Should You Check Their Head When the Light Blinks Red? The Clinical Utility of Head Impact Sensors for Diagnosing Sport-Related Concussion

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OHSU Mild Traumatic Brain Injury Symposium

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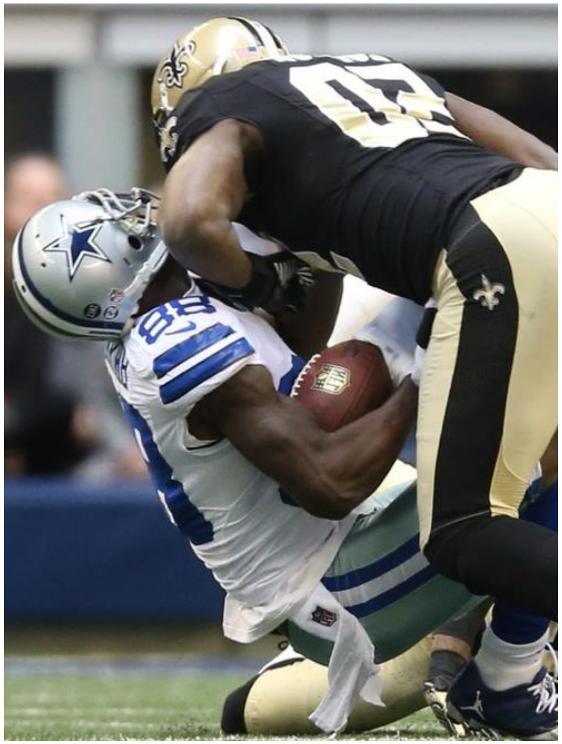
Conflict of Interest

- I have no conflicts of interest or financial relationships to disclose

Objectives

1. Remember the available head impact sensors on the market and their capabilities
2. Understand the determinants for accurate head impact sensor technologies
3. Evaluate how head impact sensors can be implemented into your clinical practice

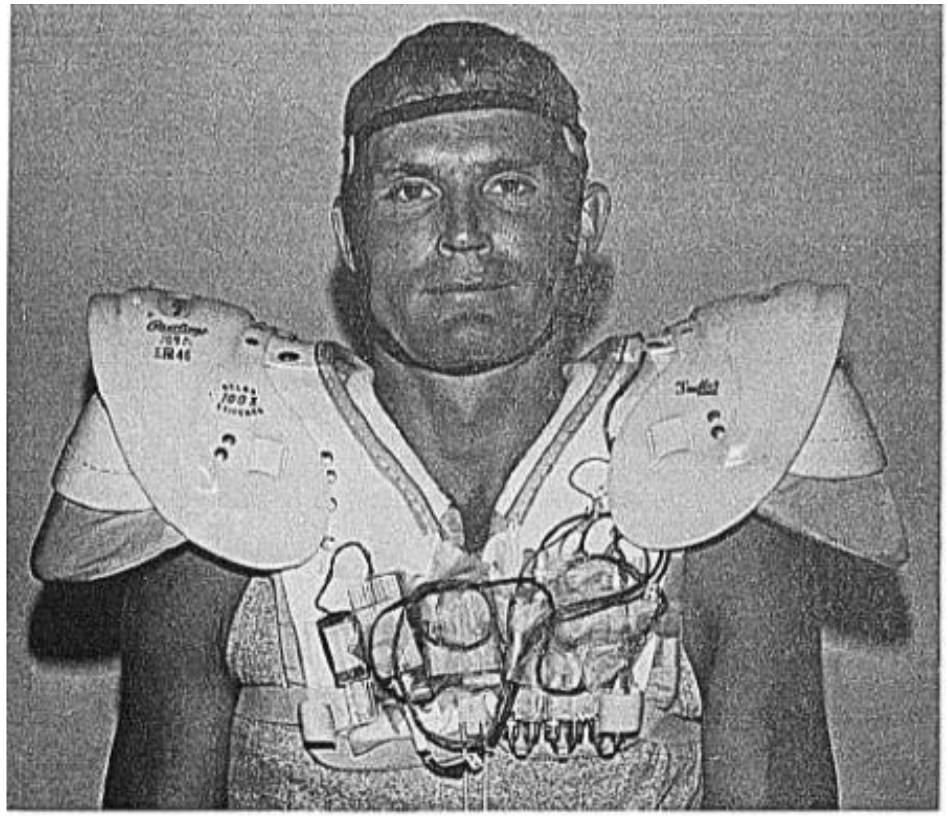
Concussion Injury Mechanism



Traumatic Biomechanical Forces: Excessive Linear and Rotational Head Acceleration

McCrory et al., 2017 - *Br J Sports Med*

The First Head Impact Sensor



Moon et al., 1971 – *Med Sci. Sports Exerc*

The First Head Impact Sensor

TABLE 2. Peak Acceleration data of football players' heads [G].

As Recorded Player* A	With 750 Hz Filter Player* A	B	C
937	867	108	1200
1065	960	108	985
981	882	493	1140
869	875	54	748
625	536	139	1053
610	684	47	1175
542	553	130	984
568	501	209	550
953	834	161	1150
738	643	350	1120
1072	1016	778	1118
984	997	596	1106
910	808	940	1136
1126	870	506	1130
725	617	275	1150

*Player A & E — Offensive Center, Age 20, Wt. 210 lbs., Ht. 5 ft. 11 in
Player B — Defensive Line, Age 16, Wt. 190 lbs., Ht. 5 ft. 10 in.
Player C — Offensive Back, Age 17, Wt. 135 lbs., Ht. 5 ft. 8 in.
Player D — Offensive Back, Age 28, Wt. 185 lbs., Ht. 5 ft. 8 in.

Moon et al., 1971 – *Med Sci. Sports Exerc*

Current Head Impact Sensors

Mihalik et al., 2017 – *Med Sci. Sports Exerc; O'Connor et al., 2017 - J Athl Train*

Helmet Based Sensors

					
Name	Head Impact Telemetry System	GForceTracker	JOLT	Brain Sentry	Shockbox
Cost	\$1000 - \$3000	\$150 / device \$8/ mo. software	\$99 / device	\$75	\$149.99 / device
Real Time	Yes	Yes	Yes	Yes	Yes
Alert	Page alert	Alarm and Flashing from Sensor	Smartphone App	Light on Sensor	Alert via Bluetooth App

Mihalik et al., 2017 – *Med Sci. Sports Exerc; O'Connor et al., 2017 - J Athl Train*

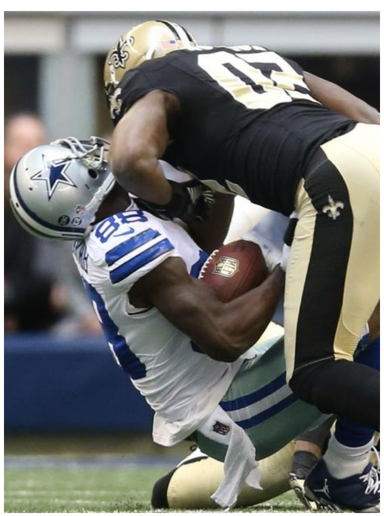
OHSU

Head Based Sensors

				
Name	X2 xPatch	Triax Sim-G	Reebok Checklight	i1Biometrics Vector
Cost	$150 / device	$189.99 / device	$97.99 / cap	N/A
Real Time	Yes	Yes	Yes	Yes
Alert	Alert in Software	Bluetooth to iOS devices	Light Indicator	Alert via computer

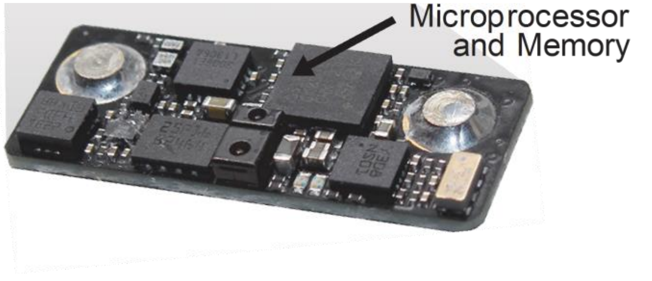
Mihalik et al., 2017 – *Med Sci. Sports Exerc; O'Connor et al., 2017 - J Athl Train*

Which One is for Your Team?



Sensor Requirements for Accurate Measurements

1. Accurate Chip Hardware



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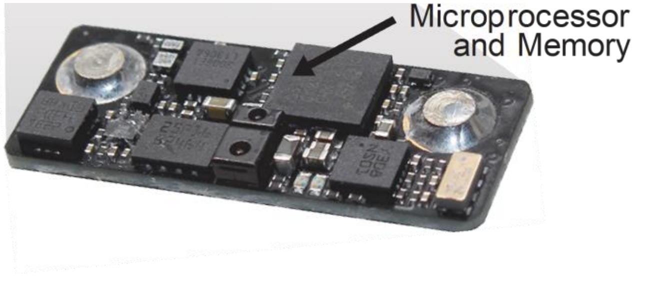

2. Rigid Skull Coupling

Sensor Requirements for Accurate Measurements

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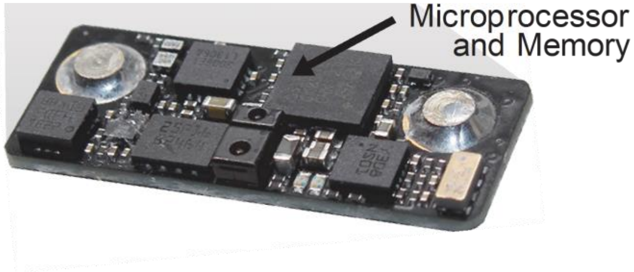
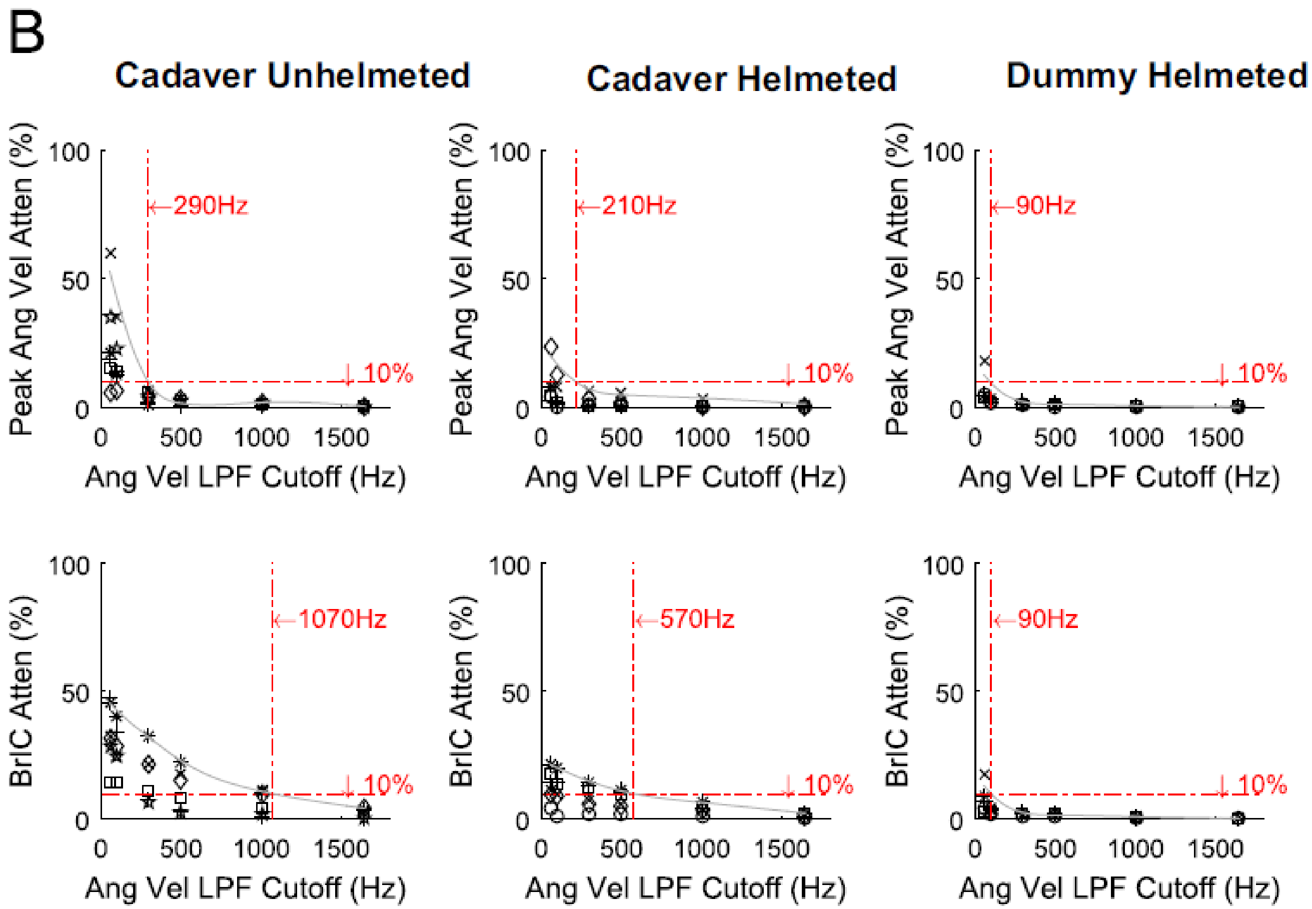


2. Rigid Skull Coupling

3. Impact Filtering

Hardware Requirements

500 Hz bandwidth minimum for un-helmeted sports

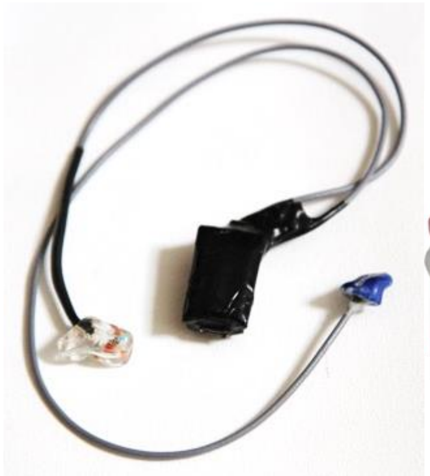


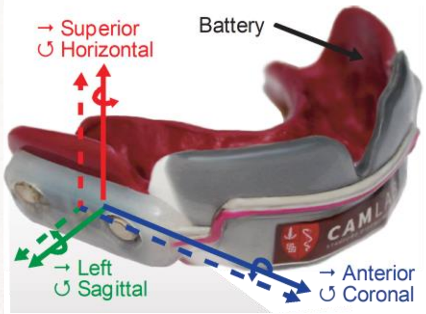
Wu et al., 2016 – *Med Sci. J Biomech*

Rigid Skull Coupling

Helmet mounted sensors measured 37% less and up to 71% more than the head sensors on Peak Resultant Angular Velocity

VS





Peak Resultant Linear Acceleration 2 – 5x higher than the Head Acceleration

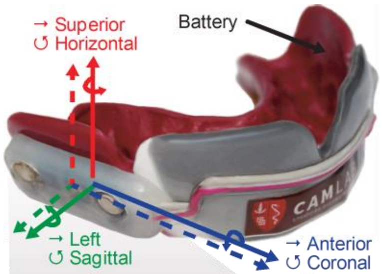
Joodaki et al., 2019 – *J Biomech Eng*

Impact Filtering

Impact Filtering

Impact Filtering

Impact Filtering



Wu et.al., 2017 – Football

	VV	VS
AV	136	10
AS	20	221
	0.87	**0.96**
	Sens	**Spec**

Number of reviewed impacts = 3822

Unobstructed impacts for sens/spec analysis = 387

Nevins et.al., 2017 – Soccer

	VV	VS
AV	78	20
AS	14	4
	0.85	**0.17**
	Sens	**Spec**

Number of reviewed impacts = 119

Unobstructed impacts for sens/spec analysis = 116

Press and Rowson, 2016 – Soccer

	VV	VS
AV	1463	7536
AS	240	8626
	0.86	**0.53**
	Sens	**Spec**

Number of reviewed impacts = 17,865

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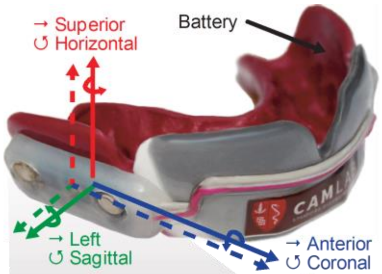
Wu et al., 2017 – *Sci Rep* ; Nevins et al., 2017 - *Proc Inst Mech Eng P J Sport Eng Technol;* Press and Rowson, 2016 - *Clin J Sport Med*

Impact Filtering



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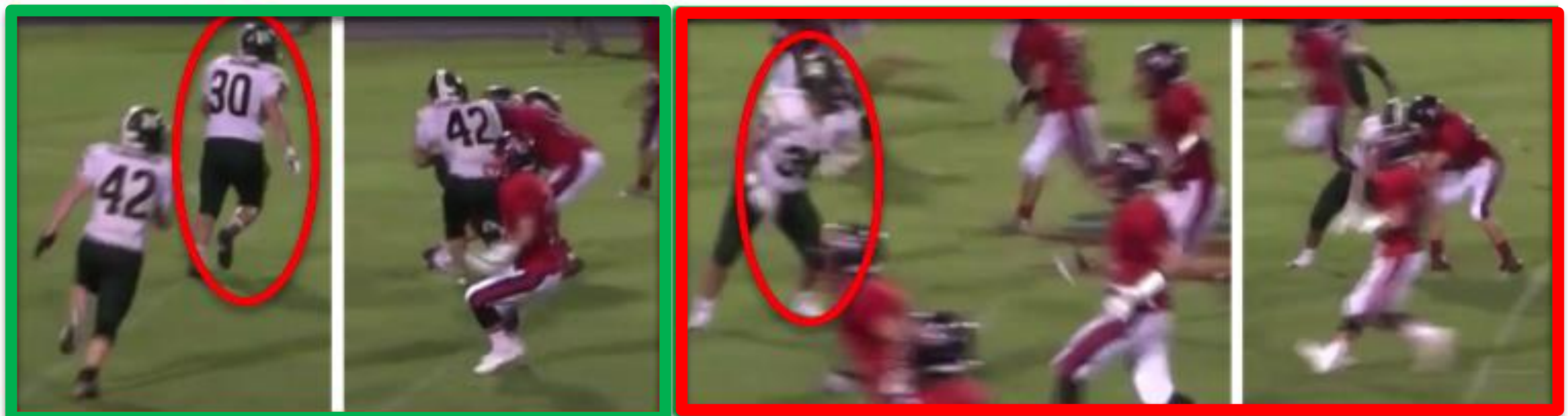
Impact Filtering

Camera Time: **00:05:53.329** Camera Time: **00:05:54.703**

Campbell et al., *Med Sci Sports Exerc. (In Review)*

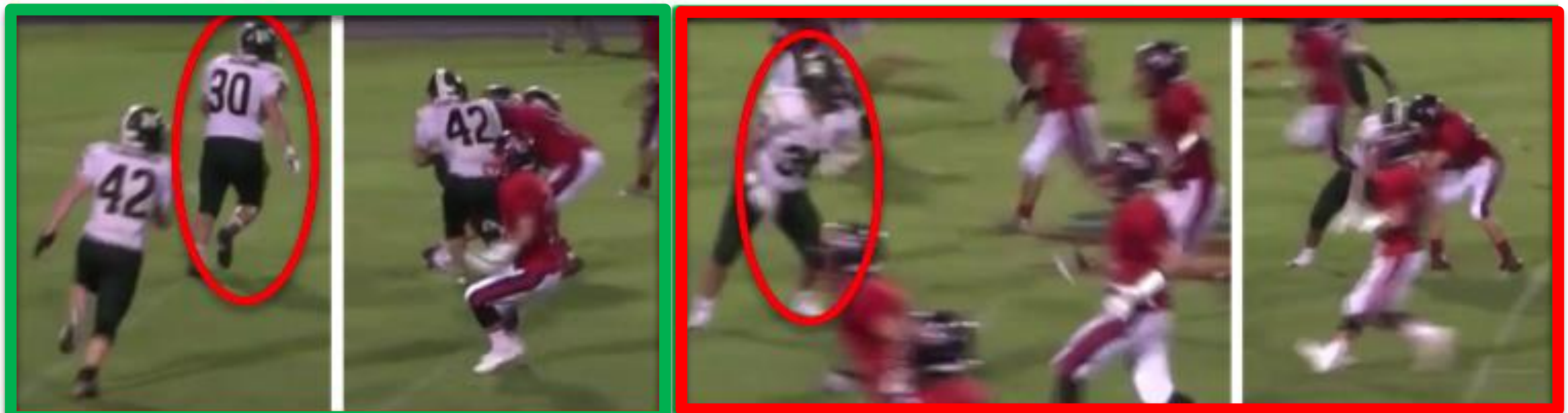
Impact Filtering



Camera Time: **00:05:53.329** | Camera Time: **00:05:54.703** | Camera Time: **00:07:05.982** | Camera Time: **00:07:06.494**

Campbell et al., *Med Sci Sports Exerc. (In Review)*

Impact Filtering



Camera Time: **00:05:53.329**   Camera Time: **00:05:54.703**   Camera Time: **00:07:05.982**   Camera Time: **00:07:06.494**

Retained Data		
Event ID	Impact Time	Estimated Camera Time
62761	20:38:51.940	00:02:28.596
62778	20:42:18.130	00:05:54.786
62779	20:42:18.300	00:05:54.956
62872	20:45:09.330	00:08:45.986
63164	20:58:14.000	00:21:50.656

Campbell et al., *Med Sci Sports Exerc. (In Review)*

Impact Filtering

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Retained + Removed Data		
Event ID	Impact Time	Estimated Camera Time
62761	20:38:51.940	00:02:28.596
62778	20:42:18.130	00:05:54.786
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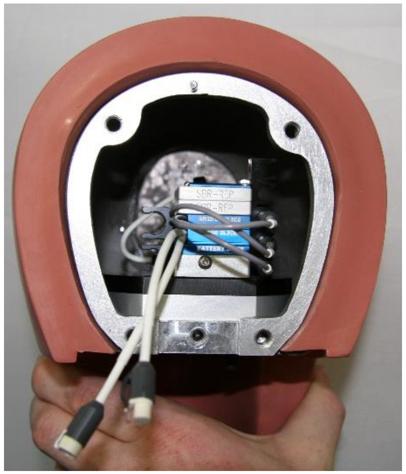
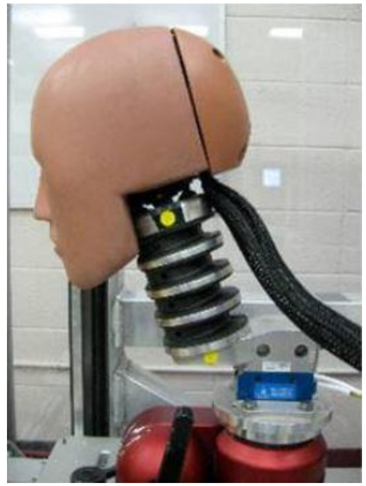
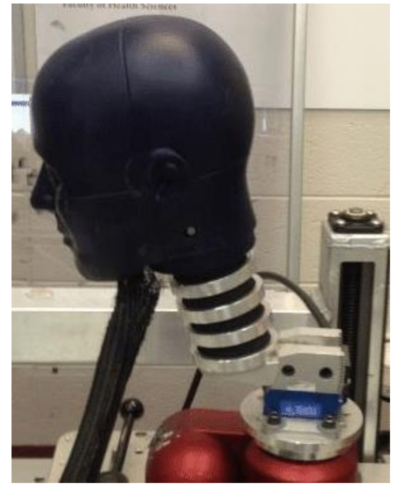
	20:43:29.860	00:07:06.516
62872	20:45:09.330	00:08:45.986
		00:20:17.436
63164	20:58:14.000	00:21:50.656

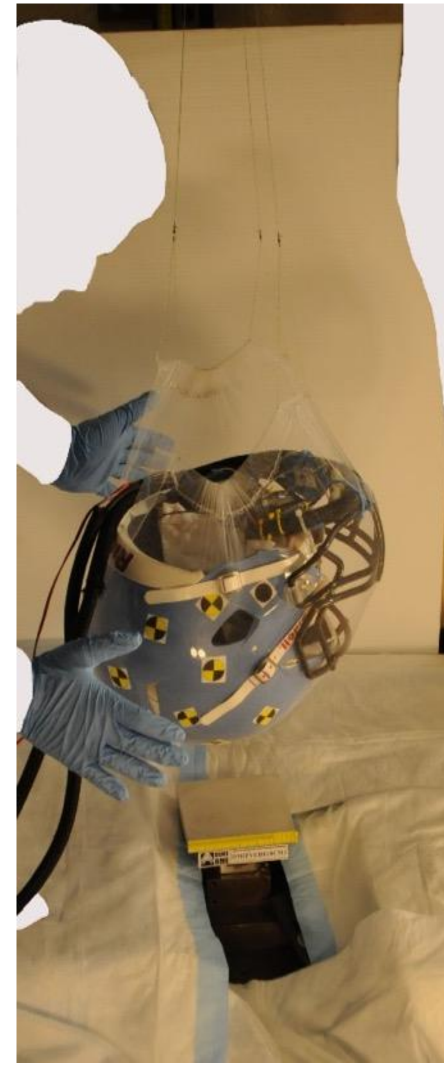
Campbell et al., *Med Sci Sports Exerc. (In Review)*

Sensor Evaluation









Head-Helmet Coupling Parameters

Rigid sensor coupling = more accurate measurements

Fit

Jadischke et al., 2013 - *J Biomech* ; Trotta et al., 2018 - *J Biomech*

Head-Helmet Coupling Parameters

Rigid sensor coupling = more accurate measurements

Fit

Friction Coefficient

≠

Jadischke et al., 2013 - *J Biomech* ; Trotta et al., 2018 - *J Biomech*

HIT System Validity: Sensor Coupling Spectrum

Directly fixed

PLA error up to 5%

Avg. ± 10° AZ and EL error
(Crisco 2004)

Crisco et al., 2004 - *J Biomech Eng* ; Siegmund et al., 2016 - *Ann Biomed Eng*

HIT System Validity: Sensor Coupling Spectrum

Directly fixed

PLA error up to 5%

Avg. ± 10° AZ and EL error
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Hybrid III ATD

PLA 32% error
PAA 35% error

Avg AZ and EL error = 32.5°
(Siegmund 2016)

Crisco et al., 2004 - *J Biomech Eng* ; Siegmund et al., 2016 - *Ann Biomed Eng*

HIT System Validity: Sensor Coupling Spectrum

Directly fixed

PLA error up to 5%

Avg. ± 10° AZ and EL error
(Crisco 2004)

Hybrid III ATD

PLA 32% error
PAA 35% error

Avg AZ and EL error = 33°
(Siegmund 2016)

Cadaveric Specimen

PLA R^2 36% error
PAA 248% error
(Campbell Unpublished)

Avg AZ and EL error = 64°
(Campbell – in review)

Crisco et al., 2004 - *J Biomech Eng* ; Siegmund et al., 2016 - *Ann Biomed Eng;* Campbell et al., - *Ann Biomed Eng (In Review)*

Can you diagnose concussions with an acceleration-based threshold?

Head Impact Sensor Determined:

Average Concussive Peak Resultant Linear Acceleration:

104 ± 30 g

Average Concussive Peak Resultant Rotational Acceleration:

4726 ± 1931 rad/s^2

Laboratory Reconstructions:

Average Concussive Peak Resultant Linear Acceleration:

98 ± 28 g

Average Concussive Peak Resultant Rotational Acceleration:

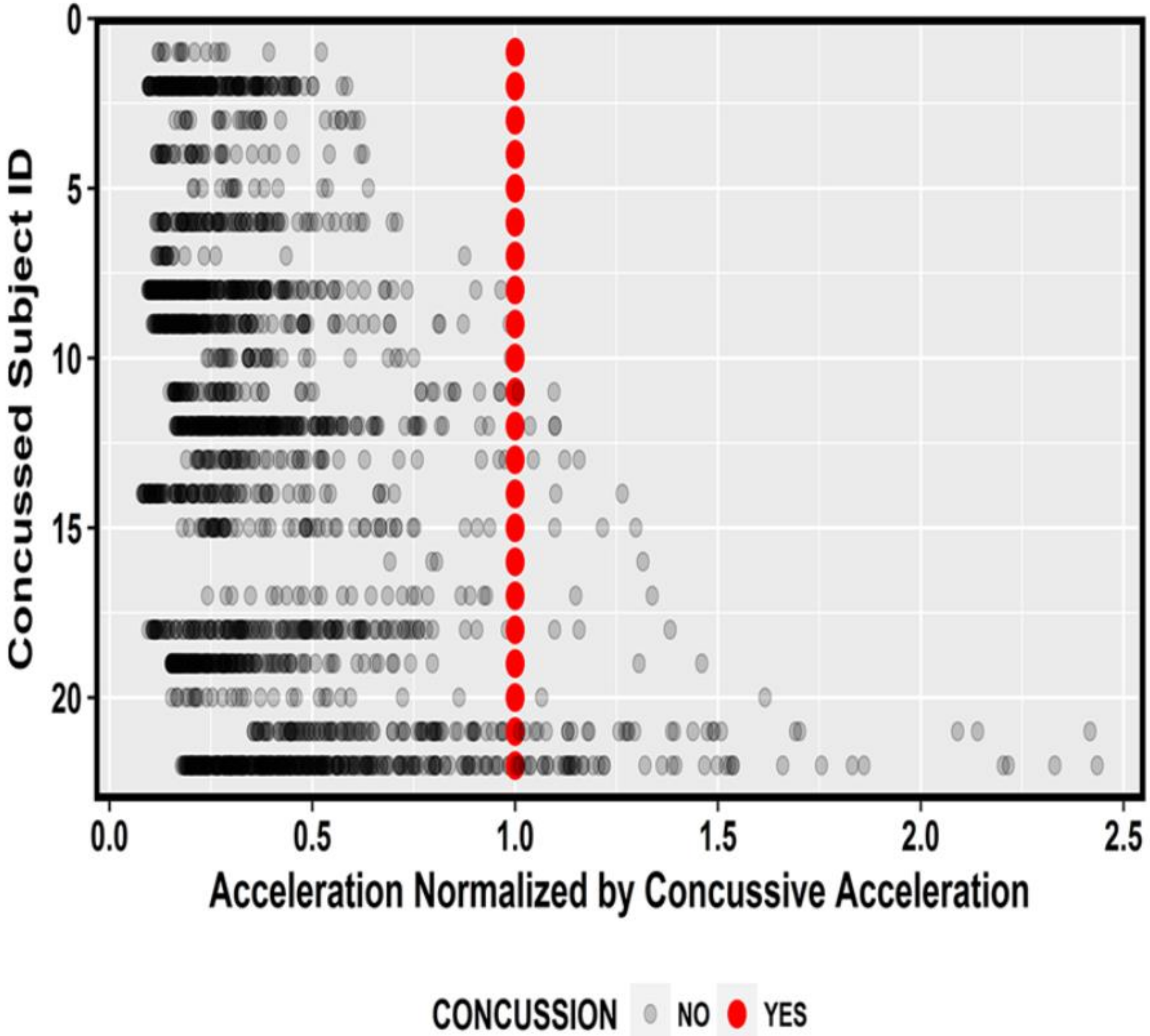
6432 ± 1813 rad/s^2

Rowson et al., 2013 - *Ann Biomed Eng;* Pellman et al., 2003 - *Neurosurgery*

Case #	Player Position*	Linear Magnitude (g)	Rotational acceleration (rad/s^2)	Impact Location
1	OL	60.31	5419.18	Front
2	RB	60.51	163.35	Top
3	LB	63.84	5923.27	Front
4	WR	66.36	5573.42	Front
5	RB	77.68	3637.48	Top
6	DB	84.07	5299.57	Front
7	DB	85.10	3274.05	Top
8	LB	94.20	7665.10	Front
9	DL	99.74	8994.40	Front
10	OL	100.36	1085.26	Top
11§[3]	LB	102.39	6837.62	Right
12	OL	107.07	2811.45	Top
13§[5]	RB	108.02	6711.00	Front
14	DB	109.88	6632.77	Top
15§[14]	DB	115.50	2303.63	Top
16	DL	119.23	7974.22	Right
17	LB	157.50	1020.00	Front
18	WR	168.71	15397.07	Back
19	RB	173.22	4762.74	Top

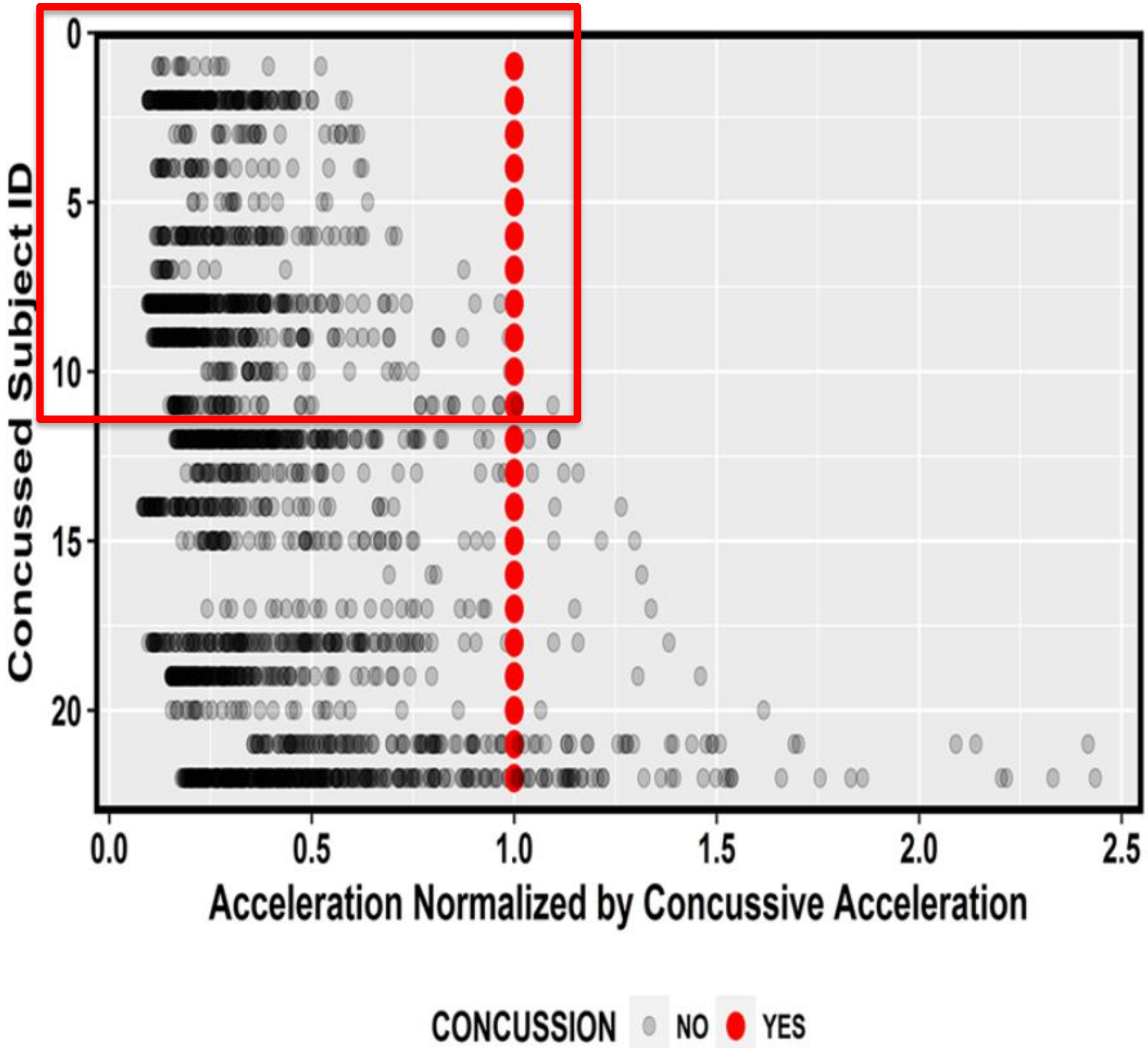
Guskiewicz et al., 2007 - *Neurosurgery*

Individual Concussion Threshold?



Rowson et al., 2017 - *Journal of Neurotrauma*

Individual Concussion Threshold?



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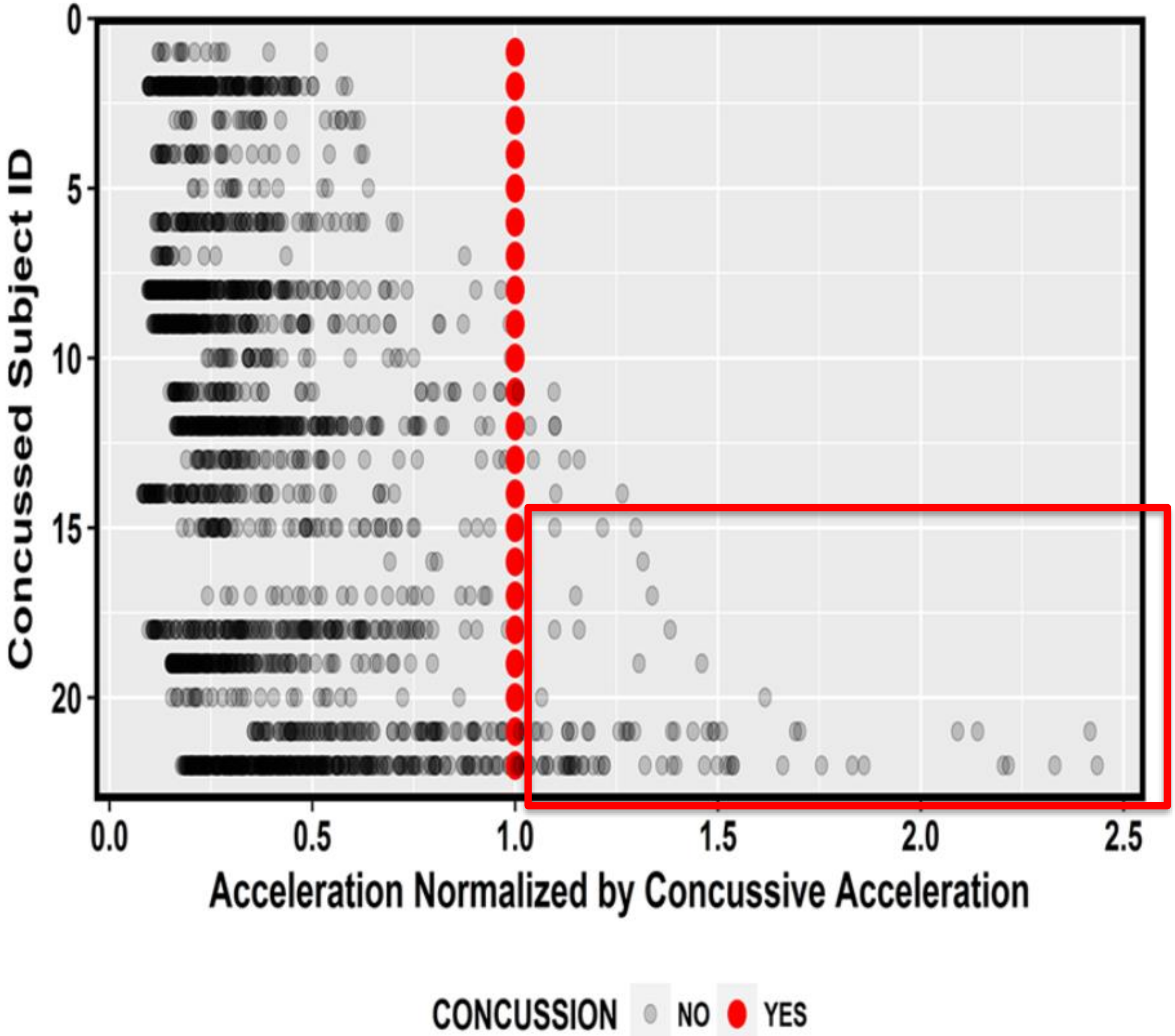
Individual Concussion Threshold?



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Evaluating Every Time the Light Blinked Red

	Threshold	Sensitivity (95% CI)	Specificity (95% CI)	Positive Predictive Value
Resultant Linear Head Acceleration	20 g	100%	56%	0.01%
	50 g	95.8%	90.4%	0.1%
	75 g	75.0%	97.0%	0.2%
	100 g	45.8%	99.0%	0.4%

Mihalik et al., 2017 - *Med Sci Sports Exerc*

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Thank You