Is There An Increased Risk Of Subsequent Musculo-skeletal Injury Following A Concussion?

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  - State of Delaware Economic Development Office
  - Applied Cognitive Engineering (Not Discussed today)

NIH National Institute of Neurological Disorders and Stroke

DELAWARE ECONOMIC DEVELOPMENT OFFICE

NCAA

DEPARTMENT OF DEFENSE UNITED STATES OF AMERICA

SCIENCE TO SHAPE THE FUTURE OF THE ARMY ARMY RESEARCH OFFICE 1951

NATA RESEARCH & EDUCATION FOUNDATION

Concussion 101

- Defined: Concussion is a brain injury and is defined as a complex pathophysiological process affecting the brain, induced by biomechanical forces.
  - McCrory et al, 2013
- Epidemiology: 1.6 – 3.8 million annually/US
  - Langlois et al, 2006
- Risk Factor:
  - Second Impact Syndrome
  - ↑3 – 6x risk of subsequent concussion.
  - Later life neuropathological consequences
    - WAY BEYOND THE SCOPE OF THIS TALK TODAY
  - Subsequent MSK injury??

Professional Sports

- Australian Football League
  - A non-significant **↑2.23x** one match post-concussion (4 seasons: 2000 – 2003)

TABLE 3
Injury Rates for Concussed and Control Players in Games on Return to Play[a]

	Number of Injuries	Games	Injury Rate	Ratio
Concussed	10	138	7.25 (3.48-13.33)	2.23 (0.93-5.04)
Controls	19	585	3.25 (1.96-5.07)	

A Prospective Study of Postconcussive Outcomes After Return to Play in Australian Football

Michael Makdissi,*† MBBS, PhD, Paul McCrory,† MBBS, PhD, Antony Ugoni,† BSc(Hons), MSc, David Darby,‡ MBBS, PhD, and Peter Brukner,† MBBS

Professional Sports

- Professional European Soccer
  - A ↑**2.2x** risk of MSK injury in year post-concussion.

Table 3 Risk of injury after concussion (n=66) or randomly selected injury (n=1599) in the year after the index trauma, divided into different time periods

	At least one injury (n=874)		At least one sudden onset injury (n=709)		At least one gradual onset injury (n=414)	
	HR	95% CI	HR	95% CI	HR	95% CI
0 to <3 months	1.56	1.09 to 2.23	1.76	1.12 to 2.76	2.44	1.36 to 4.37
3 to <6 months	2.78	1.58 to 4.89	3.00	1.52 to 5.92	4.36	1.57 to 12.10
6 to 12 months	4.07	2.14 to 7.76	3.69	1.72 to 7.95	7.94	2.39 to 26.44

Hazards were adjusted for the number of injuries in the year before the index injury.

  - Injury rate increases over time.
  - BUT…..also a ↑**2.0** risk in the year PRIOR.
    - Injury prone? Risk Taker?

Sports-related concussion increases the risk of subsequent injury by about 50% in elite male football players

Anna Nordström,[1] Peter Nordström,[2] Jan Ekstrand[3]

Professional Sports

- Professional Rugby
  - 60% greater risk of same season time loss injury for those with concussion vs no concussion.

Table 1 Match incidence rates (injuries/1000 h) in players with a
IRRs used to determine effect size

Player group	All injuries
Players without diagnosed concussion (n=660)	1398
Players with diagnosed concussion (n=135)	
Postinjury (following return to play)	119
Pre-injury (before the concussion)	67

*Shows significant difference versus the reference group.
IRR, Incidence rate ratio; Ref, denotes reference group for IRR calculations.

- No pre-concussion inju
- Injury occurs sooner

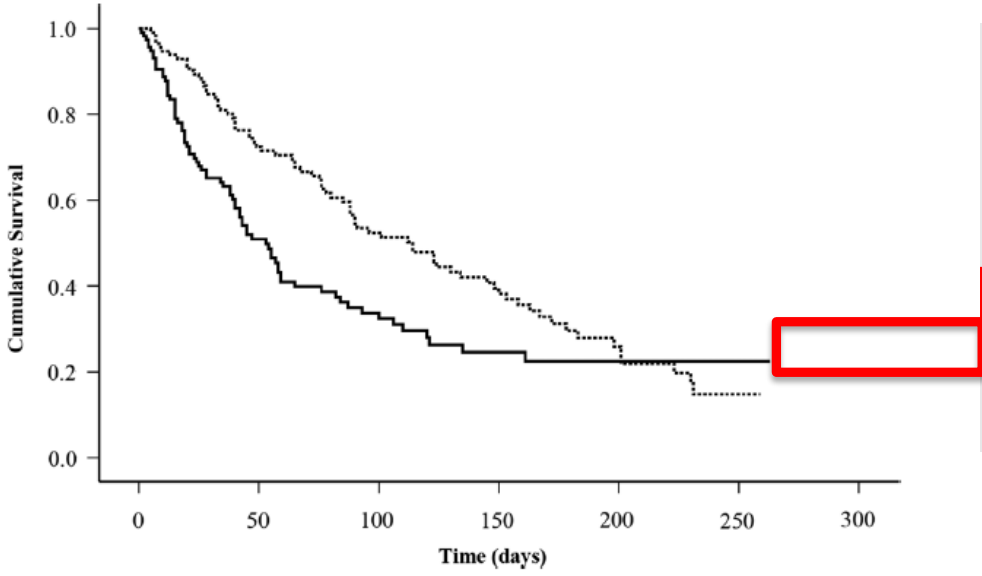


Figure 2 Time to subsequent injury following return to play in players who reported concussion(s) (solid line) and an equal number (n=135) of randomly selected injured players who did not report a concussion (dashed line).

Retrospective: Professional Sports

- Swedish Ice Hockey Elite League
  - Retrospective analysis over 28 years
    - Knee injury (N=104) vs Concussion (N=144)
  - No injury rate differences overall
  - Significant increase in severe injuries (time loss >28 days) within 21 days post-concussion.

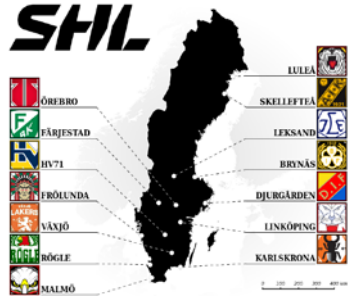


TABLE 2
Severe subsequent injuries (>28 days absence from play) for concussions and knee injuries (binary scale)

Period	Type of injury	Players with subsequent injuries that were severe	Players with subsequent injuries that were not severe	P
Within 7 days after RTP (game and practice injuries)	Concussion	2	13	0.44
	Knee injury	0	4	
Within 21 days after RTP (game and practice injuries)	Concussion	7	33	0.037
	Knee injury	0	22	
Within 42 days after RTP (game and practice injuries)	Concussion	6	62	0.19
	Knee injury	1	40	

Data presented as n unless otherwise indicated. RTP Return to play

Subsequent traumatic injuries after a concussion in elite ice hockey: A study over 28 years

Gusten Nyberg MD[1], Karl Hjort Mossberg MD[2], Jack Lysholm MD PhD[3], Yelverton Tegner MD BA PhD[4]

Retrospective: Professional Sports

- National Football League Retired Players
  - Reviewed self-reported medical history of 2,429 former NFL players from 1930 – 2001.
  - Dose Dependent increased rate of "serious" MSK
    - "higher number of concussions is linked with higher odds of reporting a musculoskeletal injury"

TABLE 3. Odds ratios (95% confidence intervals) adjusted for number of NFL years played, BMI during NFL, and playing position.

	Total No. of Lower Extremity Musculoskeletal Injuries (One, Two, Three, Four or More)	Presence of at Least One Injury at the Knee (MCL, PCL, ACL, LCL, and Meniscus)	Presence of at Least One Injury at the Ankle/Foot (Achilles Rupture, Ankle Ligament Rupture, and Ankle/Foot Fracture)
One vs zero concussion	1.59 (1.30–1.94)	1.36 (1.08–1.70)	1.36 (1.06–1.75)
Two vs zero Concussions	2.29 (1.85–2.83)	1.73 (1.36–2.21)	2.20 (1.70–2.83)
3+ vs 0 Concussions	2.86 (2.36–3.48)	1.92 (1.54–2.40)	2.37 (1.88–2.99)

Concussion Frequency Associates with Musculoskeletal Injury in Retired NFL Players

BRIAN PIETROSIMONE[1,2,3], YVONNE M. GOLIGHTLY[4,5,6], JASON P. MIHALIK[1,6,7], and KEVIN M. GUSKIEWICZ[1,7,8]

College Sports

- UNC Athletes – Acute LE MSK
  - Tightly controlled study: Conc +/-1 year
    - ↑**1.97x** vs year prior to concussion &1.64x vs control

TABLE 2. Injury incidence per 1000 athlete exposures and risk ratios for (after/before) within-group comparisons.

	Group with Concussion					Control Group				
	Injury Incidence					Injury Incidence				
	Before	After	Risk Ratio	95% CI	*P* Value	Before	After	Risk Ratio	95% CI	*P* Value
90 d	2.17	4.55	2.10	0.91–4.81	0.07	3.27	3.10	0.95	0.48–1.90	0.89
180 d	2.05	4.14	2.02	1.08–3.78	0.02	3.08	2.55	0.83	0.48–1.42	0.50
365 d	1.78	3.51	1.97	1.19–3.28	0.01	2.56	2.14	0.83	0.53–1.30	0.42

TABLE 3. Risk ratios (concussion/control) for between-group comparisons.

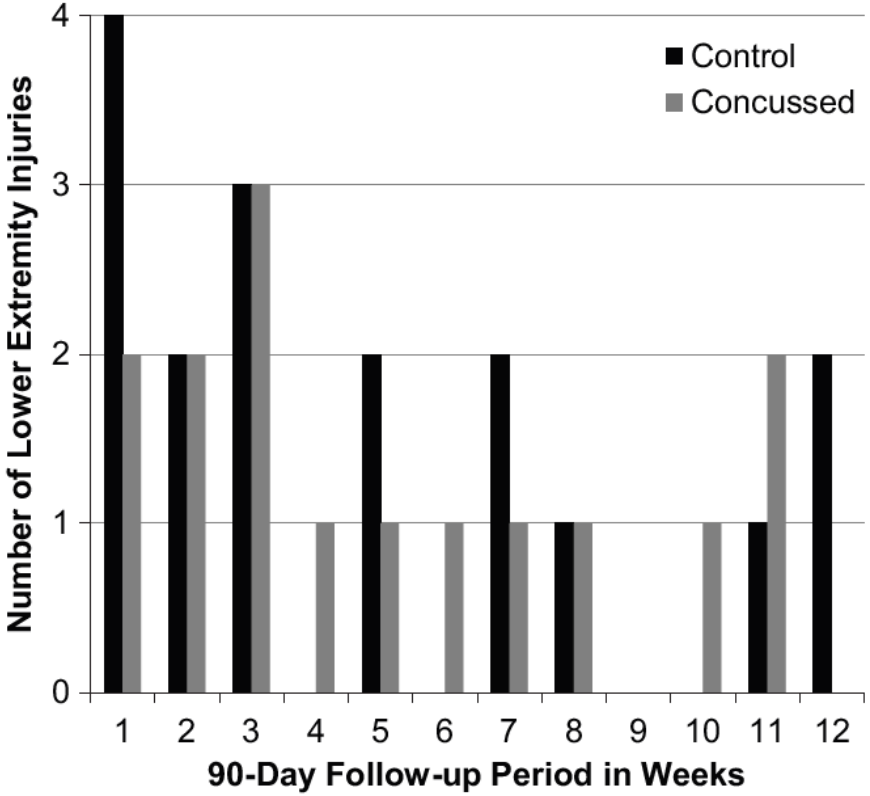
	Before Concussion			After Concussion		
	Risk Ratio	95% CI	*P* Value	Risk Ratio	95% CI	*P* Value
90 d	0.66	0.28–1.55	0.33	1.47	0.67–2.87	0.28
180 d	0.66	0.35–1.26	0.20	1.62	0.96–2.73	0.08
365 d	0.69	0.41–1.17	0.16	1.64	1.07–2.51	0.02

Acute Lower Extremity Injury Rates Increase after Concussion in College Athletes

ROBERT C. LYNALL[1,2], TIMOTHY C. MAUNTEL[2,3], DARIN A. PADUA[2,3], and JASON P. MIHALIK[1,2,4]

College Sports

- Wisconsin Athletes – Acute LE MSK
  - Tightly controlled & matched study
    - 87 Concussions & 182 Control
    - ↑**2.48x** in the 90 days post-concussion



Concussion Increases Odds of Sustaining a Lower Extremity Musculoskeletal Injury After Return to Play Among Collegiate Athletes
M. Alison Brooks, Kaitlin Peterson, Kevin Biese, Jennifer Sanfilippo, Bryan C. Heiderscheit and David R. Bell
Am J Sports Med published online January 19, 2016

Retrospective: College Sports

- NCAA Athletes: End of Career
  - 335 athletes from 13 sports & 17 schools
  - Differentiated Reported, Unreported, Unrecognized

Table 3. Association between concussion history and lower extremity injury ACL Issue

	Lateral Ankle Sprain (N = 214)			Knee Injury (N = 103)			Muscle Strain (N = 156)		
	χ^2	*P* Value	Odds Ratio	χ^2	*P* Value	Odds Ratio	χ^2	*P* Value	Odds Ratio
Reported concussion (N = 108)	0.95	0.329	—	8.93	0.003	2.08	2.47	0.116	—
Unreported concussion (N = 38)	0.10	0.922	—	9.64	0.002	2.87	0.63	0.426	—
Unrecognized concussion (N = 112)	10.52	0.001	2.29	2.71	0.099	—	7.56	0.006	1.90
Any concussion (N = 155)	6.28	0.012	1.79	10.04	0.002	2.13	4.65	0.031	1.61

Association Between Concussion and Lower Extremity Injuries in Collegiate Athletes

Frances C. Gilbert, MS,† G. Trey Burdette, EdD,‡ A. Barry Joyner, PhD,§ Tracy A. Llewellyn, MS,‖ and Thomas A. Buckley, EdD, ATC*¶#

Hospital Database

- Missed Concussions during ED visits for serious Orthopedic Trauma
  - Patients suffering from an upper limb monotrauma are significantly more at risk of sustaining a mTBI compared to lower limb fractures ($x^2 = 6.70$; $p = 0.010$).
  - Patients with a proximal upper limb injury were significantly more at risk of sustaining concomitant mild TBI compared to distal upper limb fractures ($x^2 = 7.07$; $p = 0.008$).

Incidence rate of mild traumatic brain injury among patients who have suffered from an isolated limb fracture: Upper limb fracture patients are more at risk☆

Marianne Jodoin[a,b], Dominique M. Rouleau[b,d,*], Camille Charlebois-Plante[d], Benoit Benoit[b,d], Stéphane Leduc[b,d], G-Yves Laflamme[b,d], Nadia Gosselin[a,b], Camille Larson-Dupuis[a,b], Louis De Beaumont[b,c]

Hospital Database

- Ice Hockey and Football Athletes
  - Athletes with a concussion were more likely to sustain injuries compared with the control group, both before (↑**1.98**) and after concussion (↑**1.72**).
  - No increased risk within Concussion group.
    - Injury prone?
    - Risk Takers?

Group	Time	Total injuries (n)	Uninjured individuals (n)	Injured individuals (n)
Concussion (n=281)	Before	103	211	70 Odds 0.33 OR 1.98
	After	93	215	66 Odds 0.31 OR 1.72
Control (ankle injury) (n=1259)	Before	214	1079	180 Odds 0.17
	After	236	1069	190 Odds 0.18

Concussed athletes are more prone to injury both before and after their index concussion: a data base analysis of 699 concussed contact sports athletes

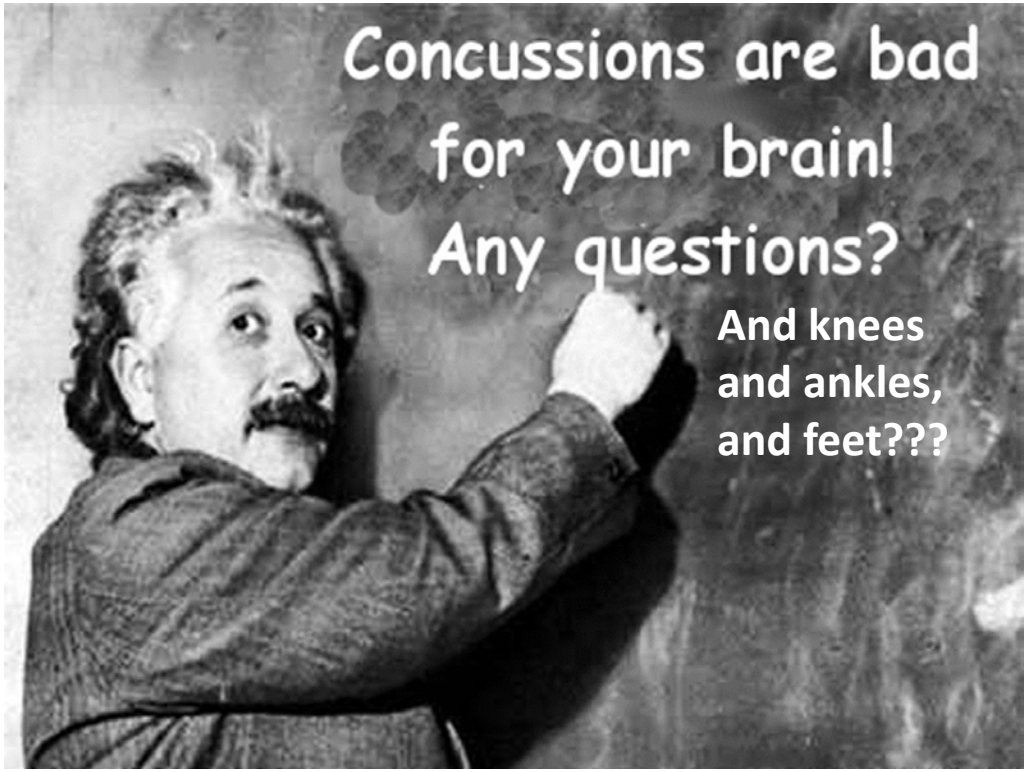
Erik Burman,[1] Jack Lysholm,[2,3] Pashtun Shahim,[4] Christer Malm,[5] Yelverton Tegner[6]

High School Data

- Unpublished Materials
  - NATION Dataset
    - 27 HS Sports, 147 High Schools, & 26 States
  - 2011 – 2015 Academic Years
    - 8,064 Athletes
  - Small, but significant, (↑**31.5%**) risk of LE injury
    - Risk is higher in a non-contact sport
    - NATION dataset also showed non-contact sports have a higher rate of PCS than collision or contact sports
      - Different from College data sets.
    - Limitations

Summary

- General trend for elevated risk (~↑1.5-2.0x) of MSK injury up to 2 years post-concussion across a wide range of sports, levels, and study design (prospective & retrospective)



Limitations

- Limitations in the Approach
  - How do we define “injury”
    - NCAA ISS/Datalys Center Definition, “received medical attention by an AT or physician”
    - Older Definitions, “Required time loss from participation”
  - Populations
    - College is only DI. No published HS data. No existing data for youth sports.

WHY??

- No proven explanations
- 2 General Hypothesis
  - 1) Innate Characteristic
    - Playing Style, position, risk taking, injury prone, etc
  - 2) Unresolved Deficits at RTP
    - Lingering deficits in balance and/or cognition especially during dual task performance

1. Innate Characteristics

- Psychological Considerations
  - Injury associated with impulsive, revenge-seeking behavior often modelled and encouraged by coaches, parents and teammates. They disregard their injury-causing potential and perform an aggressive act "in the heat of the moment". (Hockey)
    - Impulse Control Considerations?
      - Cusimano et al, PLOS One. 2016.
  - Psychological Characteristics for New Injuries
    - High Life Stressors, Perception of Mastery Climate (effort and outcome) (Soccer)
      - Steffen et al, Scan J Med Sports, 2009: 19: 442 – 451.
    - Type A behavior pattern and exercise dependency
      - Ekenman et al, Scand J Sports Med, 2001: 11(2): 87-95.
    - Sensation Seeking (seeking out new and exciting experiences)
      - Smith et al, J Personality Social Psych, 1992: 62(6) 1016 – 1024
    - "Tough Minded", "Lack of Caution", Very High or Very Low Anxiety
      - Junge et al, Am J Sports Med. 2000: 28(5): S10-15

1. Innate Characteristics

Studies Concerning Life Events and Sports Injuries

Study	No. of subjects	Type of sport	Method[a]	Result[b]
Bramwell et al.[6]	92	American football	SARRS	LCU: Injured > uninjured
Coddington and Troxell[10]	114	American football	LES-A	LCU: Injured > uninjured
Cryan and Alles[13]	151	American football	SARRS	LCU: Injured > uninjured
Passer and Seese[42]	104	American football	ALES	LCU: Injured > uninjured in one of two groups
May et al.[34]	73	Skiing	SARRS, LES-A	LCU: Correlation with health problems
Schafer and McKenna[49]	572	Running	Modified SRRS	LCU: Correlation with frequency of injury
Lysens et al.[30]	99	Physical education	LEQ	LCU: Injured > uninjured
Williams et al.[63]	179	Volleyball	SARRS, ALES	No effect
Hardy and Riehl[20]	86	4 types	ALES	TLC, NLC: Effect on frequency of injury
Kerr and Minden[27]	41	Gymnastics	Modified SARRS	LCU: Injured > uninjured
Blackwell and McCullagh[4]	105	American football	ALES	TLC, NLC, PLC: Difference in extreme groups
Smith et al.[54]	424	3 types	APES	No effect
Hardy et al.[19]	170	7 types	ALES	TLC: Effect on frequency of injury
Hanson et al.[18]	181	Track and field	ALES	NLC: Effect on severity of injury PLC: Effect on frequency of injury
Petrie[45]	103	Gymnastics	SARRS, LESCA	No effect TLC: Injured > uninjured
Smith et al.[52]	425	3 types	APES	LCU: only for "low sensation seekers"
Petrie[43]	158	American football	LESCA	PLC: Effect on days missed
Petrie[44]	98	American football	LESCA	NLC: Effect on frequency of injury
Thompson and Morris[59]	120	American football	Modified SARRS	LCU: Increased risk of injury
Rider and Hicks[46]	67	Basketball	SARRS, ALES	No effect
van Mechelen et al.[61]	139	Not specified	LES	Life events related to occurrence of injury

[a] SARRS, Social Readjustment Rating Scale; LES-A, Life Event Scale for Adolescents; ALES, Athletic Life Experience Survey; LEQ, Life Event Questionnaire; APES, Adolescent Perceived Events Scale; LESCA, Life Event Survey for Collegiate Athletes.

[b] LCU, life change units; TLC, total life change; NLC, negative life change; PLC, positive life change.

1. Innate Characteristics

- Performance Considerations
  - Brains & Sprains?
  - Athletes with NC-ACL tears have lower baseline ImPACT test results
    - Swanik et al. Am J Sports Med, 2007: 35(6): 943 – 948.

TABLE 3
Neuropsychological Test Score for NCACL and Control Groups (n = 160)[a]

Neurocognitive Test	Mean ± SD	F Test (score)	*P* Value	Effect Size	95% CI	
				Cohen *d*	Lower	Upper
Verbal memory 77, 79						
NCACL	.84 ± .08	4.08	.045[b]	–.47	.83	.86
Control	.88 ± .09				.85	.89
Visual memory 66						
NCACL	.72 ± .12	19.16	.00[c]	–.77	.70	.76
Control	.82 ± 14				.79	.85
Processing speed 33						
NCACL	36.9 ± 6.6	12.04	.001[c]	–.55	35.3	38.6
Control	41.0 ± 8.2				39.4	42.7
Reaction time (ms) .65						
NCACL	.57 ± .07	9.66	.002[c]	.46	.55	.59
Control	.53 ± .10				.51	.55

1. Innate Characteristics

- Performance Considerations
  - Modifiable Physical Capabilities?
    - Wilkerson et al, JAT 2012: 264-272

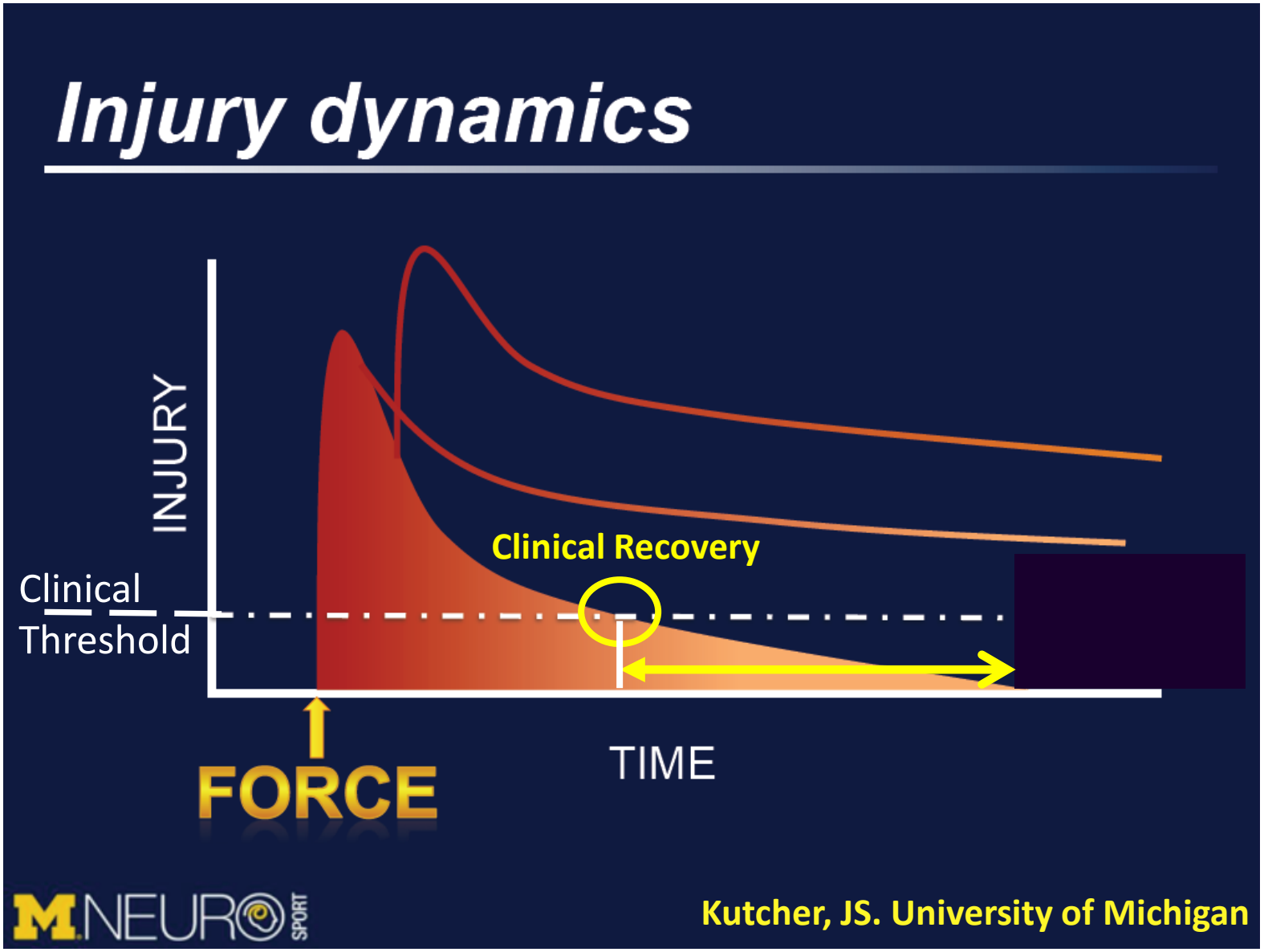
Table 3. Logistic Regression Results

Model	Components
4 Factor	
	Game exposure ≥3 games started or 11 games played
	Trunk-flexion hold ≤161 s
	Oswestry Disability Index ≥6
	Wall-sit hold ≤88 s
3 Factor	
	Trunk-flexion hold ≤161 s
	Oswestry Disability Index ≥6
	Wall-sit hold ≤88 s

Table 4. Accuracy Statistics for Prediction Models

Model	Clinical Prediction Rule Criteria	*P* Value[a]	Value (95% Confidence Interval)				
			Receiver Operating Characteristic Area Under the Curve	Sensitivity	Specificity	Odds Ratio	Relative Risk
4-Factor A[b]	≥3 Factors	<.001	0.82 (0.73, 0.91)	0.62 (0.46, 0.75)	0.91 (0.79, 0.96)	16.00 (4.76, 53.84)	3.14 (1.95, 4.98)
4-Factor B[c]	≥3 Factors	<.001	0.81 (0.71, 0.90)	0.67 (0.51, 0.79)	0.84 (0.71, 0.92)	10.57 (3.71, 30.11)	3.03 (1.84, 5.00)
4-Factor C[d]	≥3 Factors	<.001	0.78 (0.68, 0.88)	0.49 (0.34, 0.64)	0.93 (0.82, 0.98)	12.98 (3.43, 49.08)	2.63 (1.77, 3.91)
3-Factor A[b,e]	≥2 Factors	.002	0.70 (0.59, 0.82)	0.77 (0.62, 0.87)	0.57 (0.42, 0.70)	4.39 (1.69, 11.39)	2.31 (1.27, 4.22)
3-Factor B[c,e]	≥2 Factors	.007	0.69 (0.57, 0.80)	0.82 (0.67, 0.91)	0.48 (0.34, 0.62)	4.17 (1.52, 11.45)	2.33 (1.18, 4.59)
3-Factor C[d,e]	≥2 Factors	.012	0.66 (0.54, 0.78)	0.59 (0.43, 0.73)	0.66 (0.53, 0.80)	3.08 (1.25, 7.58)	1.79 (1.12, 2.86)

2. Unresolved Deficits at RTP



2. Unresolved Deficits at RTP

- Balance
  - Gait, Gait Initiation/Termination, Quiet Stance, Sensory Organization Test.
  - Dual task consistently exaggerates the deficits
- Cognition
  - Computerized neurocognitive tests, pen & paper tests.
- Brain Activity
  - Visual-Kinesthetic Integration, EEG activity profiles and patterns, Reduced Intra-Cortical Facilitation
- Neuroimaging
  - fMRI, DTI, MRS, SWI, etc
  - Meaningfulness of imaging changes?

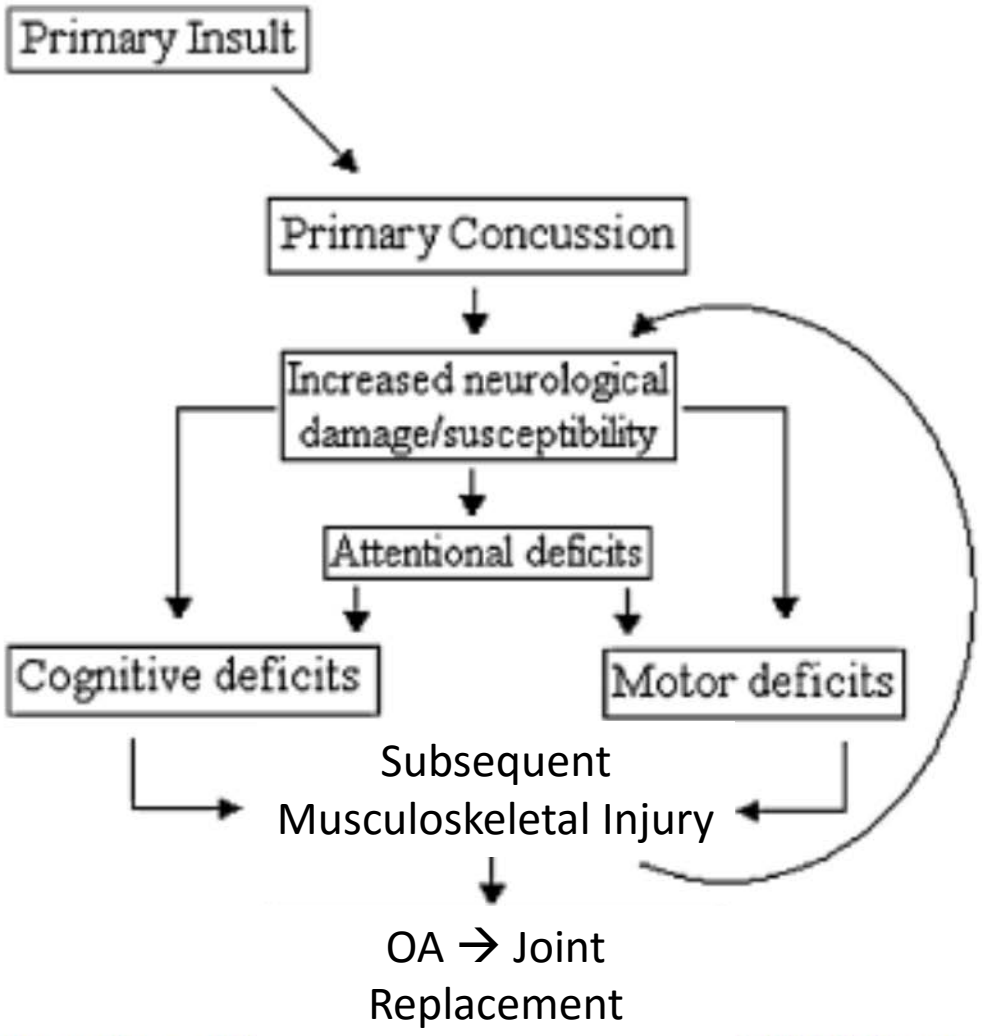


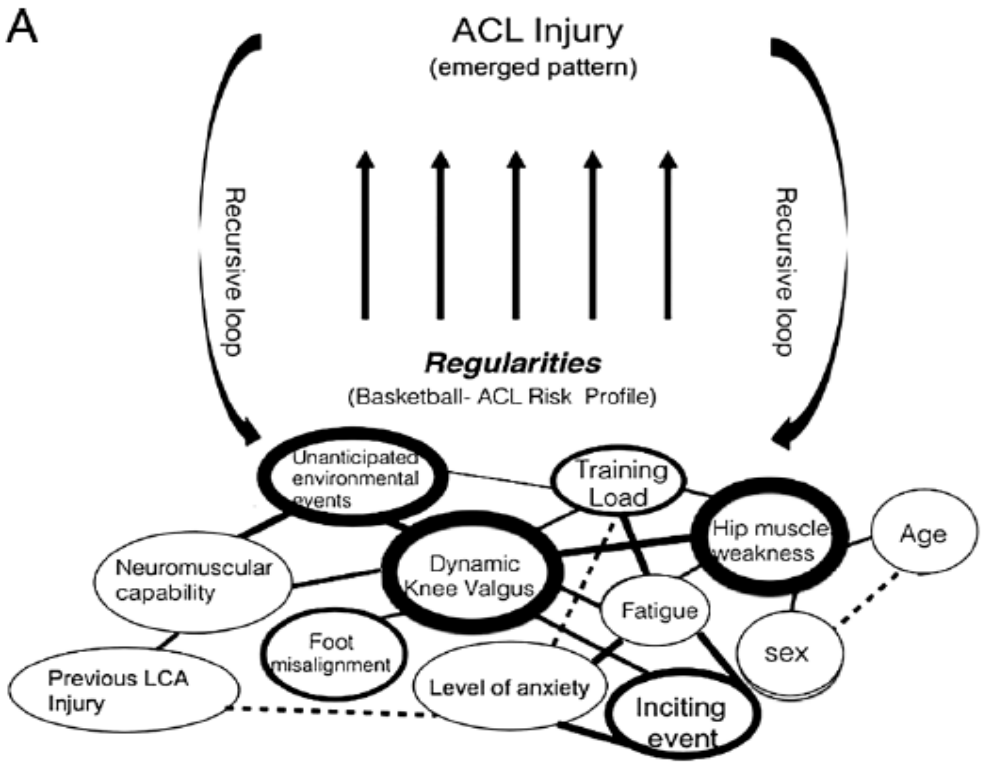
Fig. 1. An outline of the concussive pathway from initial injury to permanent brain damage. One-directional arrows indicate a sequential order of events.

Clinical Applications

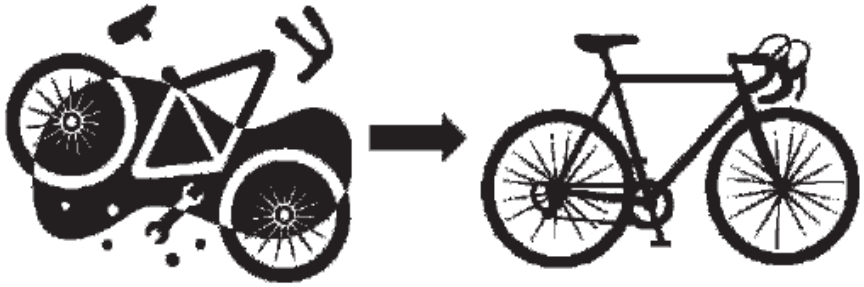
- If we accept elevated risk of subsequent MSK in the year post-concussion,
- If we accept there are some factors which may be modifiable,
- What are the clinical implications?
  - Injury Prediction?
  - Injury Prevention?

Injury Prediction Modeling

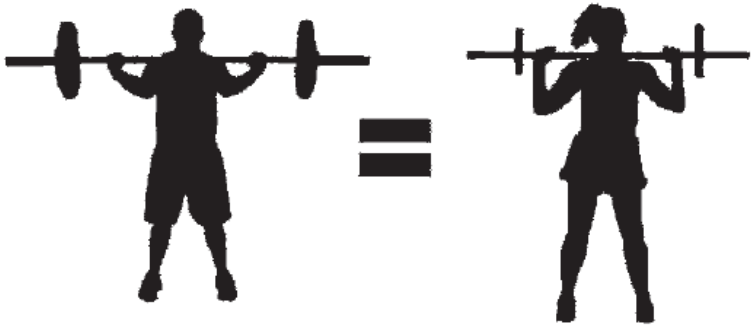
- The multifactorial complex nature of sports injuries arises not from the linear interaction between isolated and predictive factors, but from the complex interaction among a web of determinants.



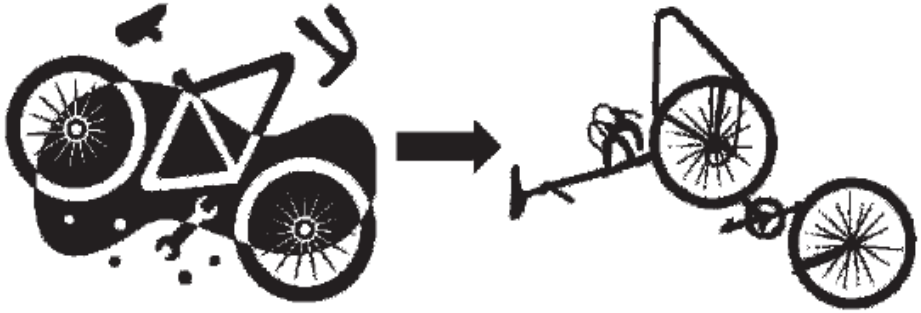
Injury Prediction Modeling



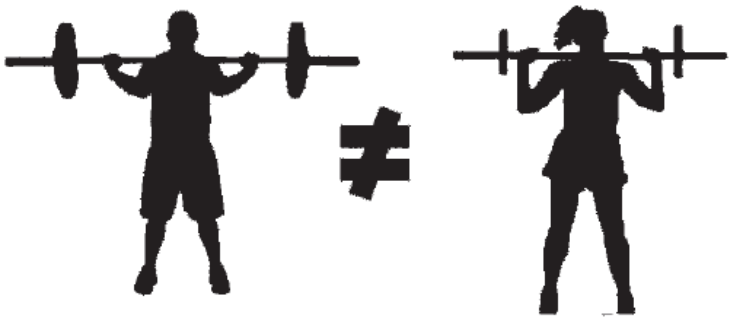
Sum of the parts equals the whole



Assume homogeneity of subjects



Can't reduce the parts and retain the meaning of the whole



When in reality subjects are not homogeneous

Injury Prevention – We have to Try!

Role Delineation Study/ Practice Analysis, 6th Edition

Domain 1	**Injury/illness prevention and wellness protection** – Educating participants and managing risk for safe performance and function.
0101	**Minimize risk of injury and illness of individuals and groups impacted by or involved in a specific activity through awareness, education, and intervention.**
0102	**Interpret individual and group pre-participation and other relevant screening information (e.g., verbal, observed, written) in accordance with accepted and applicable guidelines to minimize the risk of injury and illness.**

Prevention and Health Promotion (PHP)

Athletic trainers develop and implement strategies and programs to prevent the incidence and/or severity of injuries and illnesses and optimize their clients'/patients' overall health and quality of life. These strategies and programs also incorporate the importance of nutrition and physical activity in maintaining a healthy lifestyle and in preventing chronic disease (eg, diabetes, obesity, cardiovascular disease).

Injury Prevention

- Subsequent MSK typically associated with Acute Lower Extremity Injury
- Lateral Ankle Sprain
  - Prophylactic balance and coordination training substantially reduced the risk of ankle sprains in athletes, with a greater effect seen in those with a history of sprain. Completing at least 6 weeks of balance and coordination training during recovery from an acute ankle sprain substantially reduced the risk of recurrent ankle sprain for up to 1 year.
    - McKeon et al, *JAT* 2008: 43(3): 305 – 315

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- Subsequent MSK typically associated with Acute Lower Extremity Injury
- Lateral Ankle Sprain
  - Prophylactic balance and coordination training substantially reduced the risk of ankle sprains in athletes, with a greater effect seen in those with a history of sprain. **Completing at least 6 weeks of balance and coordination training** during recovery from an acute ankle sprain substantially reduced the risk of recurrent ankle sprain for up to 1 year.
    - McKeon et al, *JAT* 2008: 43(3): 305 – 315

Injury Prevention

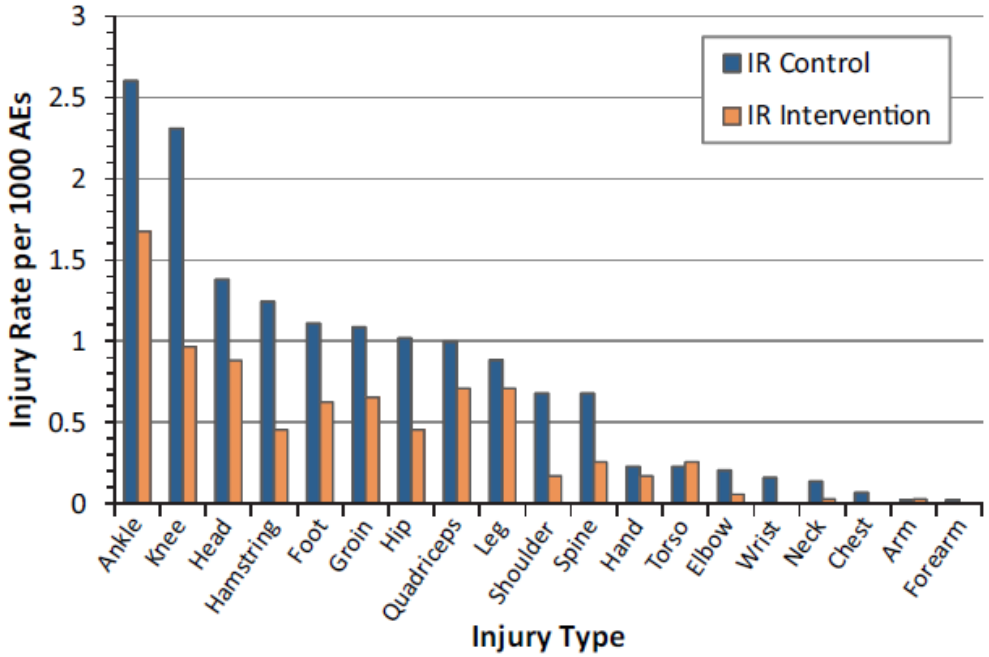
- ACL Risk Reduction
  - The analysis found that preventive neuromuscular Training (PNMT) with strengthening and proximal control exercises significantly reduced ACL injury incidences compared to PNMT programs without those exercise components
    - Incorporating plyometrics, strengthening and proximal control training into PNMT programmes can lead to ACL injury risk reduction by **61%** in plyometrics, **68%** in strengthening, and **67%** in proximal control in young females

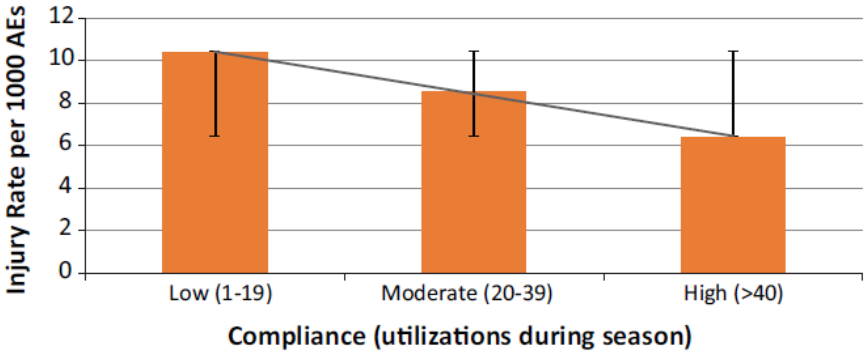
Specific exercise effects of preventive neuromuscular training intervention on anterior cruciate ligament injury risk reduction in young females: meta-analysis and subgroup analysis

Dai Sugimoto,[1,2,3,4,5] Gregory D Myer,[1,3,4,6,7] Kim D Barber Foss,[3,4] Timothy E Hewett[3,4,5,6,7,8]

Injury Prevention

- Sports Injury Reduction
  - FIFA 11+ Injury Prevention





Efficacy of the FIFA 11+ Injury Prevention Program in the Collegiate Male Soccer Player

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Summary

- Consistent association between concussion and subsequent MSK.
- Underlying mechanisms are currently theoretical
- Injury Prediction modeling has limited value
- Targeted Injury Prevention can be highly effective

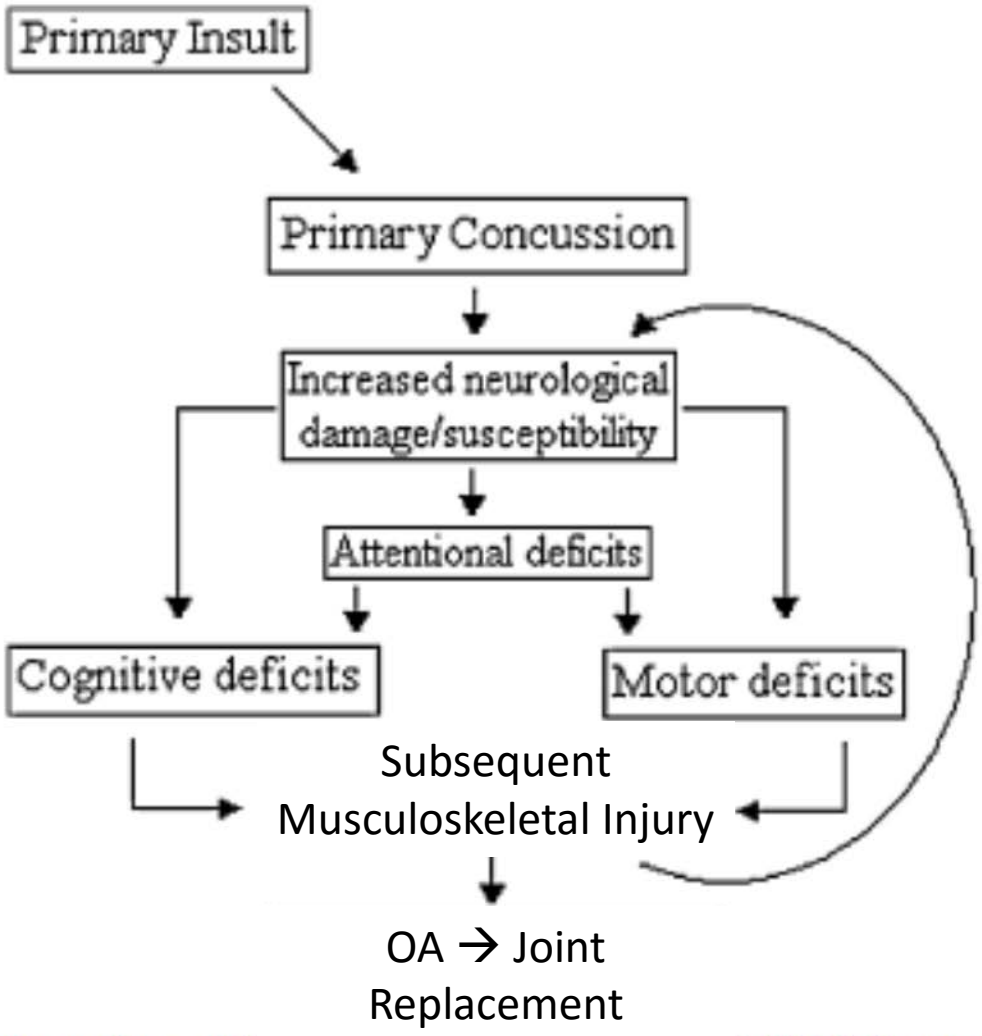

Fig. 1. An outline of the concussive pathway from initial injury to permanent brain damage. One-directional arrows indicate a sequential order of events.


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