gender  M  F

Years of education completed \_\_\_\_\_

Examiner \_\_\_\_\_

**What is the SCAT2?**  
This tool represents a standardized method of evaluating injured athletes for concussion and can be used in athletes aged from 10 years and older. It supersedes the original SCAT published in 2005<sup>1</sup>. This tool also enables the calculation of the Standardized Assessment of Concussion (SAC)<sup>3,4</sup> score and the Maddocks questions<sup>5</sup> for sideline concussion assessment.

**Instructions for using the SCAT2**  
The SCAT2 is designed for the use of medical and health professionals. Preseason baseline testing with the SCAT2 can be helpful for interpreting post-injury test scores. Words in italics throughout the SCAT2 are the instructions given to the athlete by the tester.

This tool may be freely copied for distribution to individuals, teams, groups and organizations.

**What is a concussion?**  
A concussion is a disturbance in brain function caused by a direct or indirect force to the head. It results in a variety of non-specific symptoms (like those listed below) and often does not involve loss of consciousness. Concussion should be suspected in the presence of **any one or more** of the following:

- Symptoms (such as headache), or
- Physical signs (such as unsteadiness), or
- Impaired brain function (e.g. confusion) or
- Abnormal behaviour.

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.

**Symptom Evaluation**

**How do you feel?**  
You should score yourself on the following symptoms, based on how you feel now.

	none	mild	moderate	severe			
Headache	0	1	2	3	4	5	6
"Pressure in head"	0	1	2	3	4	5	6
Neck Pain	0	1	2	3	4	5	6
Nausea or vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Blurred vision	0	1	2	3	4	5	6
Balance problems	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling like "in a fog"	0	1	2	3	4	5	6
"Don't feel right"	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Fatigue or low energy	0	1	2	3	4	5	6
Confusion	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
Trouble falling asleep (if applicable)	0	1	2	3	4	5	6
More emotional	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervous or Anxious	0	1	2	3	4	5	6
<b>Total number of symptoms</b> (Maximum possible 22)							
<b>Symptom severity score</b>							
(Add all scores in table, maximum possible: 22 x 6 = 132)							
Do the symptoms get worse with physical activity? <input type="checkbox"/> Y <input checked="" type="checkbox"/> N							
Do the symptoms get worse with mental activity? <input type="checkbox"/> Y <input checked="" type="checkbox"/> N							
<b>Overall rating</b>							
If you know the athlete well prior to the injury, how different is the athlete acting compared to his / her usual self? Please circle one response.							
<input type="checkbox"/> no different <input type="checkbox"/> very different <input checked="" type="checkbox"/> unsure							

## 2. Memory function

Failure to answer all questions correctly may suggest a concussion.

*"At what venue are we at today?"*

*"Which half is it now?"*

*"Who scored last in this game?"*

*"What team did you play last week/game?"*

*"Did your team win the last game?"*

## 3. Balance testing

### Instructions for tandem stance

*"Now stand heel-to-toe with your **non-dominant** foot in back. Your weight should be evenly distributed across both feet. You should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."*

Observe the athlete for 20 seconds. If they make more than 5 errors (such as lift their hands off their hips; open their eyes; lift their forefoot or heel; step, stumble, or fall; or remain out of the start position for more than 5 seconds) then this may suggest a concussion.

**Any athlete with a suspected concussion should be IMMEDIATELY REMOVED FROM PLAY, urgently assessed medically, should not be left alone and should not drive a motor vehicle.**

# SCAT2 Cards

Following is the state of art for scanning symptoms

## 6 Balance examination

This balance testing is based on a modified version of the Balance Error Scoring System (BESS). A stopwatch or watch with a second hand is required for this testing.

### Balance testing

"I am now going to test your balance. Please take your shoes off, roll up your pant legs above ankle (if applicable), and remove any ankle taping (if applicable). This test will consist of three twenty second tests with different stances."

#### (a) Double leg stance:

"The first stance is standing with your feet together with your hands on your hips and with your eyes closed. You should try to maintain stability in that position for 20 seconds. I will be counting the number of times you move out of this position. I will start timing when you are set and have closed your eyes."

#### (b) Single leg stance:

"If you were to kick a ball, which foot would you use? [This will be the dominant foot] Now stand on your non-dominant foot. The dominant leg should be held in approximately 30 degrees of hip flexion and 45 degrees of knee flexion. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."

#### (c) Tandem stance:

"Now stand heel-to-toe with your non-dominant foot in back. Your weight should be evenly distributed across both feet. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."

### Balance testing – types of errors

- 1. Hands lifted off iliac crest
- 2. Opening eyes
- 3. Step, stumble, or fall
- 4. Moving hip into > 30 degrees abduction
- 5. Lifting forefoot or heel
- 6. Remaining out of test position > 5 sec

Each of the 20-second trials is scored by counting the errors, or deviations from the proper stance, accumulated by the athlete. The examiner will begin counting errors only after the individual has assumed the proper start position. The modified BESS is calculated by adding one error point for each error during the three 20-second tests. The maximum total number of errors for any single condition is 10. If a athlete commits multiple errors simultaneously, only one error is recorded but the athlete should quickly return to the testing position, and counting should resume once subject is set. Subjects that are unable to maintain the testing procedure for a minimum of five seconds at the start are assigned the highest possible score, ten, for that testing condition.

Which foot was tested:  Left  Right  
(i.e. which is the non-dominant foot)

### Condition

Double Leg Stance (feet together)  
Single leg stance (non-dominant foot)  
Tandem stance (non-dominant foot at back)

Balance examination score (30 minus total errors)

## 7 Coordination examination

### Upper limb coordination

Finger-to-nose (FTN) task: "I am going to test your coordination now. Please sit comfortably on the chair with your eyes open and your arm (either right or left) outstretched (shoulder flexed to 90 degrees and elbow and fingers extended). When I give a start signal, I would like you to perform five successive finger to nose repetitions using your index finger to touch the tip of the nose as quickly and as accurately as possible."

Which arm was tested:  Left  Right

Scoring: 5 correct repetitions in < 4 seconds = 1

Note for testers: Athlete fail the test if they do not touch their nose, do not fully extend their elbow or do not perform five repetitions. Failure should be scored as 0.

### Coordination score

of 1

## 8 Cognitive assessment

### Standardized Assessment of Concussion (SAC)

#### Delayed recall

"Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order."

Circle each word correctly recalled. Total score equals number of words recalled.

List	Alternative word list
elbow	candle
apple	paper
carpet	sugar
saddle	sandwich
bubble	sunset
	wagon
	iron

### Delayed recall score

of 5

## Overall score

Test domain	Score
Symptom score	of 22
Physical signs score	of 2
Glasgow Coma score (E + V + M)	of 15
Balance examination score	of 30
Coordination score	of 1
<b>Subtotal</b>	<b>of 70</b>
Orientation score	of 5
Immediate memory score	of 5
Concentration score	of 15
Delayed recall score	of 5
<b>SAC subtotal</b>	<b>of 30</b>
<b>SCAT2 total</b>	<b>of 100</b>
<b>Maddocks Score</b>	<b>of 5</b>

Definitive normative data for a SCAT2 "cut-off" score is not available at this time and will be developed in prospective studies. Embedded within the SCAT2 is the SAC score that can be utilized separately in concussion management. The scoring system also takes on particular clinical significance during serial assessment where it can be used to document either a decline or an improvement in neurological functioning.

**Scoring data from the SCAT2 or SAC should not be used as a stand alone method to diagnose concussion, measure recovery or make decisions about an athlete's readiness to return to competition after concussion.**

## Athlete Information

Any athlete suspected of having a concussion should be removed from play, and then seek medical evaluation.

### Signs to watch for

Problems could arise over the first 24-48 hours. You should not be left alone and must go to a hospital at once if you:

- Have a headache that gets worse
- Are very drowsy or can't be awakened (woken up)
- Can't recognize people or places
- Have repeated vomiting
- Behave unusually or seem confused; are very irritable
- Have seizures (arms and legs jerk uncontrollably)
- Have weak or numb arms or legs
- Are unsteady on your feet; have slurred speech

### Remember, it is better to be safe.

Consult your doctor after a suspected concussion.

### Return to play

Athletes should not be returned to play the same day of injury.

When returning athletes to play, they should follow a stepwise symptom-limited program, with stages of progression. For example:

1. rest until asymptomatic (physical and mental rest)
2. light aerobic exercise (e.g. stationary cycle)
3. sport-specific exercise
4. non-contact training drills (start light resistance training)
5. full contact training after medical clearance
6. return to competition (game play)

There should be approximately 24 hours (or longer) for each stage and the athlete should return to stage 1 if symptoms recur. Resistance training should only be added in the later stages.

Medical clearance should be given before return to play.

Tool	Test domain	Time	Score
	Date tested		
	Days post injury		
<b>SCAT2</b>	Symptom score		
	Physical signs score		
	Glasgow Coma score (E + V + M)		
	Balance examination score		
	Coordination score		
<b>SAC</b>	Orientation score		
	Immediate memory score		
	Concentration score		
	Delayed recall score		
	<b>SAC Score</b>		
<b>Total</b>	<b>SCAT2</b>		
	<b>Symptom severity score (max possible 132)</b>		
	<b>Return to play</b>	Y N Y N Y N Y N	

### Additional comments

## Concussion injury advice (To be given to concussed athlete)

This patient has received an injury to the head. A careful medical examination has been carried out and no sign of any serious complications has been found. It is expected that recovery will be rapid, but the patient will need monitoring for a further period by a responsible adult. Your treating physician will provide guidance as to this timeframe.

If you notice any change in behaviour, vomiting, dizziness, worsening headache, double vision or excessive drowsiness, please telephone the clinic or the nearest hospital emergency department immediately.

### Other important points:

- Rest and avoid strenuous activity for at least 24 hours
- No alcohol
- No sleeping tablets
- Use paracetamol or codeine for headache. **Do not use aspirin or anti-inflammatory medication**
- **Do not drive until medically cleared**
- **Do not train or play sport until medically cleared**

Clinic phone number

Contact details or stamp

# Graduated Return-to-Play (RTP) Protocol

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## Consensus Statement on Concussion in Sport: The 3rd International Conference on Concussion in Sport Held in Zurich, November 2008

**Paul McCrory, MBBS, PhD\***; **Willem Meeuwisse, MD, PhD†**; **Karen Johnston, MD, PhD‡**; **Jiri Dvorak, MD§**; **Mark Aubry, MD||**; **Mick Molloy, MD¶**; **Robert Cantu, MD\*\*#**

\*University of Melbourne, Parkville, Australia; †University of Calgary, Calgary, Alberta, Canada; ‡Toronto Rehabilitation Institute, Toronto, Ontario, Canada; §FIFA Medical Assessment and Research Center and Schulthess Clinic, Zurich, Switzerland; ||International Ice Hockey Federation, Hockey Canada, and Ottawa Sport Medicine Centre, Ottawa, Ontario, Canada; ¶International Rugby Board, Dublin, Ireland; #Emerson Hospital, Concord, MA

**Table 1. Graduated Return-to-Play Protocol**

Rehabilitation Stage	Functional Exercise at Each Stage of Rehabilitation	Objective of Each Stage
1. No activity	Complete physical and cognitive rest	Recovery
2. Light aerobic exercise	Walking, swimming, or stationary cycling, keeping intensity to <70% of maximum predicted heart rate; no resistance training	Increase heart rate
3. Sport-specific exercise	Skating drills in ice hockey, running drills in soccer; no head impact activities	Add movement
4. Non-contact training drills	Progression to more complex training drills, eg, passing drills in football and ice hockey; may start progressive resistance training	Exercise, coordination, and cognitive load
5. Full-contact practice	Following medical clearance, participate in normal training activities	Restore athlete's confidence; coaching staff assesses functional skills
6. Return to play	Normal game play	

# Concussion Protection

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- Rule changes in sports
  - Soccer studies show 50% of concussions due to limb-to-head contact
  - NHL: Introduced a Rule 48 “Illegal Check to the Head” in 2010-11
  - NFL: Play whistled dead as soon as player loses helmet, 2010
  - NFL: Players prohibited from using helmet to strike defenseless player
- Protective gear
  - Mouthguards
  - Helmets

# Technology-Infused Gear

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These attempt to detect possible symptom of concession,  
But NONE OF THESE CAN diagnose concession.

- Riddell's SpeedFlex smart helmet
  - Reebok's Check Light
  - Battle Sports' Impact Indicator
  - Shockbox
  - BiteTech's Smart Mouthgard
- 
- None of these technologies diagnose concussions
  - All of them aim to provide some kind of alert for hits/impact

# Riddell's Smart Helmet

5 accelerometers.

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- Riddell's InSite System
  - Riddell's Head Impact Telemetry System (HITS)
  - Set of 5 sensors that can be embedded into a helmet  
Five panel's have sensors embedded.
  - Wireless communication to coach's sideline devices
  - Player Management Software, to allow offline analysis
- SpeedFlex added polymer-film lining that develops a charge under impact
- Helmet contains a flexible panel that compresses on impact



# Riddell's Smart Helmet

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## Helmet with checklight

The checklight is in a "pig tail" -- a light on it.

# Reebok's Checklight

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- Reebok's Checklight System
  - Black skullcap embedded with sensors, worn by players under helmet
  - LED light indicator that dangled under the helmet as a small “tail”
  - LED was normally green, would flash yellow/red for abnormal impact
- Checklight showed demonstrated value for a 13-year old player
- Uses pliable sensors embedded in fabric
- Combination of accelerometer + gyroscope
- Accelerometer measures initial impact
- Gyroscope detects/measures “aftershock” effect

aftershock = the feeling I am wabbling -- a sense of recoil.
- Visible indicator, no wireless communication to sidelines



The Reebok's headlight saved a teenager football player. But the accelerometers in Riddel's smart helmet may not trigger all the time -- they are not so deterministic.

# Do These Actually Work?

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Place accelerators in the chin-strap.

# Battle Sports Science's Impact Indicator

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- Impact Indicator System
  - Accelerometers embedded in the **chin-strap of the helmet**
  - To determine the force, duration, direction of every hit on player
  - Blows with >50% chance of head injury activate the **chin-strap light**
- Patriots' BenJarvus Green-Ellis wore in the Super Bowl XLVI



# BiteTech's Smart Mouthguard

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- BTX2 Impact Sensing Mouthguard
  - Accelerometers and gyroscopes embedded in mouthguards
  - To determine the force of head impacts on players
  - Data wirelessly transmitted to computers on the sidelines
  - Synchronized with the video of the play
  - Used for data collection with Stanford University football team

One of the symptom of concession is the clinch of your jaw muscle.  
As they are clinch on them, the sensor measure and send data back.



A video demo for the BiteTech's Smart MouthGuard.

# Mouth-guards for concussion detection

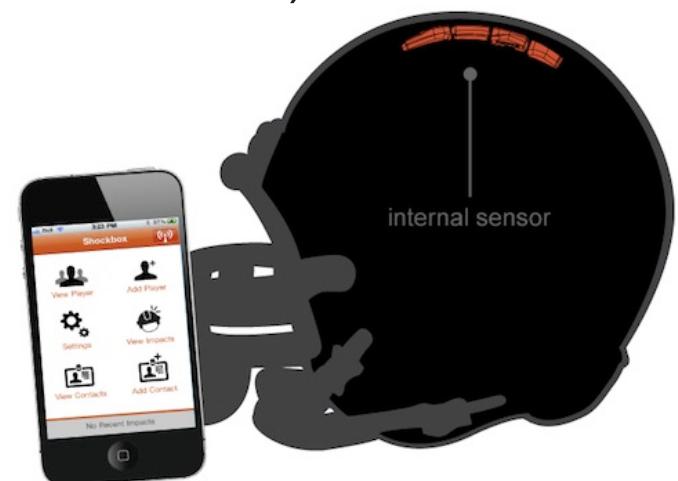
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# Shockbox

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- Shockbox
  - Helmet g-force sensor, measures impact on player
  - Alerts of need for a medical assessment
  - Flexible strip with electronics with Bluetooth transmitter and battery
  - Can be embedded into the padding of any helmet (used for any sport)
  - Color-coded alerts sent to a mobile app (orange: >50g, red: >90g)
  - 128 Shockboxes can be tracked at once (useful for coaches)



# xPatch

Band-Aid like sensor attach-on.

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- Impact-sensing skin patches

- Similar technology but miniaturized into a skin patch
- Measures linear and rotational impacts



Three chemical are released into blood when player is concussed.

## Breath Tests for Concussion

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- Three chemicals that are released into the blood stream on a player's injury
  - Developed at the University of Birmingham
  - Molecules make their way into the lungs
  - Can be detected via a breath-test
  - Currently under test for rugby and soccer
  - Additional machine that uses magnetic pulses to detect brain damage

# Our Class Project

**Personalized Concussion Diagnostics on the Sidelines using Ocular-Behavior Testing**

Ryan Quinn, Thomas Phillips, Andrew Pfeifer, & Brandon Lee, with Professor Priya Narasimhan

**Carnegie Mellon**

**Motivation: Concussion Detection & Diagnosis**

- Concussions are a major concern in modern sports, especially football
- Goal: provide tools to automate and expedite existing diagnostics
- If testing can be done more quickly & more accurately, we can return more players to the game faster

**Our Prototype:**

- A non-invasive eye-sensing device that makes use of biometric ocular responses to automatically assess potential player concussions
- Our device offers:
  - A data-driven, customized approach
  - An automated approach
  - The use of standard, proven tests

**On-Field Usage Architecture**

The diagram illustrates the workflow for on-field usage. It starts with a tablet or phone interface where a trainer activates a test. This triggers a local control board in an eye-set worn by a player. The board controls an infrared camera and eye-stimulation LEDs. The system sends video data over a local WiFi intranet to a high-performance basestation with a GPGPU. The basestation performs OpenCV image processing on pupil video data and sends processing results over standard WiFi internet to cloud services. The cloud services handle pupil response video transmission, processing, and result uploading. The entire process is monitored via a device-agnostic testing interface.

Legend:

- System Connections (Dashed blue arrow)
- Software Components (Solid green arrow)
- Hardware Components (Solid red arrow)

Key components and steps:

- (1) Concussion suspected; player moved to sideline & dons eye-set; trainer remotely activates test via tablet/mobile device.
- (2) Test cycle begins; visual stimulation using LEDs occurs; pupil responses recorded.
- (3) Pupil response video transmitted to basestation; video processing performed on pupil data; results uploaded to cloud & device.

Annotations:

- High-performance basestation with GPGPU
- OpenCV image processing on pupil video data
- Local control board
- Multi-process, multithreaded C++/Python executive
- Fixed-focus infrared camera
- Eye-stimulation LEDs
- Send processing results over standard WiFi internet
- Send video data over local WiFi intranet
- Place results in local WiFi intranet
- Send test request over local WiFi intranet
- Device-agnostic testing interface



## Technology for Player Performance

# Fitness Trackers

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- Watches for runners
  - Garmin, Nike, Timex
  - + wearable sensor: Footpod sensor for more accuracy
  - + wearable sensor: Heartstrap for measuring heartrate
- Activity trackers for everyone
  - Fitbit, Jawbone Up24, Nike Fuelband, Basis wristband
  - Adidas miCoach smart wristband
- Pedometers
  - From a variety of organizations

# MC10's BioStamp

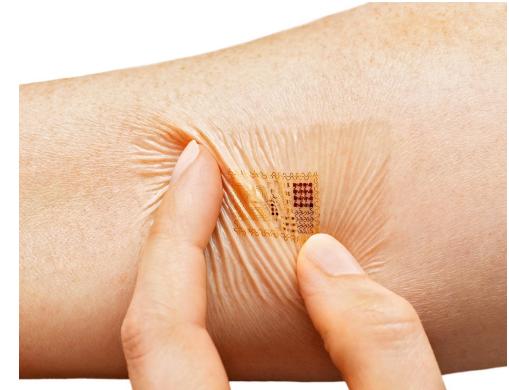
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- MC10 is the company that developed Reebok's Checklight system
- Biostamp: Wearable stretchable electronics
  - Looks like a thin wearable band-aid that can be affixed to your body
  - Input from athletes on what to monitor for recovery, performance
  - Athletes (e.g., Grant Hill) serve on the Advisory Board
  - Players can simply stick on multiple Biostamps wherever they want
- What can it measure?
  - Heart-rate, hydration

Hydration Level, Heart Rate Level...

[End of Lecture 0203](#)

When asked what data he would find most valuable, the No. 1 overall pick in the 2012 NFL Draft imagined a wearable device that could accurately count practice throws and help quarterbacks better manage their workloads outside of games. Someday, Luck could place a Biostamp on his throwing shoulder that does exactly that. At this stage in the sports wearables game, anything is possible.



# Catapult's OptimEye

GPS in catapult.

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- Catapult Sports      [Catapult is install in the label packet on the back of cloth.](#)
  - Australian company making wearable devices used in sports
  - Rugby, soccer, Australian-rules football, rowing, now the NBA, NFL
- Matchbook-size GPS tracking device called OptimEye
  - Small wearable sensor fitted to player's jersey on their upper back
  - Tracks player's position in 3D space
  - Accelerometers, magnetometers, gyros track load, distance, direction
  - ~~Steps~~ filters to process data to determine athlete's direction for each
  - For indoors, internal stadium antennas to pick up the signals

# Catapult

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In the meantime, teams will continue to use them in practice and rehab drills and compare the results with biomedical data to get a complete picture of athletic performance. The NFL's Jacksonville Jaguars had their players answer questions about emotions and sleep habits and referenced the responses against OptimEye data to prove that players perform significantly better on more sleep—a warning to rookies not to hit the clubs at night.

Catapult is not used in the field of play. Catapult is for load, for training session. NOT FOR REAL GAMES.

They don't use it in real games, just in practise sessions.

After each game those devices are place back to the docking station for data extraction.

Can measure the player's direction, position, change in accelerations. Primary goal: injury prevention. "THE LOAD"

The players want the informaiton, they also worry about the information,

What if a player runs slower than another player? It could affect salary?



# And, FIFA, too ...



FIFA has a device for training program too.

They granted license for three types of positioning systems:

1. optical (such as Hawkeye) -- limited in measuring position  
cannot measure fatigue

sometimes if there's shadow in the court - need to fix manually

but advantage is really high speed / not invasive to how player play / not limited in battery power.

2. Local positioning system methods. (RF antenna for triangulation )

Sensor inside a ball or player, use something called "ultra wideband"

Still RF, not wifi, using doppler effects to do triangulation.

You can get high number of measurements -- it's all RF speed of light

High accuracy --- we're using multiple antenna and base station

Ultra-wideband technology provides large bandwidth but need installation time and cost. We need to change infrastructure in the building. If the sensor is in the ball or player, it can be invasive.

3. GPS / GNSS systems.

Advantage: High number of measurements, short installation time, No operator needed.

Limitations:

Device attached to player

Need line-of-sight signal -- it is not very accurate, not centimeter level

FIFA EPTS -- FIFA provides details in data format, architecture, and programming details, the test methods, things they do.

0204 5:14

Accelerometer gyroscope measures player load / player position.

Physiological parameter - heart rate / fatigue, not just the movements.

This is also just for load measurement in training.

Ways to get license from FIFA: being tested - 0204 25:50

# SportVU from STATS LLC

All 29 arenas in the US has SportVU installed.

Similiar to Hawkeye but for basketball.

Cameras in the rafters trying to cover all the court.

High Speed, High Accuracy. 6 for entire court, 3 on each side.

11 data traces per game / data trace is an asset being traced.  
Records 10 players and one ball.

records X/Y coordinate of player and X/Y/Z coordinate of the ball.



Looks for player patterns, which player excel in specific type of geometry.



# SportVU from STATS LLC



# SportVU from STATS LLC

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- Information stored in a database
  - Interactive Collaboration and Evaluation (ICE)
  - Data and statistics shared across NBA teams using the service
  - Scouting reports/analysis kept private to each team
- NBA scouts use this on a regular basis
  - Accessible via mobile/tablet worldwide
- NBA trainers starting to use this
  - For fitness monitoring

Images over the image, it sees where the player is from other player, where the player is from the line. The information of report is going to improve winning statistics.

# SportVU



0204 42:48

# SportVU

You know which player plays the best in which geometry.  
Blue dots on the players while they are playing.

SportVU installed for all 30 teams in NBA.



# SportVU Challenges

Jersey is the bug number on the back of the player.

- Expected challenges due to computer vision
  - Shadows on the court
  - Dark colors on the court
  - Detecting players' jersey numbers
  - Accommodating uniform/jersey changes

Some cases it might fail:

Golden number -- too flashy surface and not much contrast.

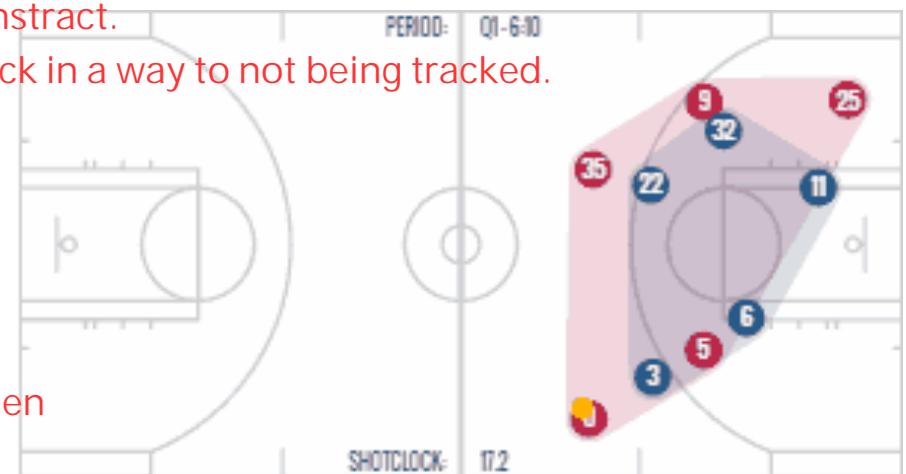
Some players don't want to be detected. They lean back in a way to not being tracked.

Shadows... flash lights might also cause problem.

NBA Replay Center in New Jersey (the state)

The main goal is to get officials the angles they need when they need it. To make judging easier.

94 monitors and 20 work stations.



# Wilson Connected Basketball

At-home shot training.

- Contains a sensor to track shots
  - Tracks how many hoops
  - Tracks how many misses
  - Does not track passes or dribbles
  - Only tracks shots at least 7ft from the hoop
  - Only works with a regulation 10ft hoop (no additional technology)
  - Built-in battery to last more than 100,000 shots
  - Saves data for later
  - Connects via Bluetooth to a mobile app

You at home can set this up and use it to train yourself.

There's no inductive charging. But will have in the future.

Shock Tacker one piece on the hoop net, another piece on the wrist and then you can start training. Wilson doesn't need that.



# Wilson Connected Basketball

Not only for professional athletes.



# Wilson Connected Basketball



# Zepplin: Improving your Golf Swing

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- Wearable Zepp sensor + Zepp GolfSense app
  - Senses swing, speed, angle; creates virtual 360-degree replay of swing
- Three-axis MEMS gyroscope
  - Pitch (up/down tilt), yaw (left/right twist), roll (longitudinal spin)
- Two accelerometers
  - Measures the g-forces due to golf swing (two for improved accuracy)
- Combination of 1,000 data points per second
  - ARM processor helps to analyze, send data via Bluetooth to app
  - Helps visualize your game/play, and improve your swing
  - Gyroscope (if in pocket) measures hip rotation, provide tips to improve

Attach the sensor to the golf glove and sync up with the app, and then you swing.

The system shows the animation / acceleration of the swing.

# Improving your Golf Swing

[https://www.youtube.com/watch?v=yrweT\\_qn680](https://www.youtube.com/watch?v=yrweT_qn680)



# Bat Sensors for Baseball

Can analyze the swing on the phone.



Entire clothing has a grid of wires. It is measuring all the movements / fatigues. Workout gear, left tie versus right tie. You have a personal trainer on the workout gear.

Entire suit is a mesh of embedded sensor and also a heart-rate sensor. It is a personal trainer. Understanding

## Athos' Connected Apparel

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It uses to use EMG, which is really expensive. 199 dollars for the shirt.

- Clothing (workout pants, full-body suit) embedded with
  - Tiny sensors to measure muscle output, heart rate, respiration
  - Data is transmitted to a small wearable module, synchs with app
  - As user moves, activity measured on skin, converted to data
- User is provided with a “muscle-effort score”
  - Indication of how much you are pushing yourself
  - Provides data on whether stretching/lifting is being done correctly
- User is provided with a heart-rate activity indicator
  - Indication of if you are in the right heartrate zone to improve fitness
- Can also track reps and workout time

# Athos' Connected Apparel



# Zebra MotionWorks

These are based RF ID tags are not GPS based, it's based on ultrawide band.

Used in NFL.

Catapult used in basketball is GPS based. Zebra is RF ID based.

Catapult is off-line analysis. But Zebra is real-time data.

- RFID tags affixable to any game asset

In shoulder pads and knee pads

- Quarter-sized RFID tags can be affixed to players' equipment  
In the helmet and the player's kit.

- UWB (ultra-wideband, 500Mhz-1GHz) with range of 300 feet or so  
RF that's in a spectrum not in Wi-Fi.

- Location granularity is claimed to be within 6 inches or so

- 12-30 installed antennas/receivers placed around the stadium

- Receivers pick up the data

- Analyze player's location, speed, direction of movement

Puraly localization,  
no hydration or heart  
rate.

- Analysis and visualization done by sideline equipment

- Used primarily for coaching and scouting right now

BuffaloBill's use of Catapult

Next-Gen Stats (powered by AWS) - -real time data less than 1 second latency.

# Zebra MotionWorks

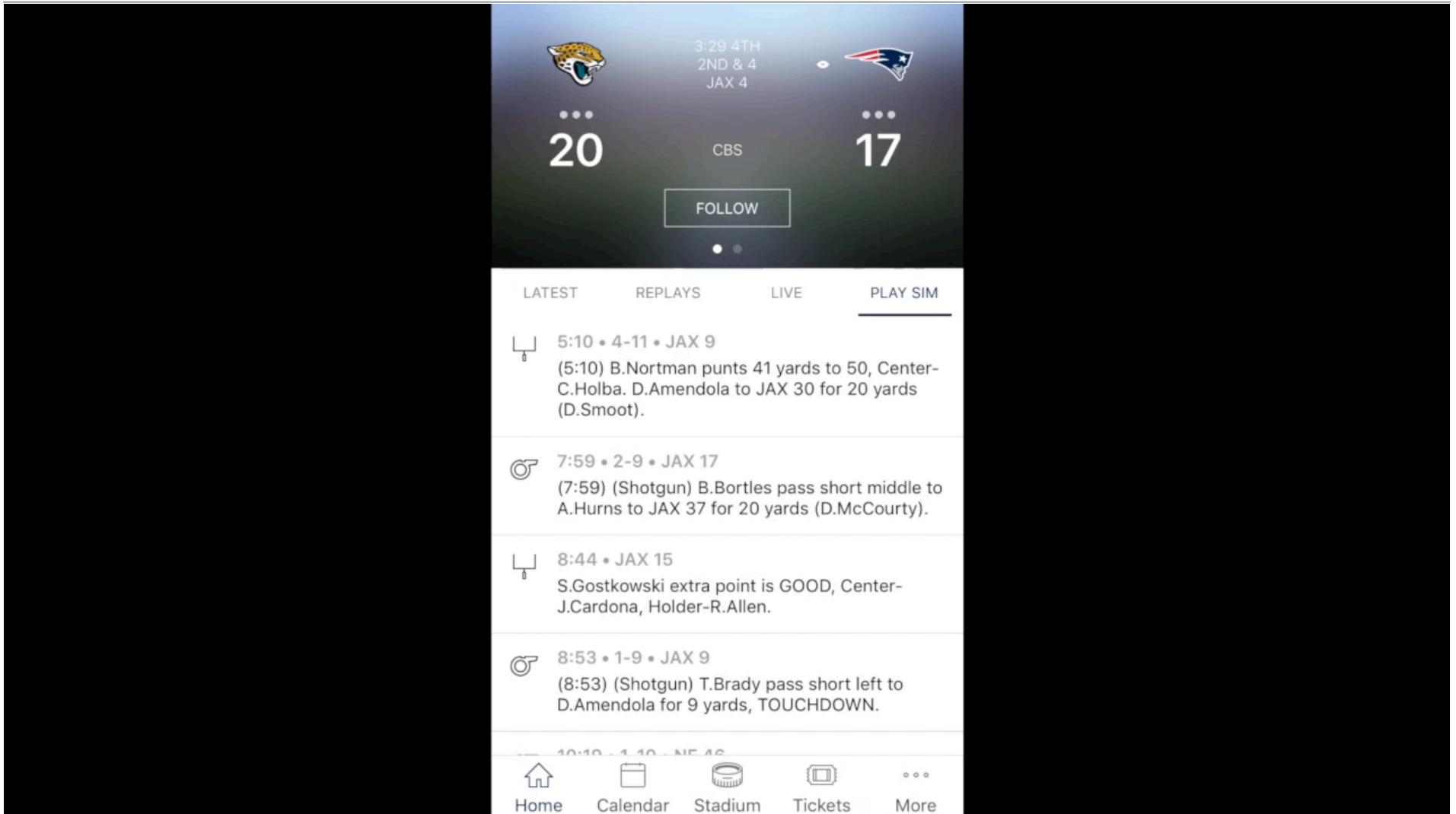


# Zebra MotionWorks



We can see the 3D visualization on a coffee table.

# We got to use the data!



# Biggest Debates

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- Who owns the data? *Atheletes worried that their data is exposed to others., it could hurt their contract, the job.*
  - Source of concern for athletes
- Questions
  - Line between fan engagement, performance and athlete privacy
  - Would the data be used in contract negotiations?
  - Would the data be used to decide who's in the starting line-up?
  - What if fans/coaches could “see” a field-goal kicker's stress?  
*Account it in your defense / offense in the game. What if there's too much analytics.*
  - What if it's too much information, and detracts from a player's instinct?  
*Sometime you just want to be device tree -- take away from the instinct,*
- Additional considerations
  - Quality of the data, quality of the device
  - Device non-invasiveness/comfort with respect to playing the game  
*Catapult is likely to invade the feeling on player.*

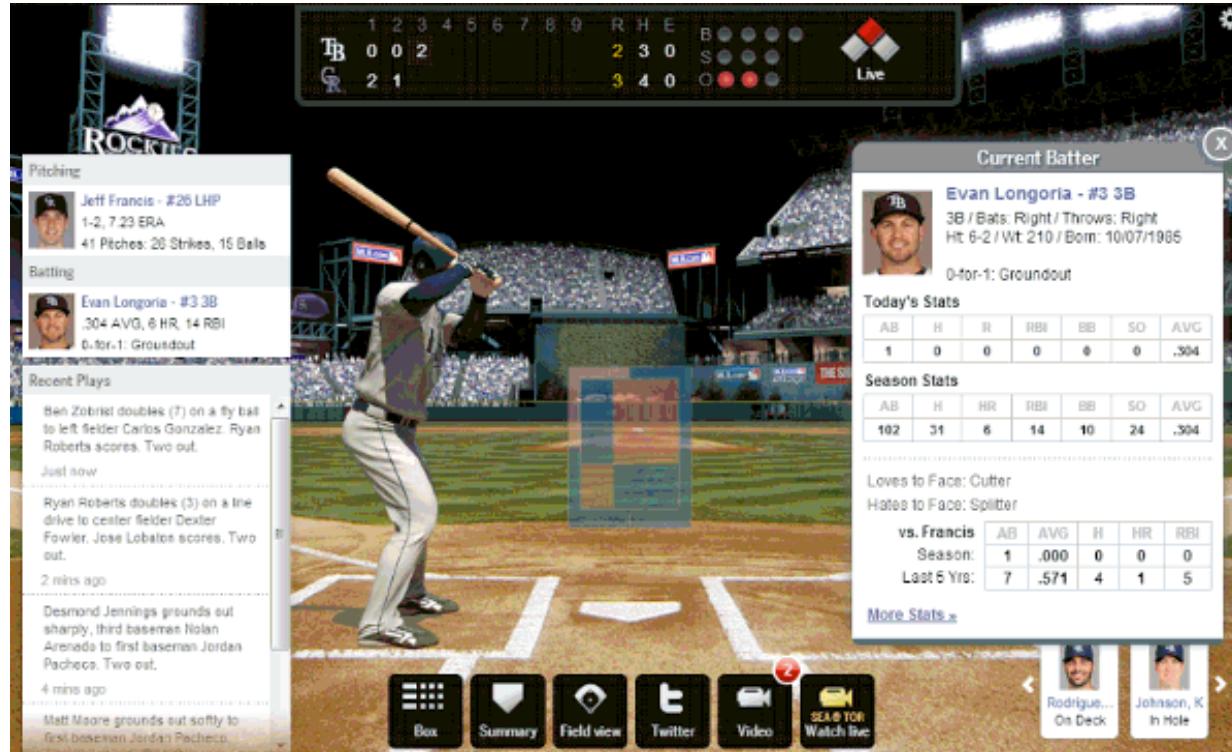
# Ways in Which Analytics Will Change Sports

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- #1 Better officiating
  - Umpires rely on eyesight to call a strike or ball in baseball
  - Sportvision's Pitchf/x has been installed in 30 MLB ballparks
  - Goal is to track pitches during a game
  - Two 60Hz tracking cameras
  - Each records pitch from leaving player's hand to crossing the plate
  - Sends data to calculate speed, location and trajectory
  - Data is used for a variety of purposes, including broadcast
  - Attempts to classify curveball, fastball, etc.

End of lecture 0204

# Ways in Which Analytics Will Change Sports



# Ways in Which Analytics Will Change Sports

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- #2 Incorporating data from wearable devices
  - Wearable data from players to track human activity/wellness
  - For scouting, fitness tracking, recovery, game-day readiness
  - For injury prevention, for injury detection/diagnostics
  - We've covered quite a bit of this in our lectures
- #3 Live on-field game-data collection
  - Game moves so fast it's impossible for humans to keep up
  - Every asset on the field is becoming trackable
  - SportVU and Hawk-Eye, for example

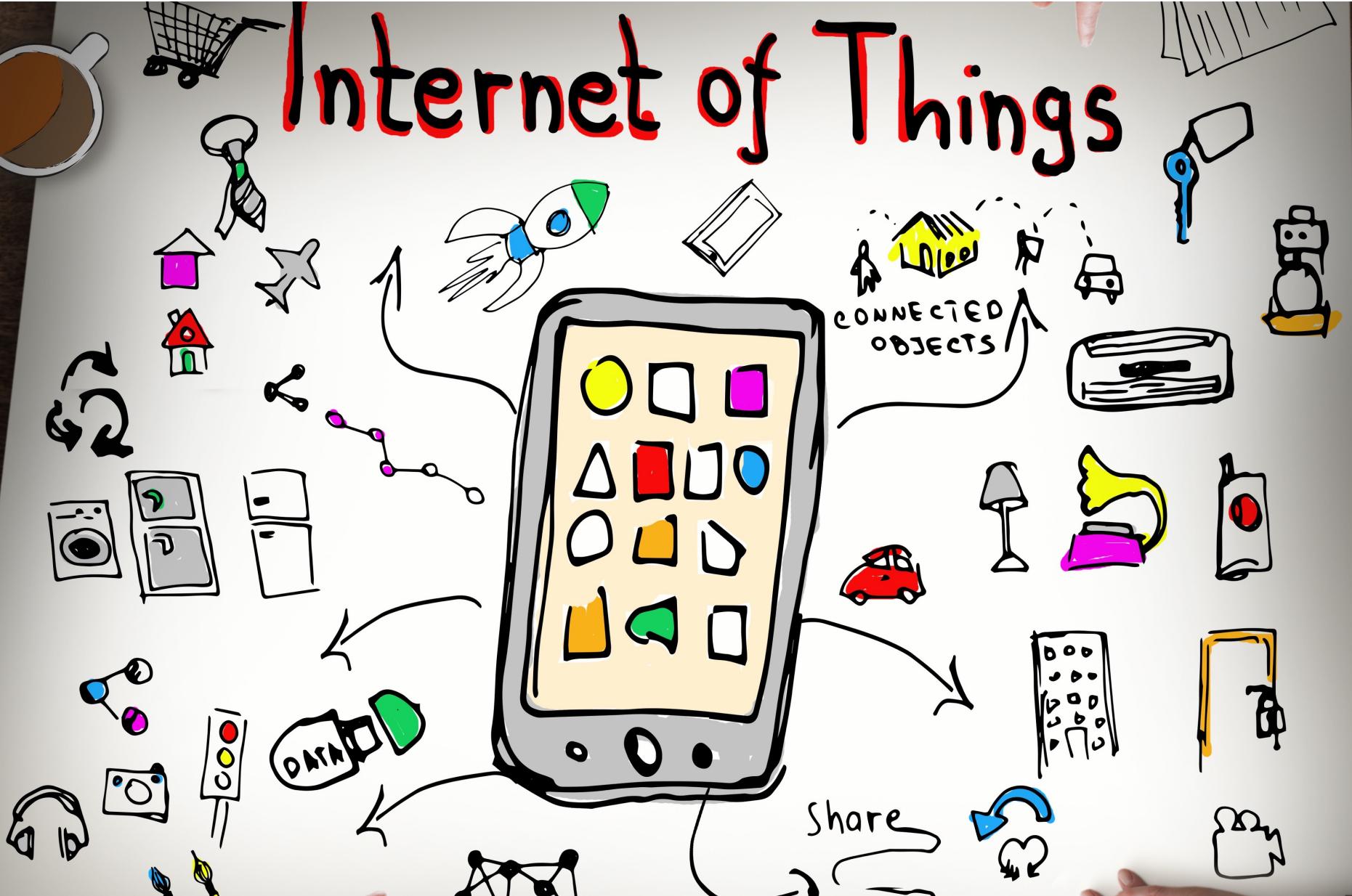
# Previous Course Projects

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- Helping kids play soccer better
  - Outfitting cleats with sensors to provide audible/visual feedback
- Smart watch for visualizing your golf swing
  - Aim to reconstruct the 3D play and provide audible/visual feedback
- Visualizing plays
  - Quarterback to visualize the play on his armband
- Embedded slow-motion glasses
  - To be able to view the play in front of you, in slow motion

# End of Class: A Sports Science Nugget





Safety and Performance  
18-738 Sports Technology

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