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The Use of 3D Motion Capture in ACLR and Athletic Groin Pain Rehabilitation

Brendan Marshall PhD

Overview

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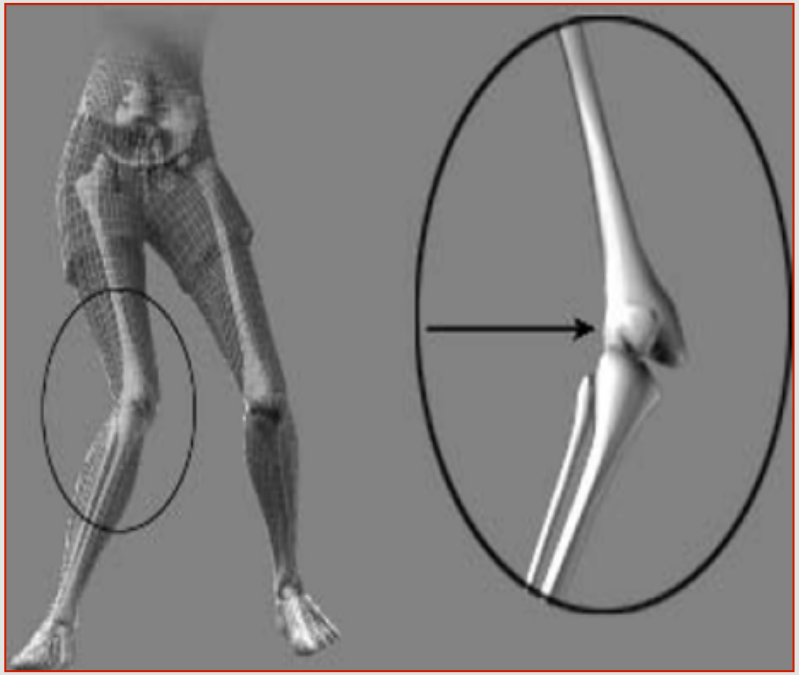

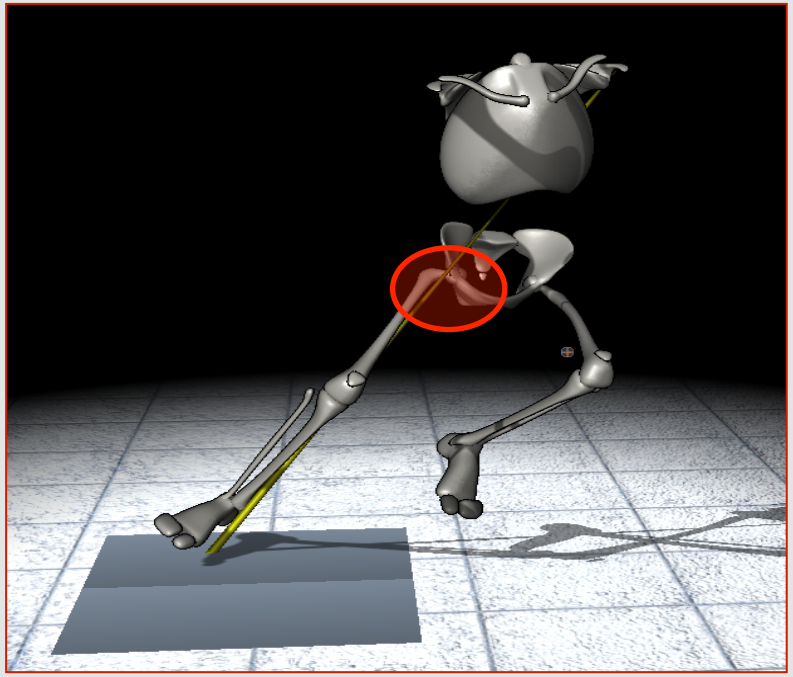

- Background
- SSC testing battery
- Research findings
- Rehabilitation

ACL Injury Epidemiology

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<1%	of total injuries in football (Ekstrand J., 2014)
1	ACL injury every 2 seasons in a pro football squad
6.5	months before team training in pro football
6-27%	risk of re-injury or contralateral injury (Shelbourne et al., 2014; Paterno et al. 2010)
75%	non contact (Agel et al. 2005)

ACL injury mechanism

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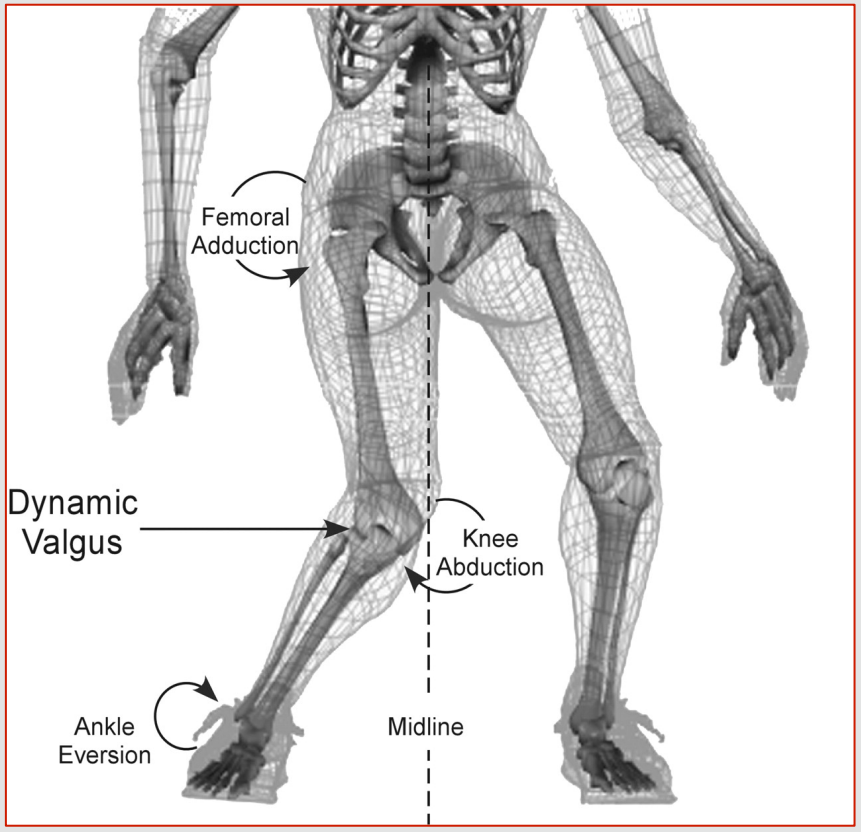
Of all non contact ACLs:

70% change of direction cutting
(Cochrane et al. 2006)

24% landing
(Walden 2014)



Biomechanical Risk Factors

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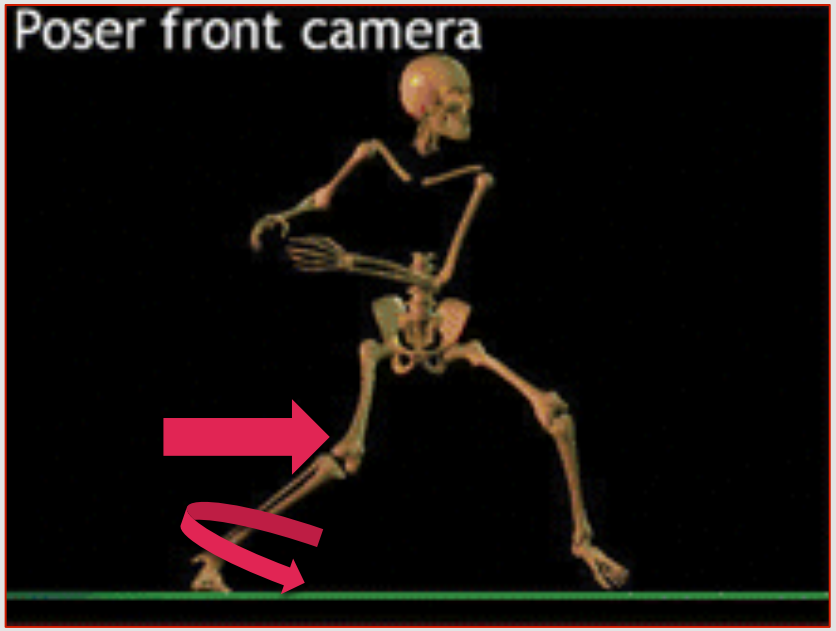

- ACL injury ~40 ms after initial contact
- Knee flexion
- Knee valgus
- Tibial internal rotation

Koga et al. 2010

Biomechanical Risk Factors

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Drop Jump

Knee abduction moment during landing predicts ACL injury risk in female athletes (Myer 2005)

205 athletes pre-screened and tracked

9 had ACL rupture, they had:

2.5 times greater knee valgus moment

20% higher ground reaction force

ACL Testing Battery

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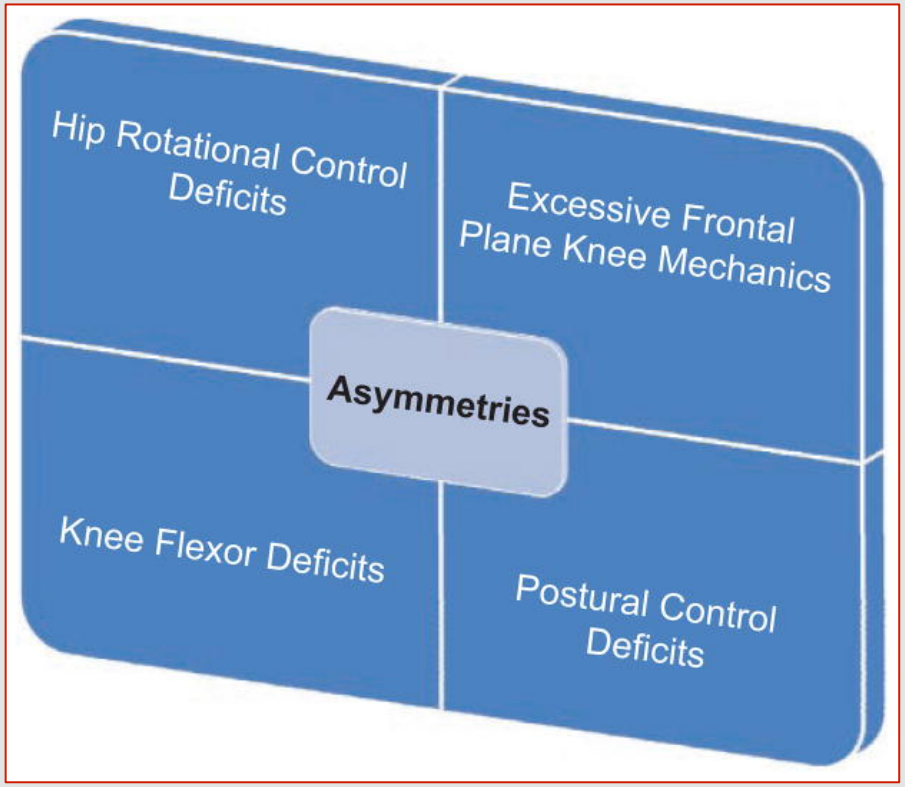
A contralateral ACL injury is strongly related to modifiable postsurgical risk factors (Hewett et al. 2013)



SSC 3D Motion Capture

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3D Marker Set

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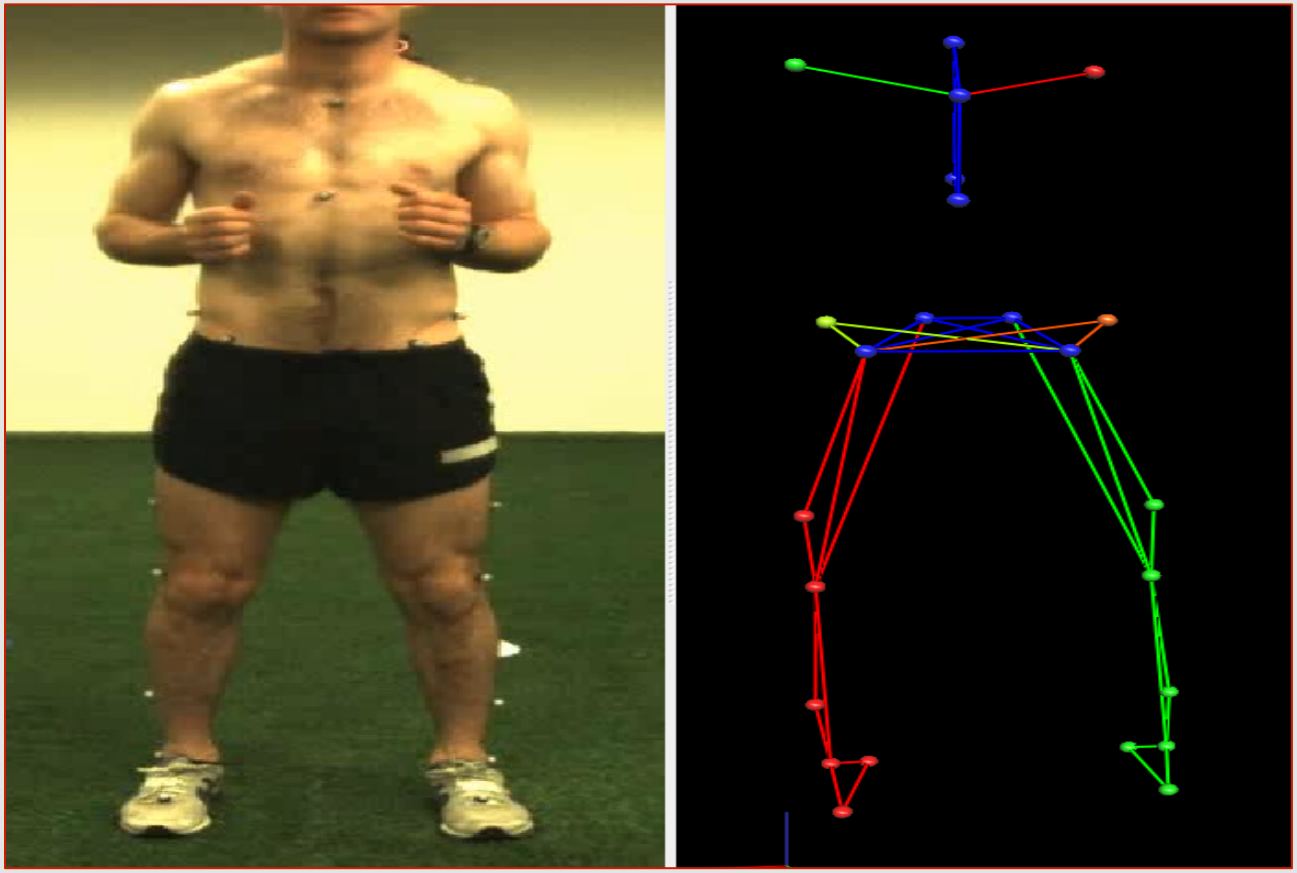

3D Motion Capture

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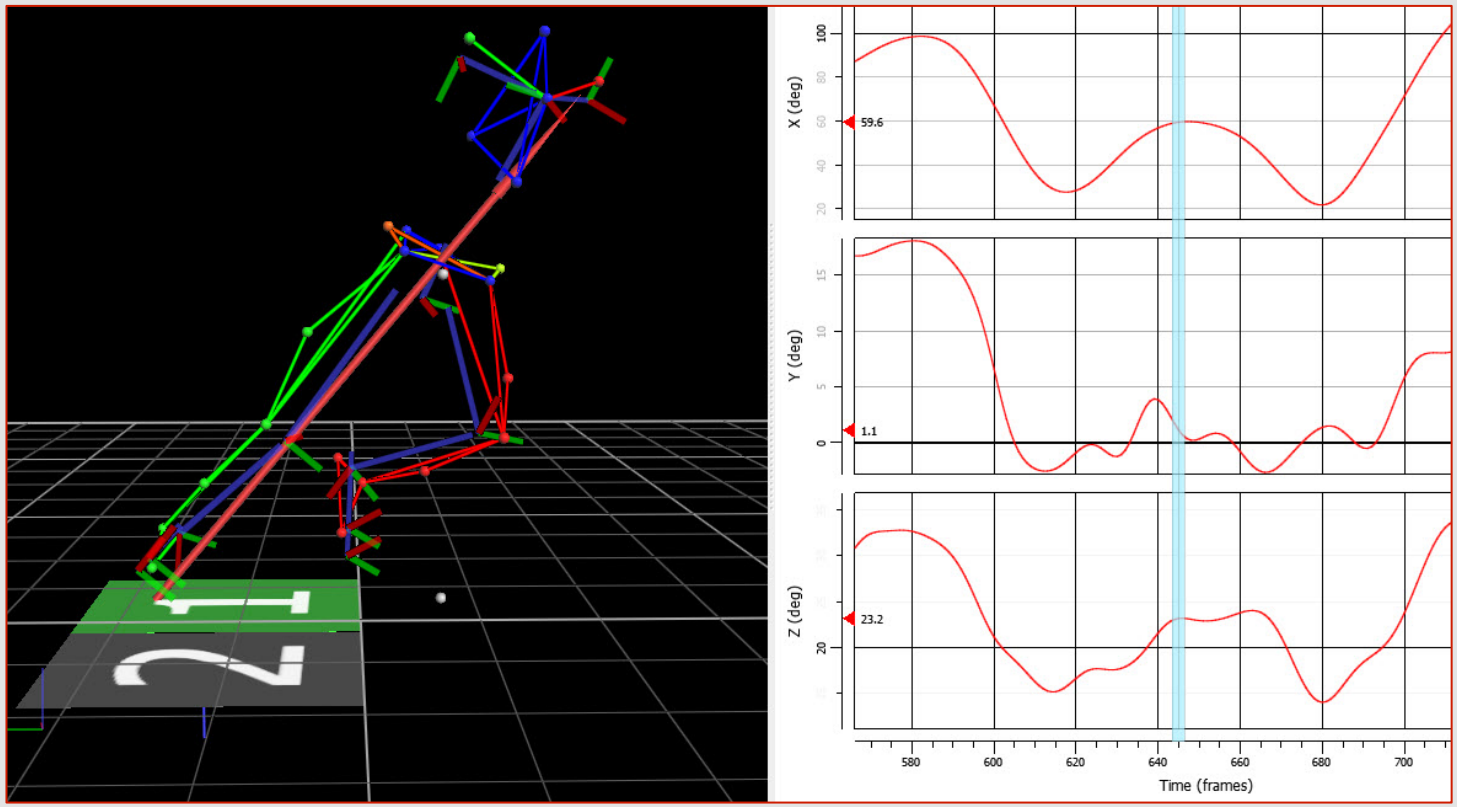
Capturing and evaluating the kinematics (angles) and kinetics (forces) of movement



ACL Rehab Pathway

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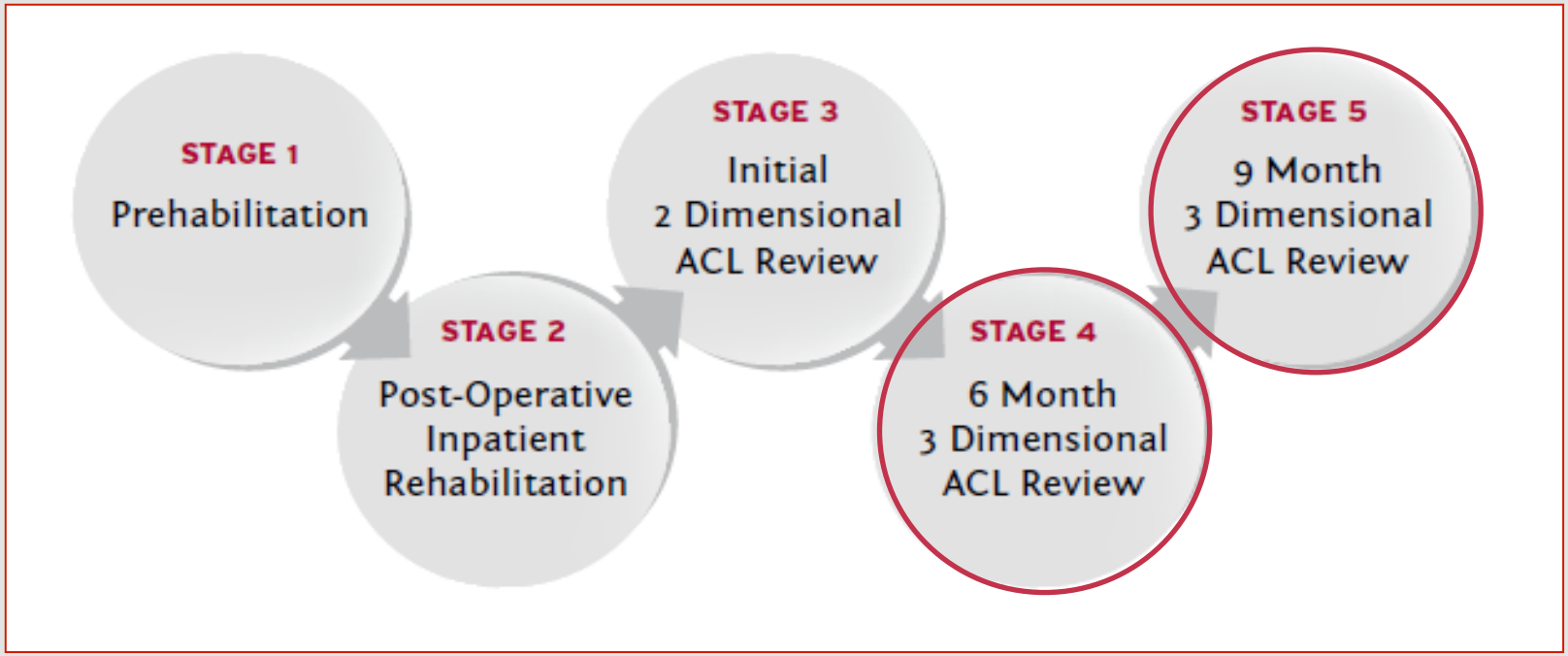

- **3D Testing**
- Isokinetic testing
- Physio review
- Surgeon review

ACL Testing Battery

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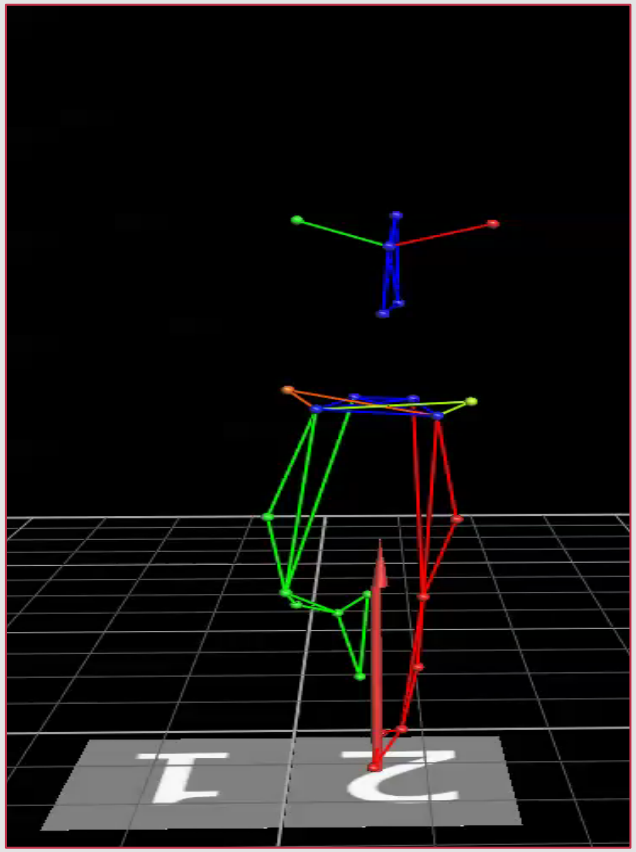

Vertical jump

Jump ability is an important contributor to performance in field sports
(Torres-Unda et al., 2013; Gabbet et al., 2011)

Excellent insight into power output
r = 0.82 (Marshall and Moran. 2015)

Relationship with jump height
Ankle power: r = 0.32
Knee power: r = 0.33
Hip power: r = 0.61

Landing – Contralateral injury risk

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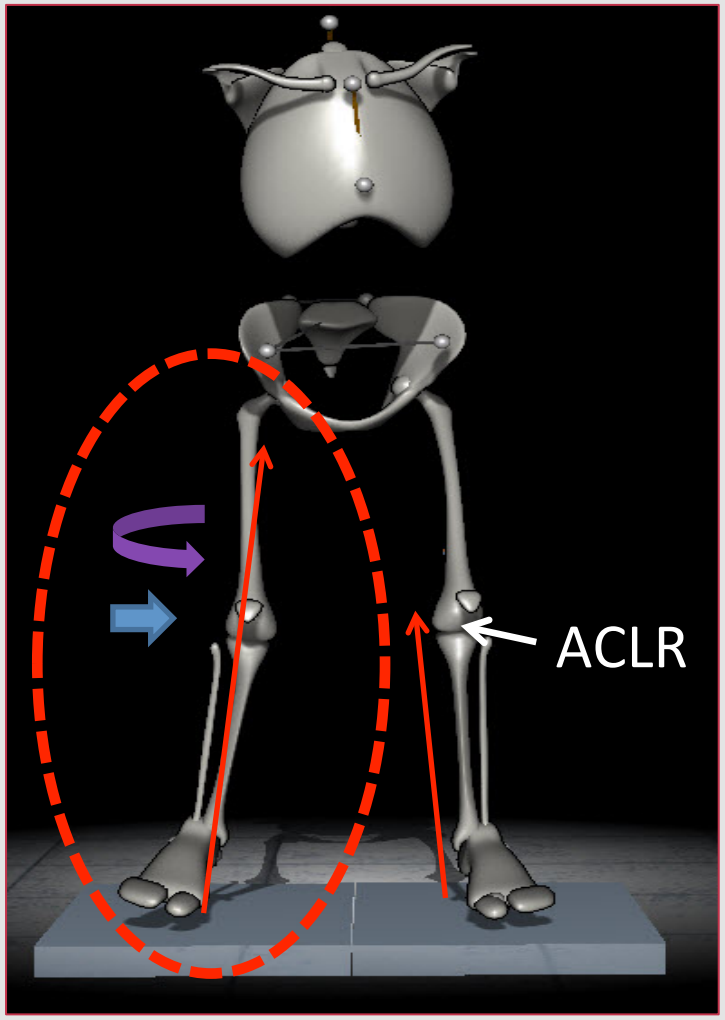

n = 30, 6 month post ACLR

60% landed with contralateral limb first

17% involved limb first

- ↑ Ground Reaction Force 20%
- ↑ Knee valgus angle 90%
- ↑ Knee valgus moment 54%
- ↑ Knee internal rotation 31%

$p < 0.05$

Landing – Contralateral injury risk

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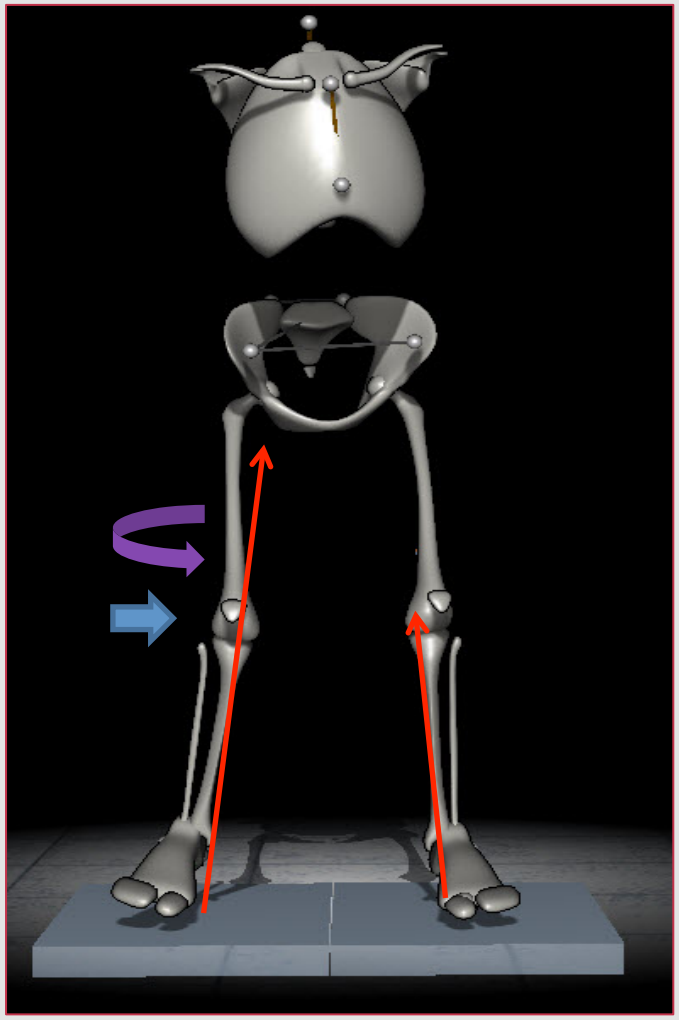

Adapted strategy to ‘protect’ the operated side, increasing the risk of contralateral injury

Implication:

Don’t neglect the contralateral side when rehabilitating

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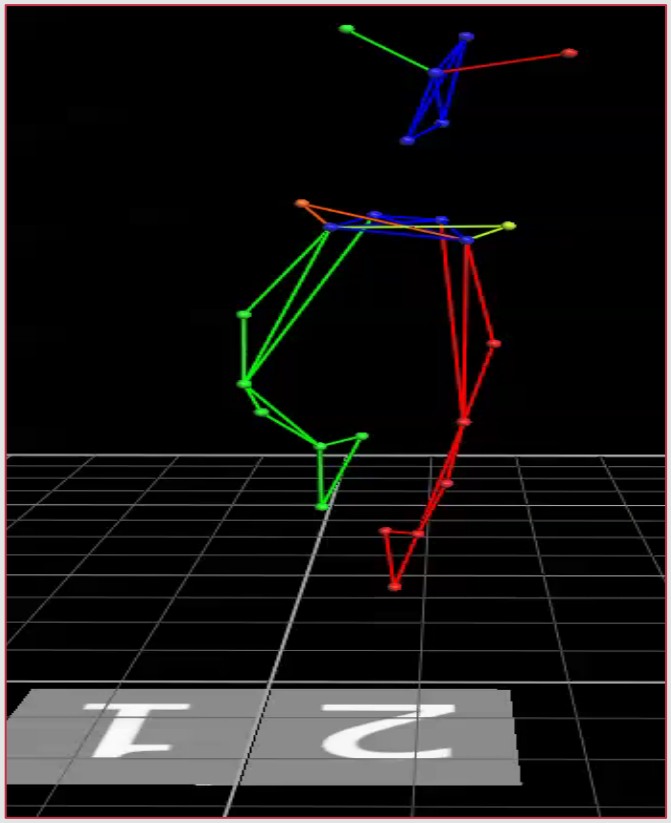

Drop landing

Single-legged landings are a common mechanism of ACL injury (Kimura et al., 2012)

Landing technique influences:

- ACL loading
- Anterior knee pain

Landing Technique and ACL Loading

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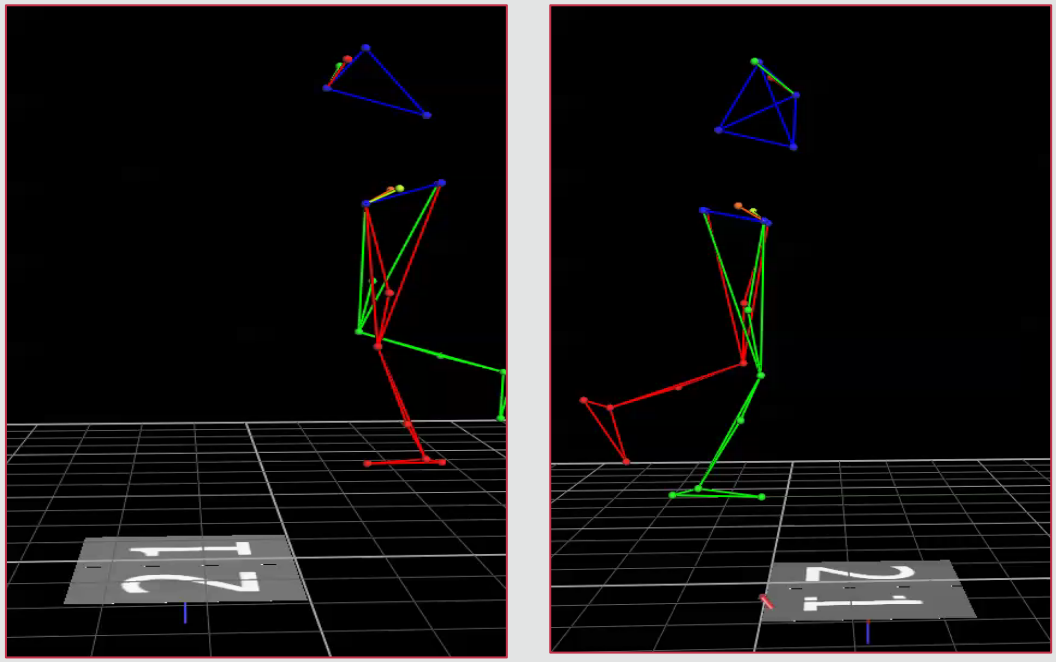
Laughlin et al. 2011 Journal of Biomechanics

Participants were asked to perform ‘stiff’ and ‘soft’ landings



Soft landings:

⇩ ACL force (11%)

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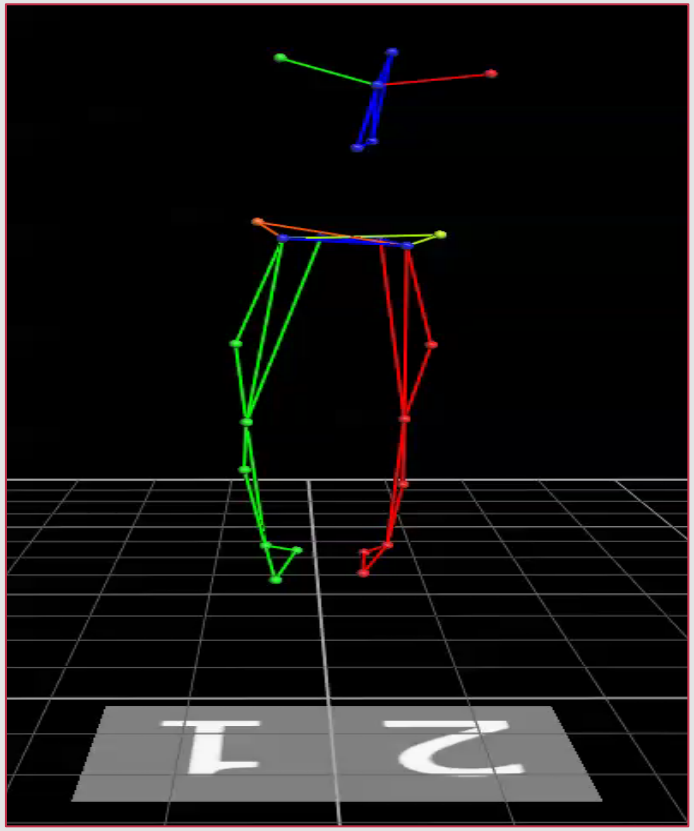

Drop Jump

Knee abduction moment during landing predicts ACL injury risk in female athletes (Myer 2005)

Single and double leg version

Useful as a performance measure

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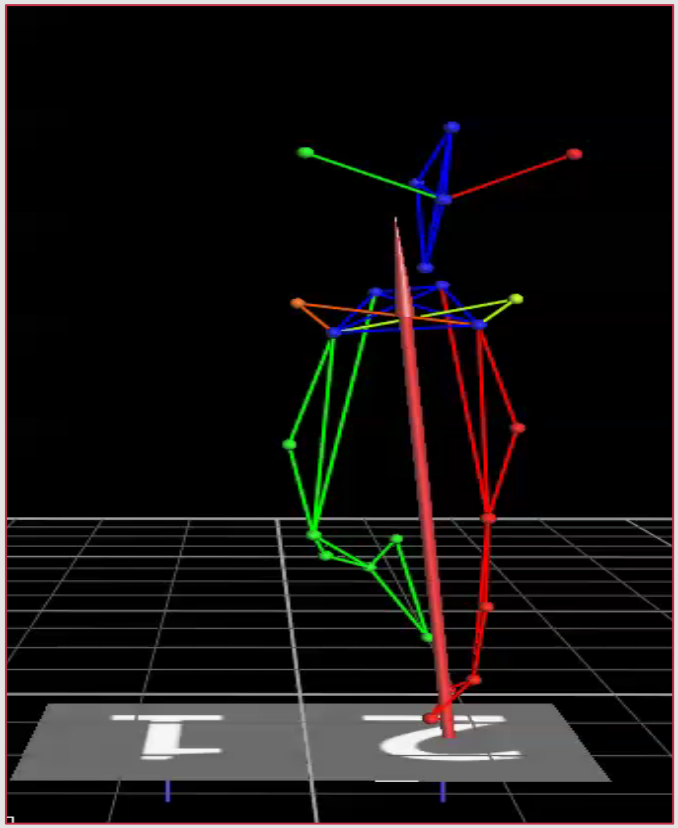

Hurdle Hop

Multi-planar landing activity particularly stressing frontal plane control (Hickey et al. 2009)

Trunk control

Poor neuromuscular control of the trunk a predictor of ACL injury
(Zazulak et al. 2007)

Excessive lateral trunk flexion increases knee internal valgus moments during single-leg landing (Kimura et al. 2014)

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Maximal Hop

A challenging test with a clear performance outcome

However, quality of movement control is often overlooked
(Paterno et al 2010)

Is movement control distinct from movement performance?

Hop for Distance Study

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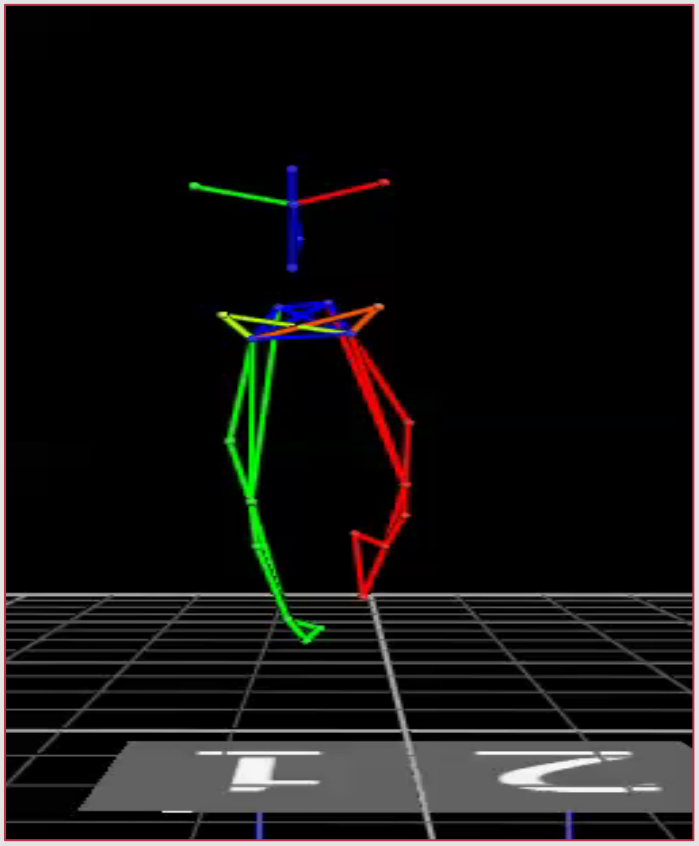
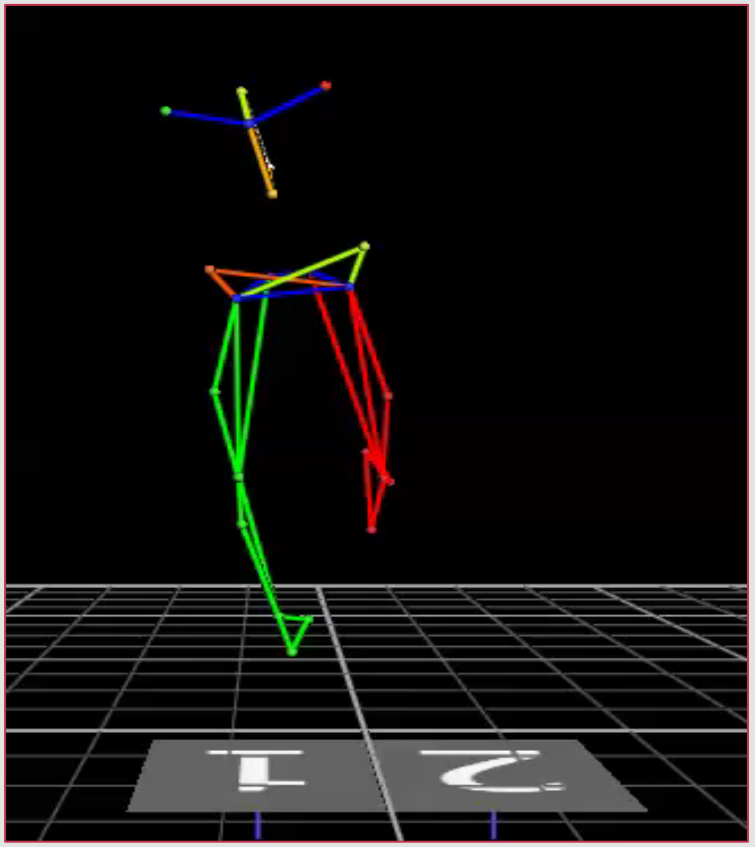
- Good control: n = 16



- Poor control: n = 14



Hop for Distance Study

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No significant ($P > 0.05$) difference in jump distance

Good control (n = 14)	**Poor control (n =16)**	**Difference**
171.3 ± 25.0cm	168.8 ± 23.8cm	2.5cm (P = 0.79)

Hop for Distance Study

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Power generation and movement control are distinct qualities

Implication:

Important to assess dynamic movement control as a distinct return to play criteria

An overreliance on performance outcome may result in a return to play with deficient control and an increased injury risk

(Myer et al 2005, Hewett et al. 2013)

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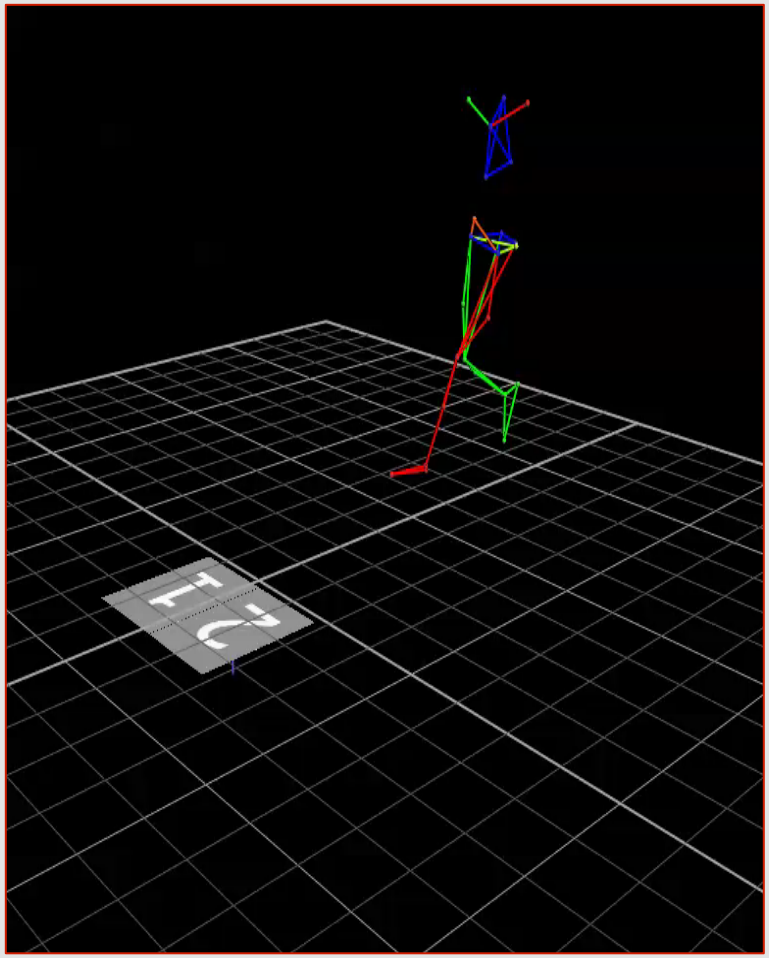

Cut

Cutting is a common mechanism of ACL injury (Kristianslund et al. 2013)

Lee et al. (2014) - ACLR patients exhibited greater knee abductor and internal rotator moments

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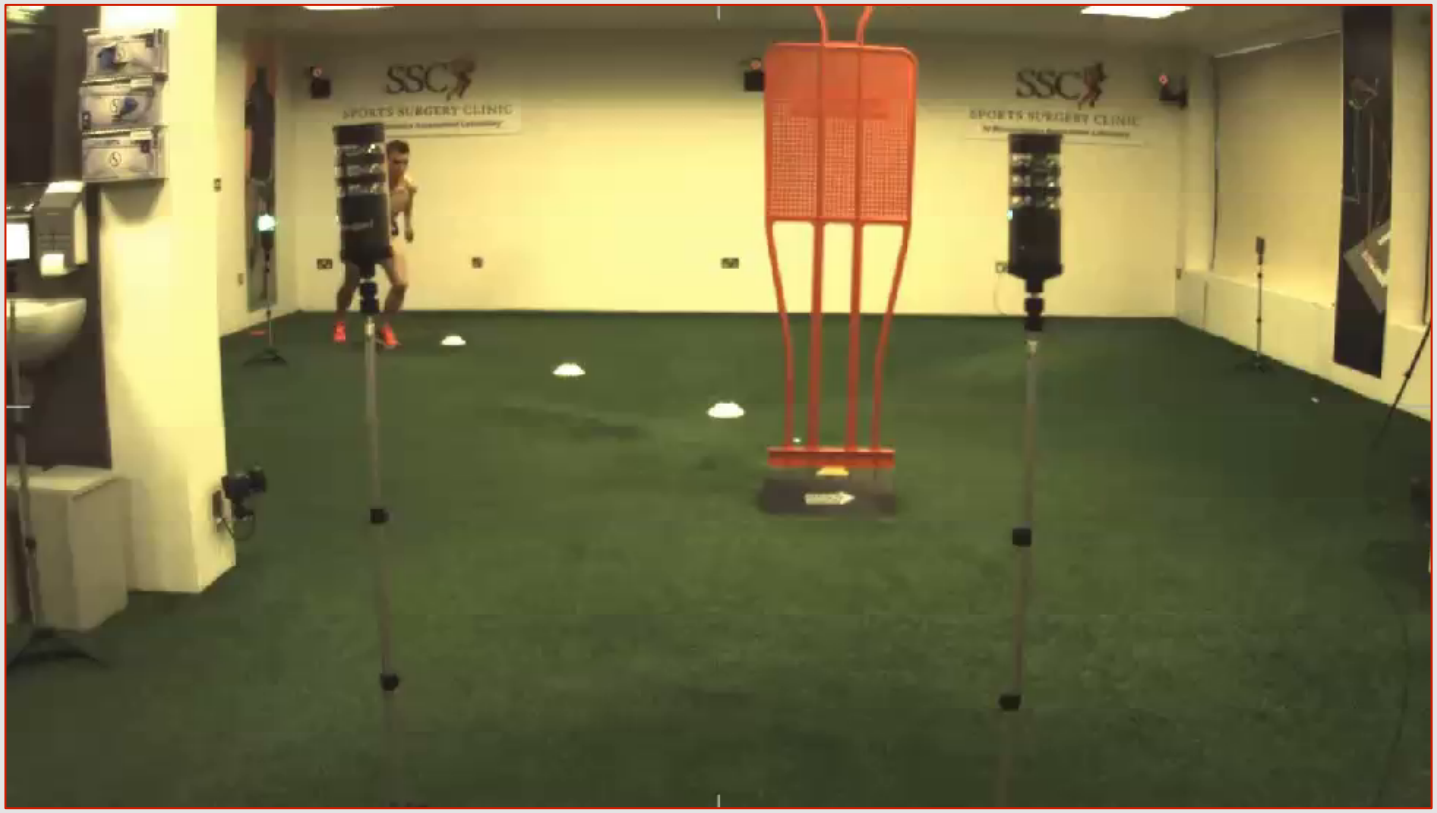

Movement in response to a sudden stimulus may elicit different and more sport specific movement patterns (O'Connor et al. 2009)

6 and 9 Month Testing

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6 and 9 Month Testing

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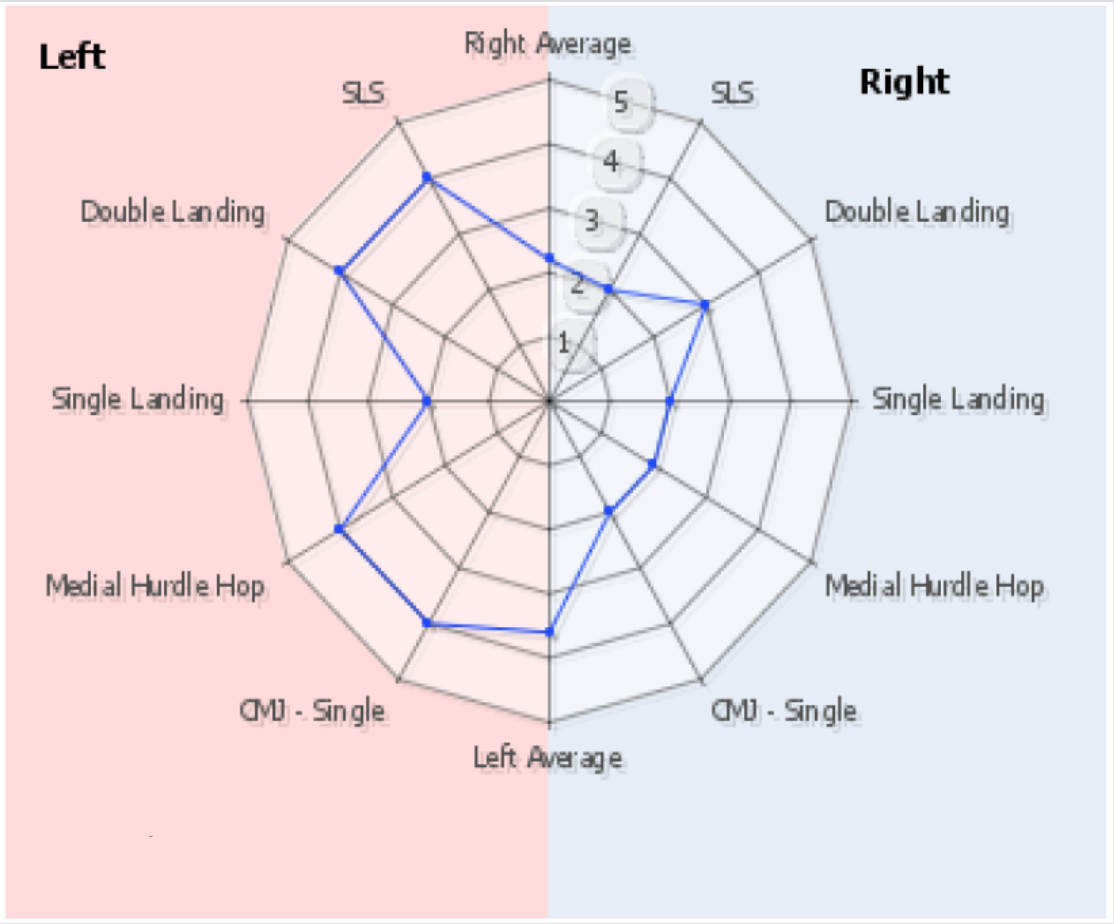
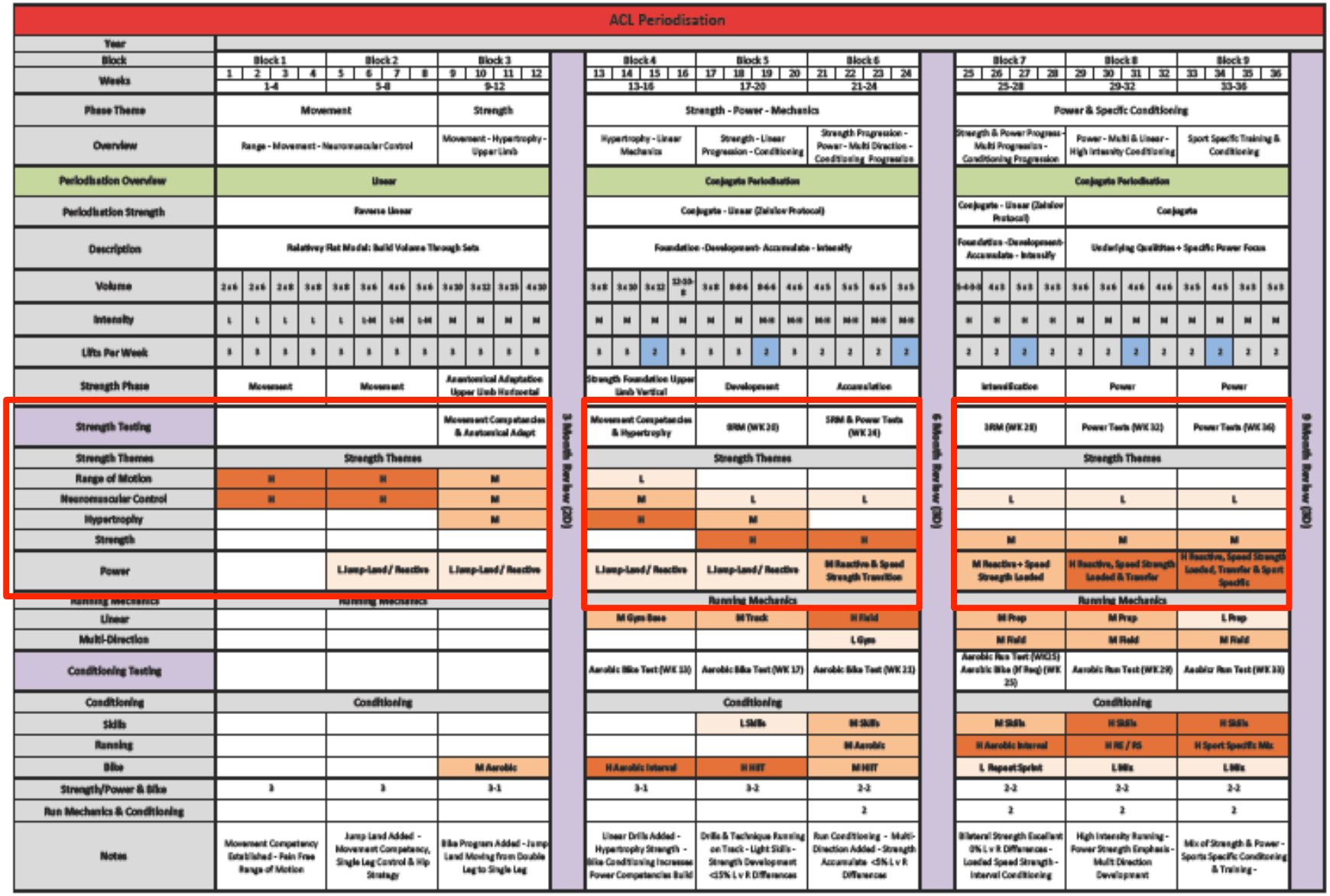


Power	CMJ (Height) (CM)			
	Double	Left	Right	LSI
3 Months	0	16	8	52

Strength	Isokinetic - Quad (Nm)				
	Left	% BW	Right	% BW	LSI
3 Months	201	218	87	95	43

ROM	Extension (Degrees)		
	Left	Right	Difference
3 Months	15	8	-7

ACLR Rehabilitation



ACL Periodisation

Year																											
Block	Block 1				Block 2				Block 3				Block 4				Block 5				Block 6				Block 7			
Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
	1-4				5-8				9-12				13-16				17-20				21-24				25-28			
Phase Theme	Movement								Strength				Strength - Power - Mechanics												Power & Specific Conditioning			
Overview	Range - Movement - Neuromuscular Control								Movement - Hypertrophy - Upper Limb				Hypertrophy - Linear Mechanics				Strength - Linear Progression - Conditioning				Strength Progression - Power - Multi Direction - Conditioning Progression				Strength & Power Progress - Multi Progression - Conditioning Progression			
Periodisation Overview	Linear												Conjugate Periodisation															
Periodisation Strength	Reverse Linear												Conjugate - Linear (Zatsiorsky Protocol)												Conjugate - Linear (Zatsiorsky Protocol)			
Description	Relatively Flat Model: Build Volume Through Sets												Foundation - Development - Accumulate - Intensify												Foundation - Development - Accumulate - Intensify			
Volume	2x6	2x6	2x8	3x8	3x8	3x6	4x6	5x6	3x10	3x12	3x15	4x10	3x8	3x10	3x12	12-10-8	3x8	8-8-6	8-6-6	4x6	4x5	5x5	6x5	3x5	6-4-3-3	4x5	5x5	3x5
Intensity	L	L	L	L	L	L-M	L-M	L-M	M	M	M	M	M	M	M	M	M	M	M-H	M-H	M-H	M-H	M-H	M-H	H	H	H	H
Lifts Per Week	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	3	3	3	2	3	2	2	2	2	2	2	2	2
Strength Phase	Movement				Movement				Anatomical Adaptation Upper Limb Horizontal				Strength Foundation Upper Limb Vertical				Development				Accumulation				Intensification			
Strength Testing									Movement Competencies & Anatomical Adapt				Movement Competencies & Hypertrophy				8RM (WK 20)				5RM & Power Tests (WK 24)				1RM (WK 28)			
Strength Themes	Strength Themes												Strength Themes												Strength Themes			
Range of Motion	H				H				M				L															
Neuromuscular Control	H				H				M				M				L				L				L			
Hypertrophy									M				H				M											
Strength																	H				H				M			
Power					L Jump-Land / Reactive				L Jump-Land / Reactive				L Jump-Land / Reactive				L Jump-Land / Reactive				M Reactive & Speed Strength Transition				M Reactive + Speed Strength Loaded			
Running Mechanics	Running Mechanics												Running Mechanics												Running Mechanics			
Linear													M Gym Base				M Track				H Field				M Prep			
Multi-Direction																					L Gym				M Field			
Conditioning Testing													Aerobic Bike Test (WK 13)				Aerobic Bike Test (WK 17)				Aerobic Bike Test (WK 21)				Aerobic Run Test (WK15) Aerobic Bike (If Req) (WK 25)			
Conditioning	Conditioning												Conditioning												Conditioning			
Skills																	L Skills				M Skills				M Skills			
Running																					M Aerobic				H Aerobic Interval			
Bike									M Aerobic				H Aerobic Interval				H HIIT				M HIIT				L Repeat Sprint			
Strength/Power & Bike	3				3				3-1				3-1				3-2				2-2				2-2			
Run Mechanics & Conditioning																					2				2			
Notes	Movement Competency Established - Pain Free Range of Motion				Jump Land Added - Movement Competency, Single Leg Control & Hip Strategy				Bike Program Added - Jump Land Moving from Double Leg to Single Leg				Linear Drills Added - Hypertrophy Strength - Bike Conditioning Increases Power Competencies Build				Drills & Technique Running on Track - Light Skills - Strength Development <15% L v R Differences				Run Conditioning - Multi-Direction Added - Strength Accumulate <5% L v R Differences				Bilateral Strength Excellent 0% L v R Differences - Loaded Speed Strength - Interval Conditioning			

Block	Block 8				Block 9			
Weeks	29	30	31	32	33	34	35	36
	29-32				33-36			
Phase Theme								
Overview	Power - Multi & Linear - High Intensity Conditioning				Sport Specific Training & Conditioning			
Periodisation Overview	Conjugate Periodisation							
Periodisation Strength	Conjugate							
Description	Underlying Qualities + Specific Power Focus							
Volume	3x6	3x6	4x6	4x6	3x5	4x5	3x5	5x5
Intensity	M	M	M	M	M	M	M	M
Lifts Per Week	2	2	2	2	2	2	2	2
Strength Phase	Power				Power			
Strength Testing	Power Tests (WK 32)				Power Tests (WK 36)			
Strength Themes	Strength Themes							
Range of Motion								
Neuromuscular Control	L				L			
Hypertrophy								
Strength	M				M			
Power	H Reactive, Speed Strength Loaded & Transfer				H Reactive, Speed Strength Loaded, Transfer & Sport Specific			
Running Mechanics	Running Mechanics							
Linear	M Prep				L Prep			
Multi-Direction	M Field				M Field			
Conditioning Testing	Aerobic Run Test (WK29)				Aerobic Run Test (WK 33)			
Conditioning	Conditioning							
Skills	H Skills				H Skills			
Running	H RE / RS				H Sport Specific Mix			
Bike	L Mix				L Mix			
Strength/Power & Bike	2-2				2-2			
Run Mechanics & Conditioning	2				2			
Notes	High Intensity Running - Power Strength Emphasis - Multi Direction Development				Mix of Strength & Power - Sports Specific Conditioning & Training -			

3 Month Review (3D)

6 Month Review (3D)

9 Month Review (3D)

ACLR Rehabilitation

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Training Blocks 1-3

Strength Testing			Movement Competancies & Anatomical Adapt
Strength Themes	Strength Themes		
Range of Motion	H	H	M
Neuromuscular Control	H	H	M
Hypertrophy			M
Strength			
Power		L Jump-Land / Reactive	L Jump-Land / Reactive

Sample training exercises:
balance (eyes closed), goblet squat (high box), below knee dead lift

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Training Blocks 4-6

Strength Testing	Movement Competancies & Hypertrophy	8RM (WK 20)	5RM & Power Tests (WK 24)
Strength Themes	Strength Themes		
Range of Motion	L		
Neuromuscular Control	M	L	L
Hypertrophy	H	M	
Strength		H	H
Power	L Jump-Land / Reactive	L Jump-Land / Reactive	M Reactive & Speed Strength Transition

Sample training exercises:
Leg press, front squat, box jump (hold), single leg rebound jumps

ACL Rehab Pathway

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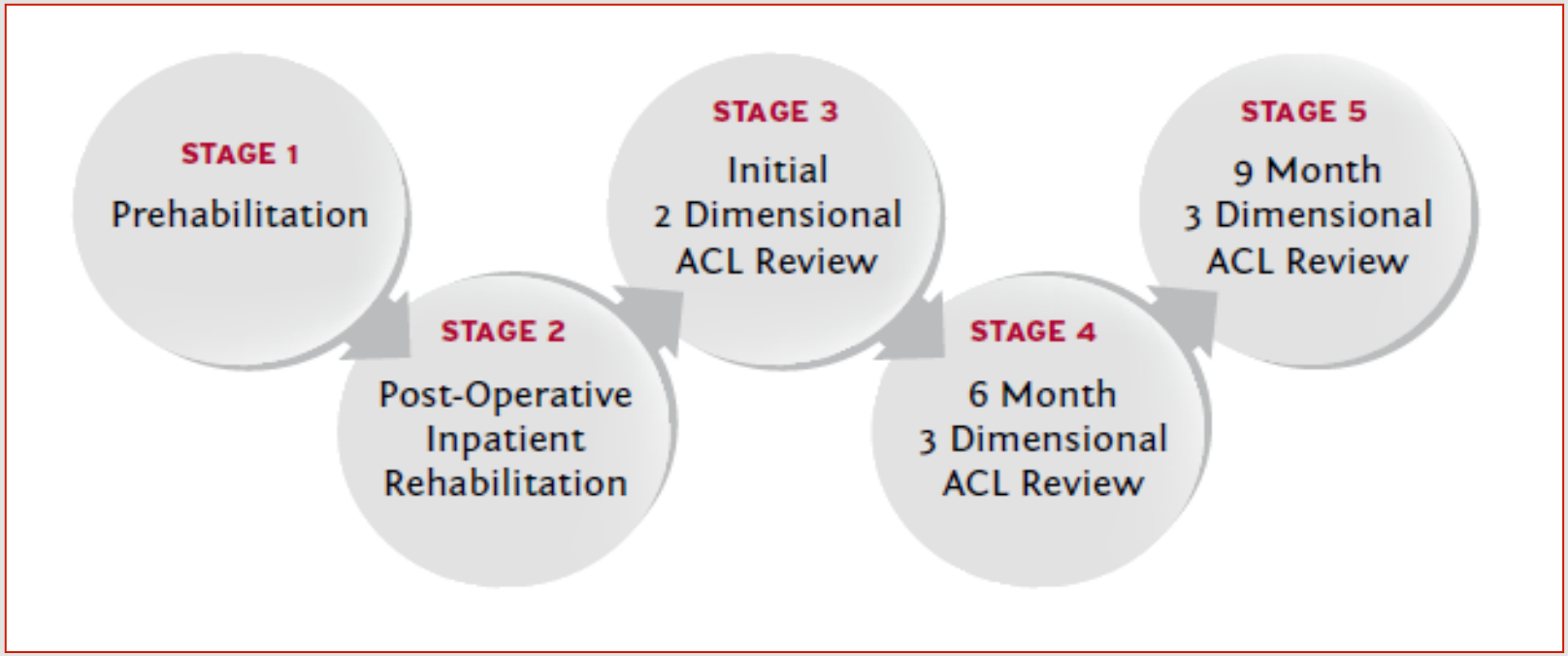

Efficient return to chosen sport

Symptom free return to performance

Reduce the risk of re-injury

3D Motion Capture and Groin Pain Rehabilitation

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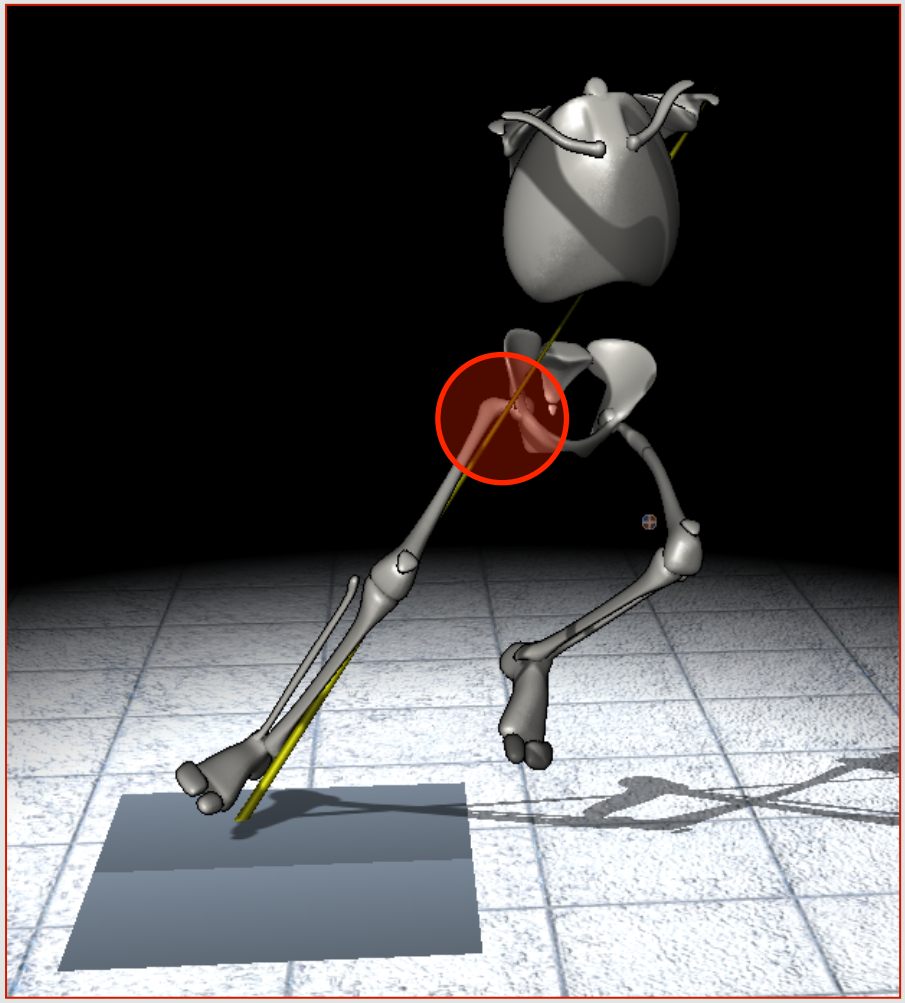

Overview

- Background
- SSC testing battery
- Research findings

Epidemiology

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10% of all attendees at sports medicine practises (Ryan et al., 2014)

24% of academy gaelic footballers (Glasgow ., 2011)

8-18% of all football injuries (Hölmich, 1998)

445 days average duration of symptoms before attending SSC groin clinic

Behind only fracture and joint reconstruction in lost playing time
(Brooks 2005)

Biomechanical factors

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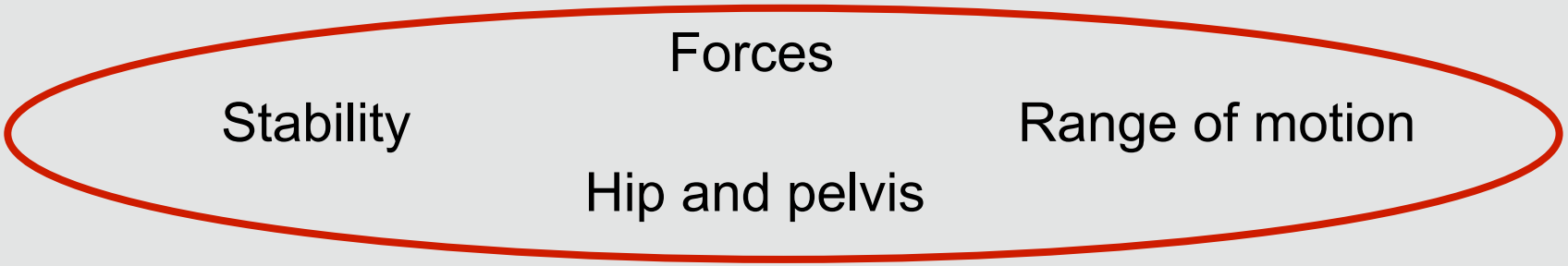
disturbed stabilisation of the hip and pelvis (Holmich 1999; Cowan 2004)

abnormal distribution of forces in the region (Pizzari 2008; Rabe 2010)

complex aetiology

restricted hip range of motion (Verrall 2005a; Verrall 2007a)



Cutting

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Rapid change-of-direction/cutting associated with groin injury

(Holmich et al. 2014)

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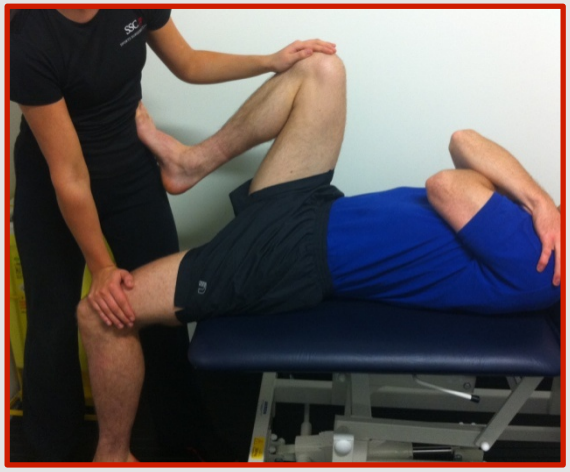
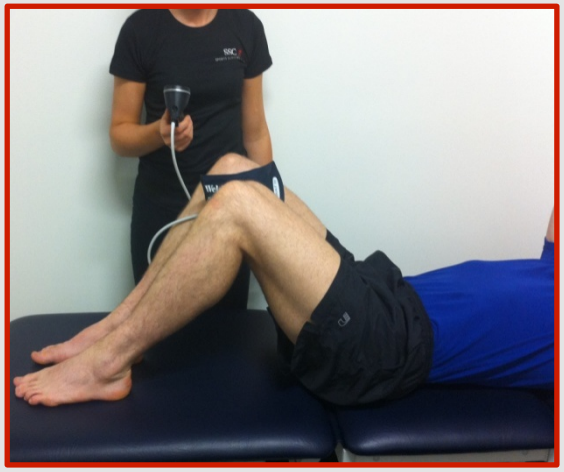
Traditional groin pain assesment:



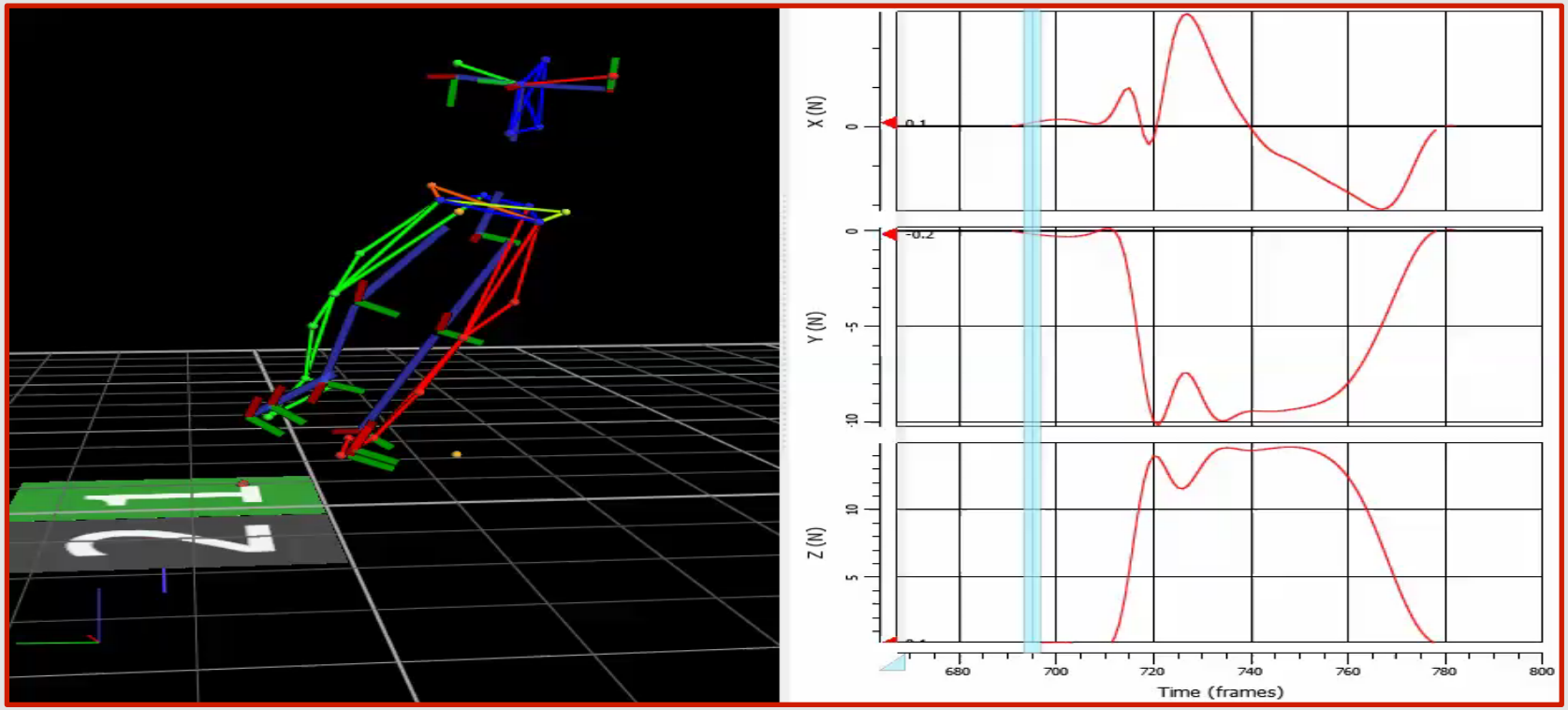


Lack of Specificity

J Strength Cond Res. 2014 Oct;28(10):2845-51. doi: 10.1519/JSC.0000000000000463.

Biomechanical factors associated with time to complete a change of direction cutting maneuver.

Marshall BM[1], Franklyn-Miller AD, King EA, Moran KA, Strike SC, Falvey EC.



SSC – Groin Clinic

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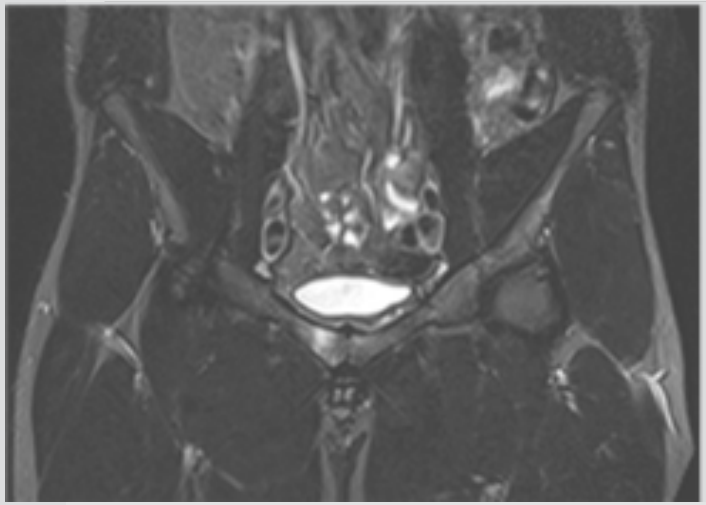

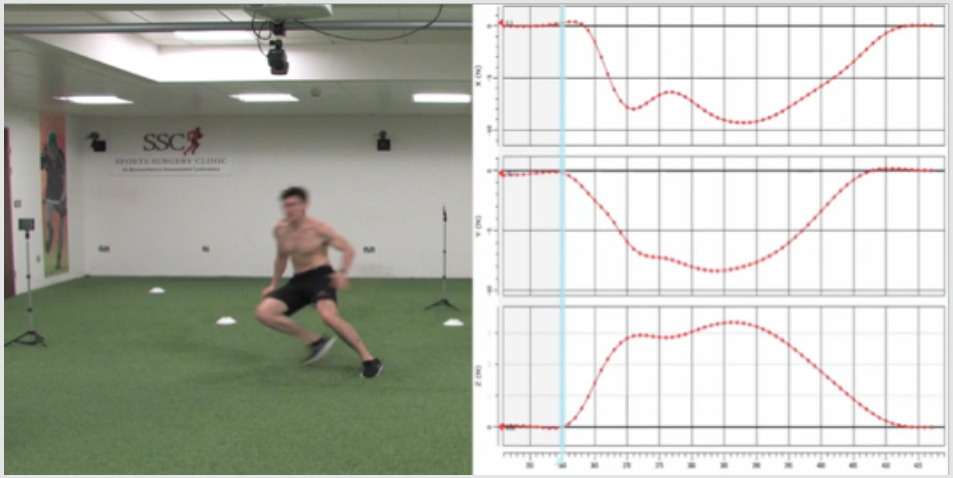

Groin Testing Battery

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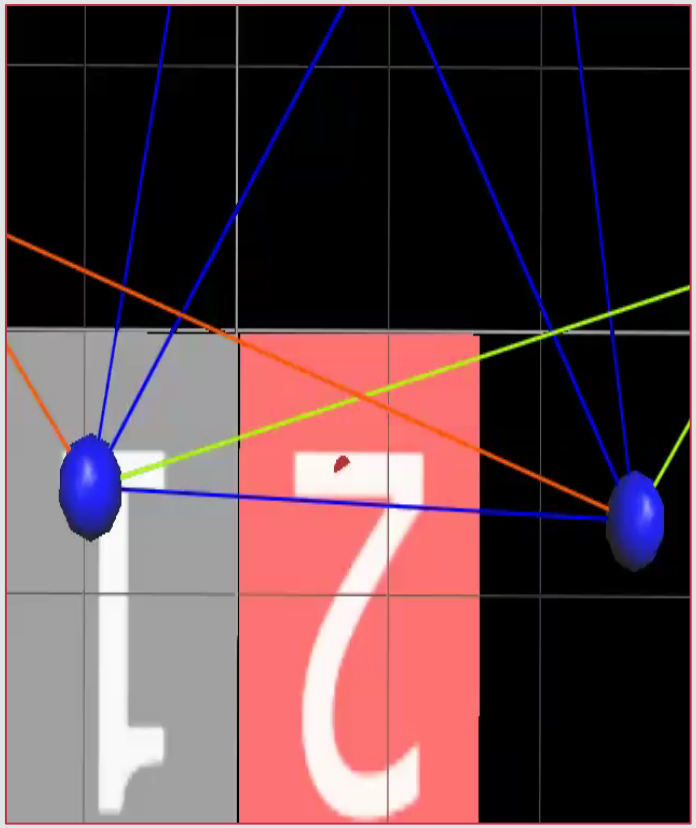

Drop landing

Examination of function in a predominantly sagital plane movement

Lumbopelvic control

Example Rehab Exercise

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Groin Testing Battery

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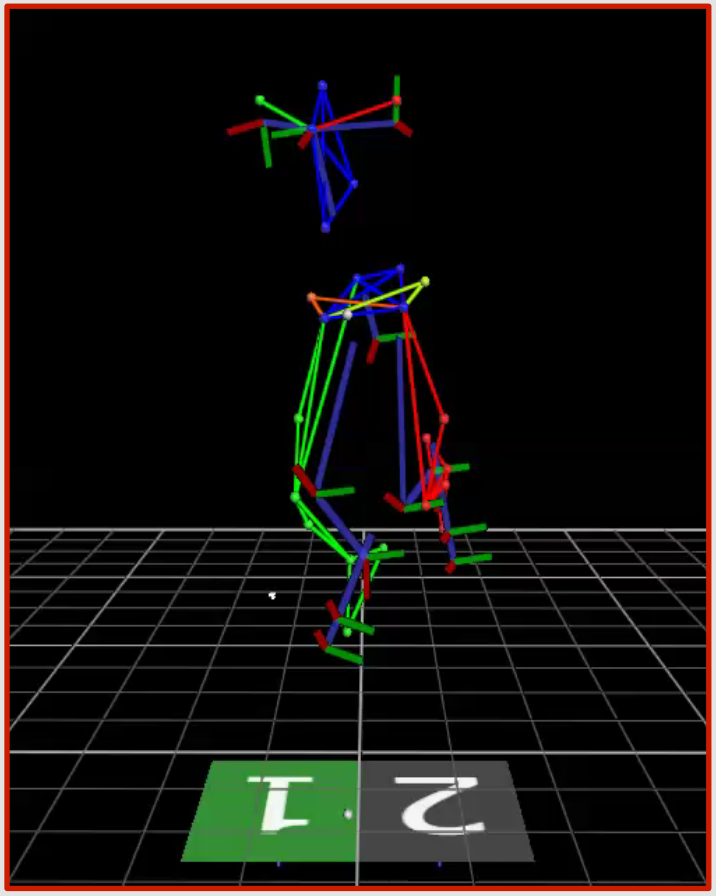

Hurdle Hop

Multi-planar landing activity particularly stressing frontal plane function (Hickey et al. 2009)

More excessive lateral trunk flexion influences frontal plane moments at more distal joints (Kimura et al. 2014)

Example Rehab Exercise

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Groin Testing Battery - Cut

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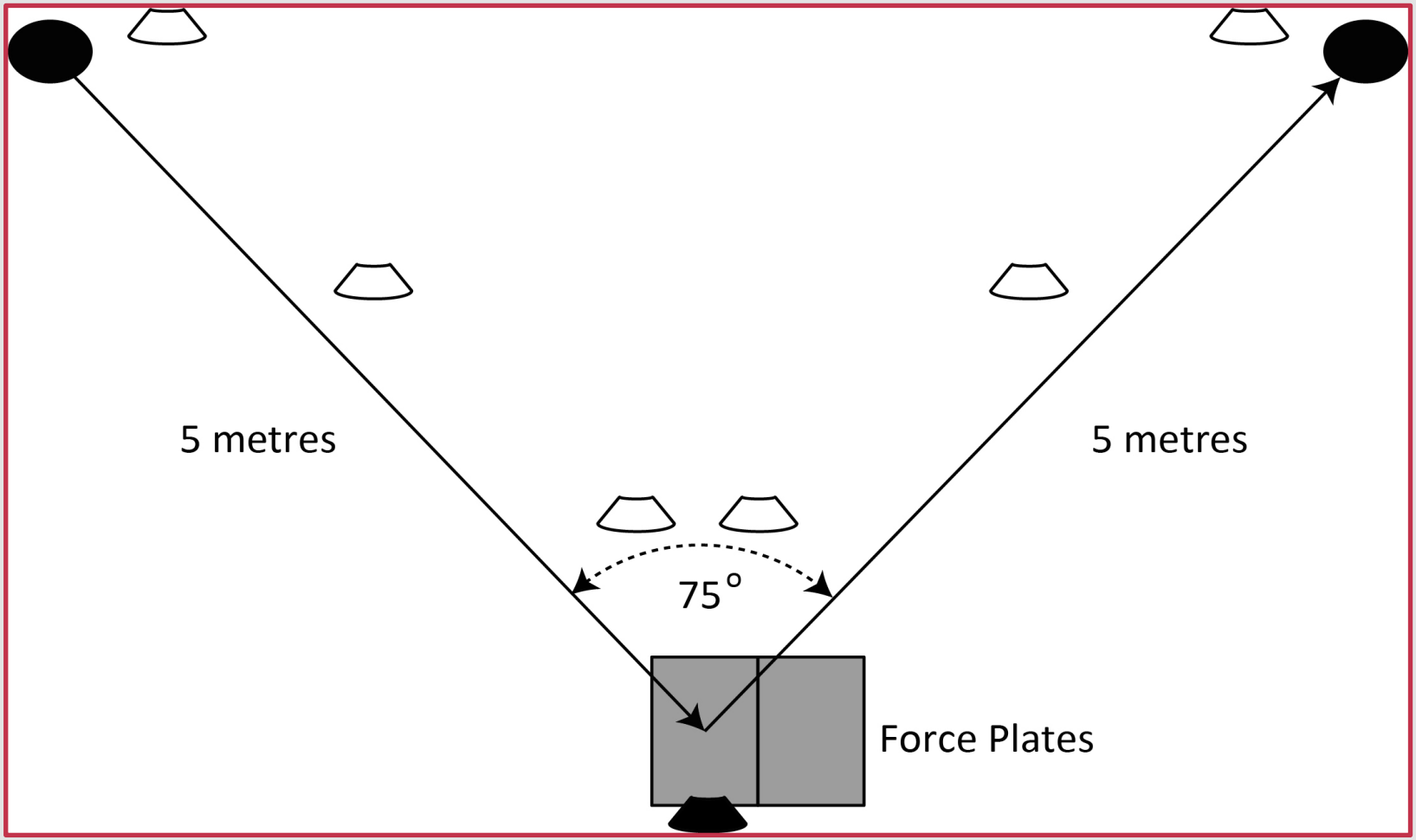

Groin Testing Battery - Cutting

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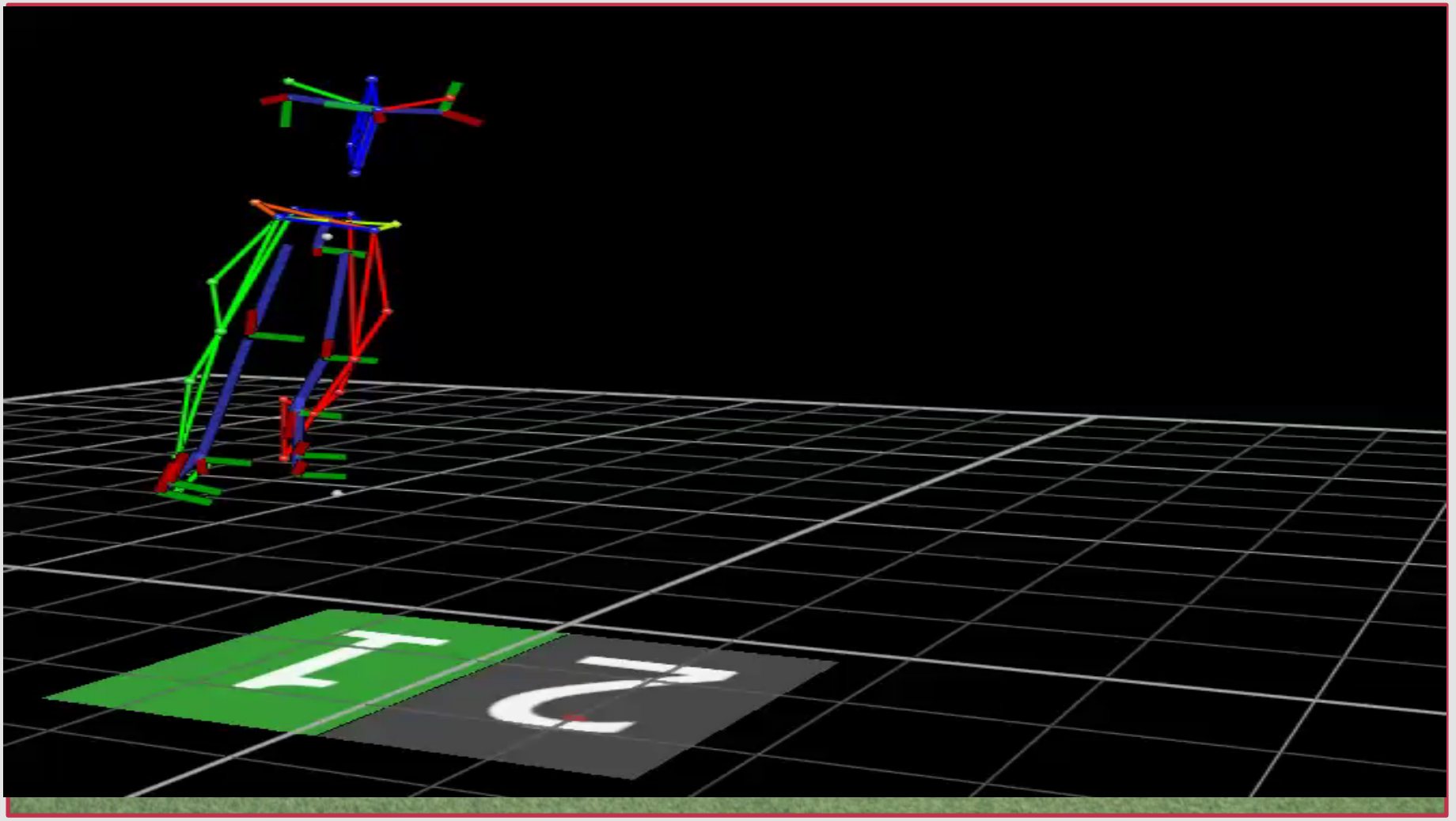

Toward a Biomechanical Diagnosis

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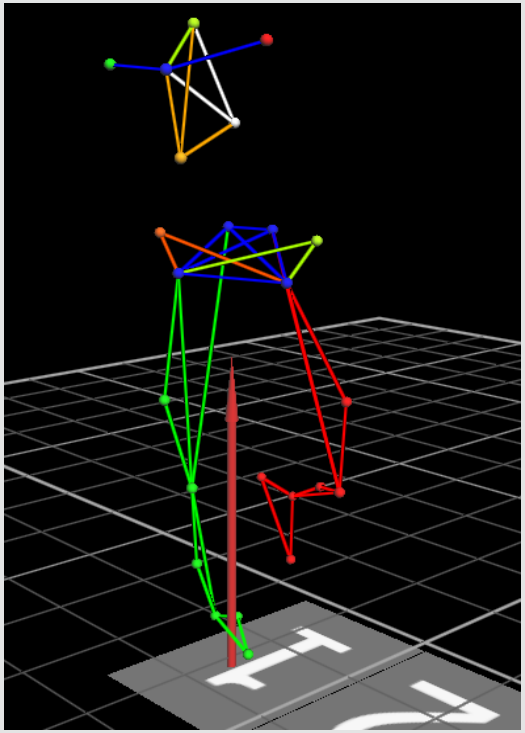
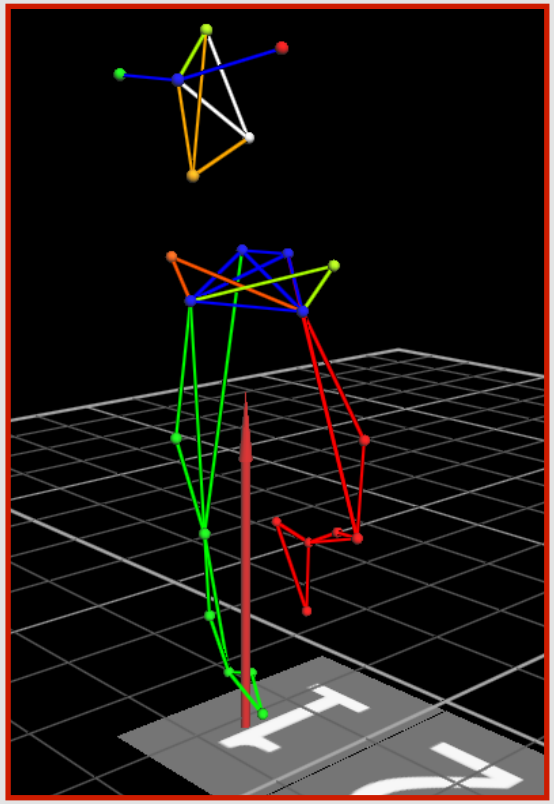
Cluster 1 (40%)



Trunk external rotation
Hip internal rotation
Hip flexion

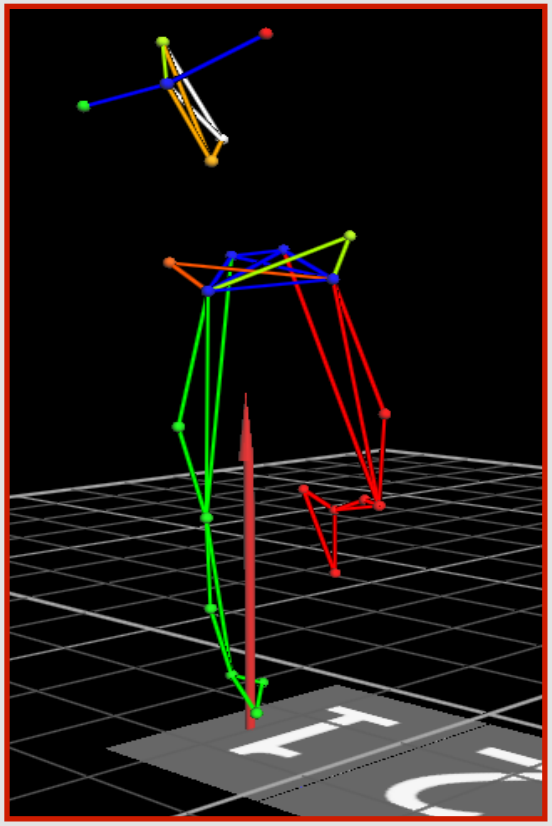
Cluster 1



↑ Hip internal rotation, hip flexion

- associated with an increase in pubic symphyseal motion (Birmingham et al 2012)
- associated with femeroacetabular impingement particularly in the presence of abnormal hip morphology

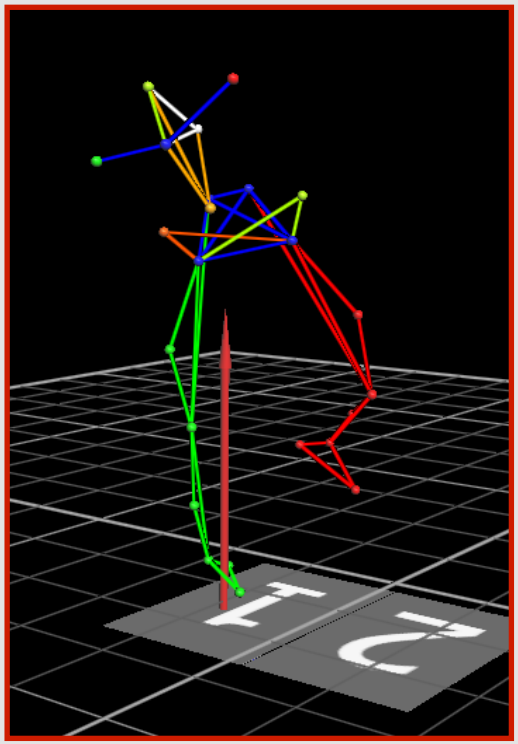
Cluster 2



↑ Hip abduction and trunk side flexion

- Dynamic hip abduction controlled by eccentric action of the adductors

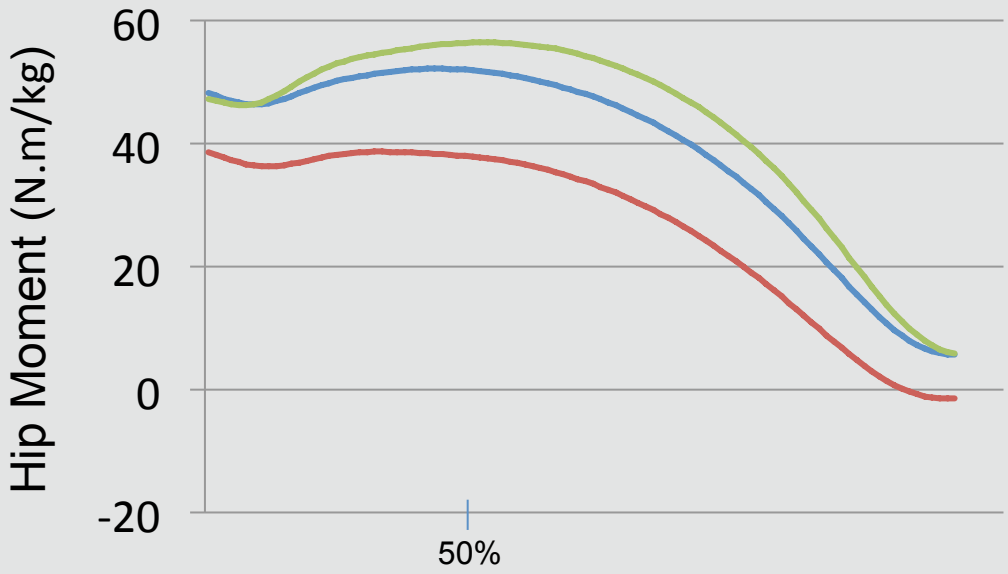
Cluster 3



↑ Trunk flexion, as well as

↑ Hip abduction and trunk side flexion

Due to a reduced posterior chain utilisation/ capacity?



Toward a Biomechanical Diagnosis

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- 3 distinct movement patterns identified – biomechanical diagnoses
- 3D assessment provides additional information to tailor rehabilitation

Groin Testing Battery - Indecision

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Movement in response to a sudden stimulus may elicit different and more sport specific movement patterns (O'Connor et al. 2009)

Groin Testing Battery - Kicking

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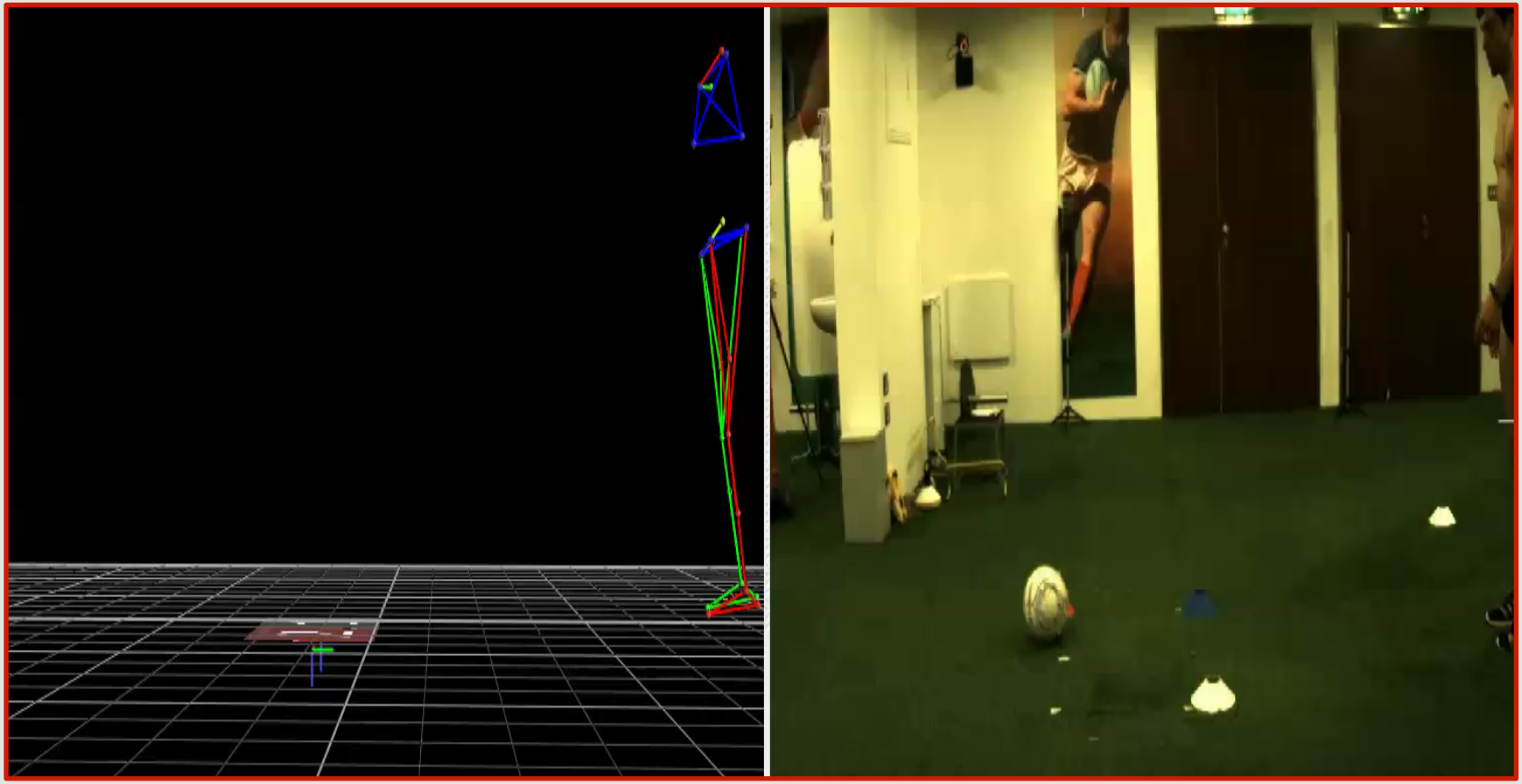

Rehabilitation

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Level 1 – Lumbopelvic Control and Strength

Level 2 – Power and Linear Running

Level 3 – Multidirectional and Sports specific

Rehabilitation – Dead Lift

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Rehabilitation

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Post Rehab Changes

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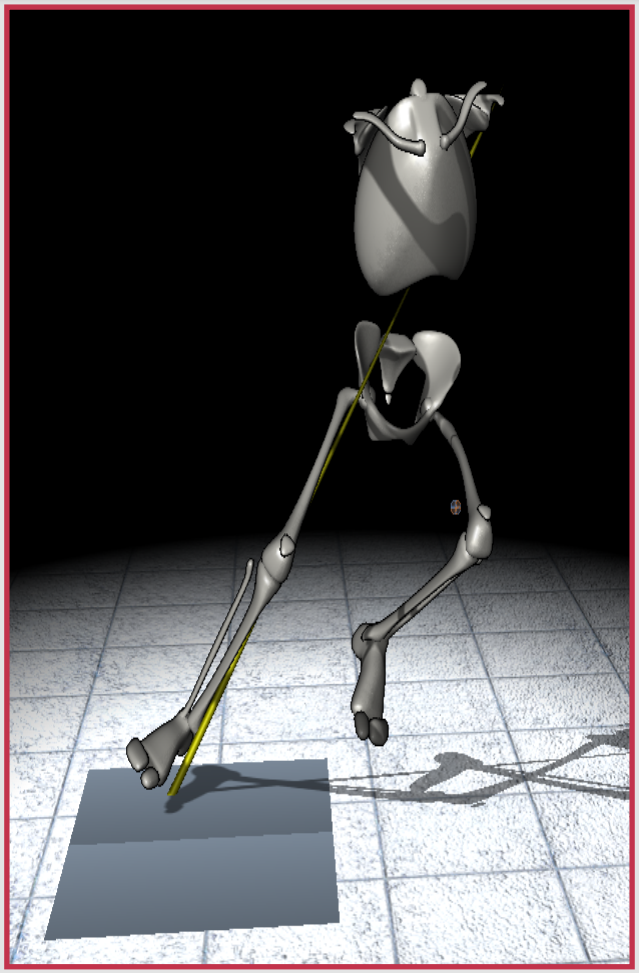
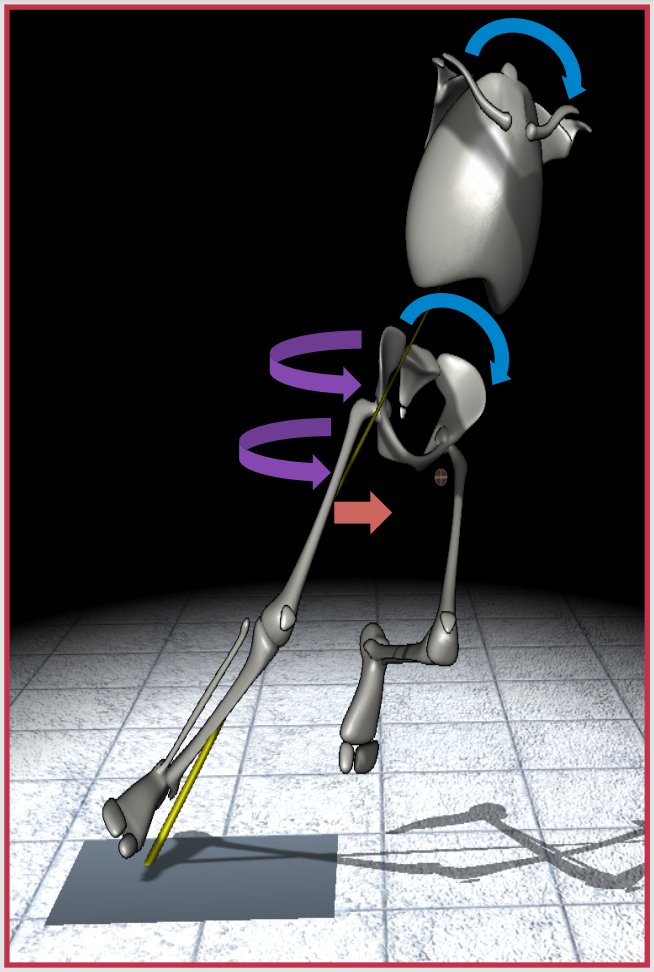


Pre Rehab



Post Rehab

Frontal Plane Kinematics Post Rehab

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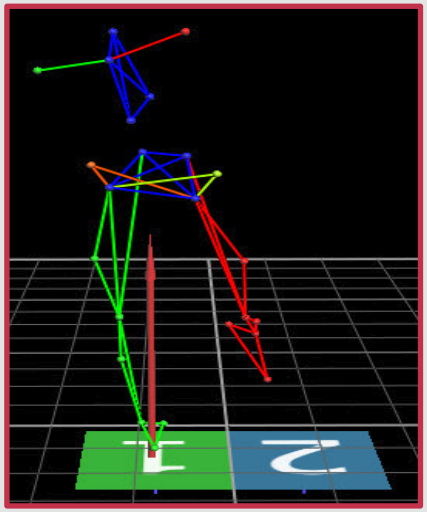
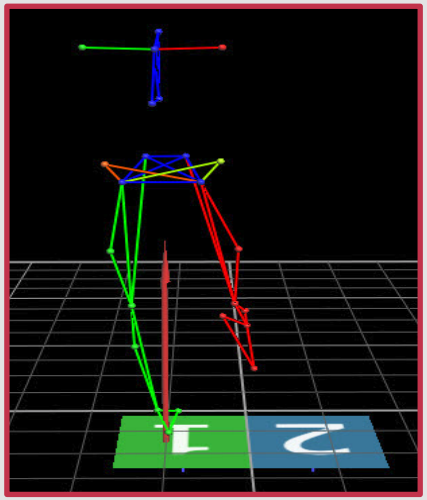


Pre- Rehab



Post- Rehab

	Pre-rehab (Mean± SD)	Post-rehab (Mean± SD)	Significance (p-value)
Frontal plane ROM (°)*	58.1 ± 20.7	53.1 ± 15.6	0.03

* Composite of thorax, pelvis, hip, knee and ankle

Conclusion

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Poor control of the hip and pelvis, and an abnormal distribution of forces in the region, are associated with AGP (Almeida 2013, Cowan 2004, Holmich 1999)

3D analysis assists diagnosis and rehabilitation

Testing battery selected to ensure:

Efficient return to chosen sport

Enhance performance

Reduce the risk of re-injury

Acknowledgements

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Dr Éanna Falvey, Dr Andy Franklyn-Miller, Enda King,
Dr Kieran Moran, Dr Chris Richter, Dr Siobhán Strike, Shane Gore

@benny_marshall @SSCSantry

Isokinetic Strength Testing

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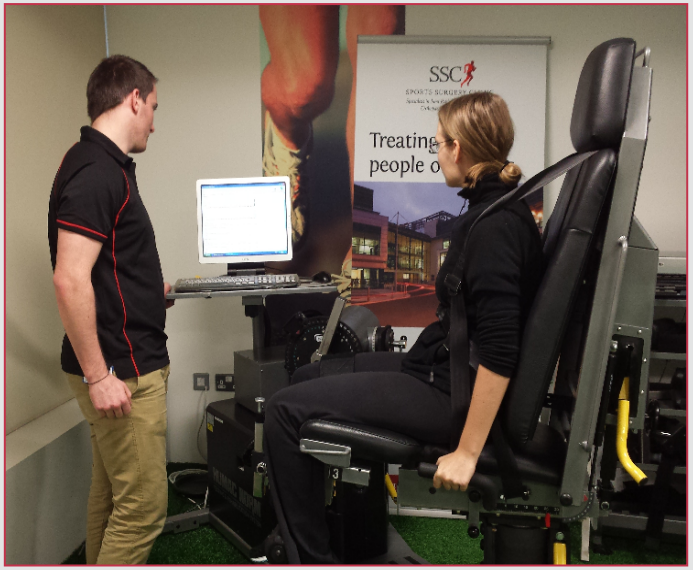

Isokinetic Testing

Athletes have demonstrated muscle strength deficits up to 2 yrs post surgery which is a risk factor for further injury (Aune, et al 2000; Bowerman et al. 2006)

Oberlander (2013) – ACLR patients compensated for knee strength deficiencies by using a more flexed trunk on landing

Systematic Review – BJSM 2015

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Key findings:

No clear standardised strength evaluation protocol following ACLR

No consensus on an appropriate RTS strength criteria following ACLR

Proposed protocol :
5 reps of concentric knee extension and flexion at 60º/s.

Marshall, Franklyn-Miller, Moran, Strike, King & Falvey. JSCR, 2014

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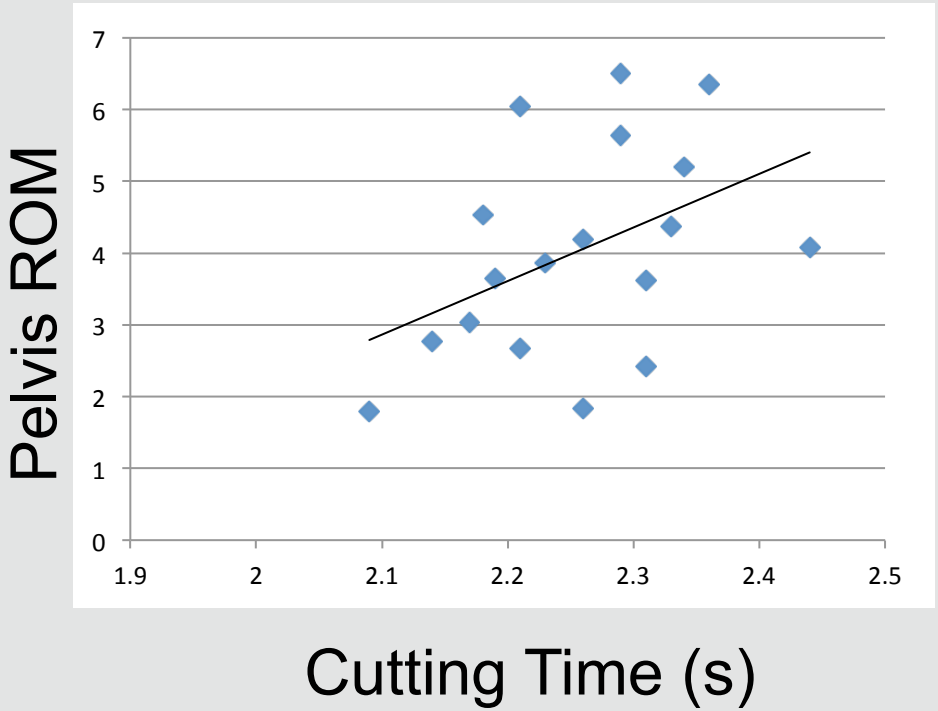
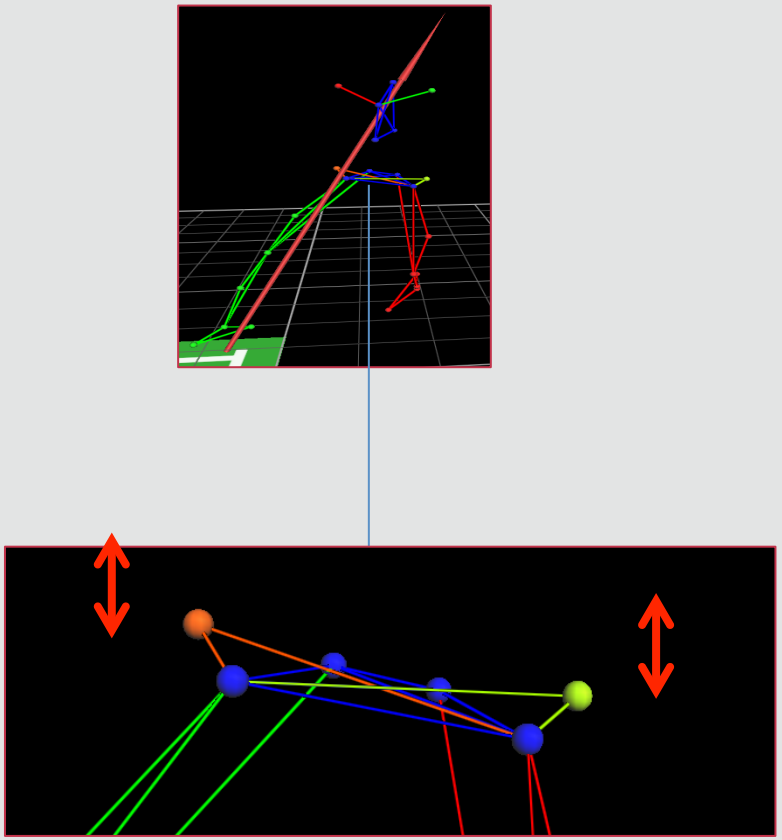
Pelvis frontal plane ROM (Ecc phase)





ACLR Rehabilitation

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Training Blocks 7-9

Strength Testing	3RM (WK 28)	Power Tests (WK 32)	Power Tests (WK 36)
Strength Themes	Strength Themes		
Range of Motion			
Neuromuscular Control	L	L	L
Hypertrophy			
Strength	M	M	M
Power	M Reactive + Speed Strength Loaded	H Reactive, Speed Strength Loaded & Transfer	H Reactive, Speed Strength Loaded, Transfer & Sport Specific

Sample training exercises:
Step up, nordics, jump squat, RDL, broad jumps, drop jumps

Single Leg Squat

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The single leg squat (SLS) is a common test used to assess neuromuscular control (Chmielewski et al. 2007)

Effect of Fatigue

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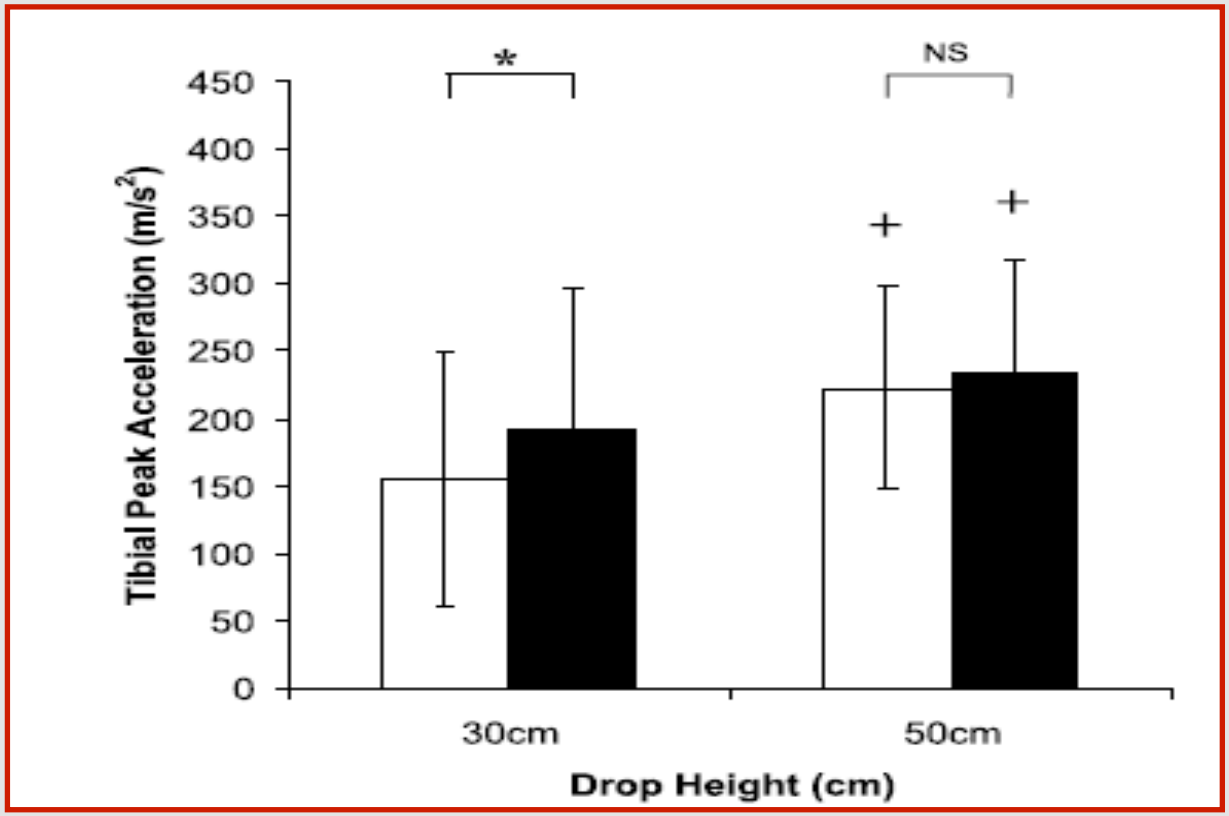
Med Sci Sports Exerc. 2006 Oct;38(10):1836-42.
Effect of fatigue on tibial impact accelerations and knee kinematics in drop jumps.
Moran KA[1], **Marshall BM.**



Marshall, Franklyn-Miller, Moran, Strike, King & Falvey. JSCR, 2014

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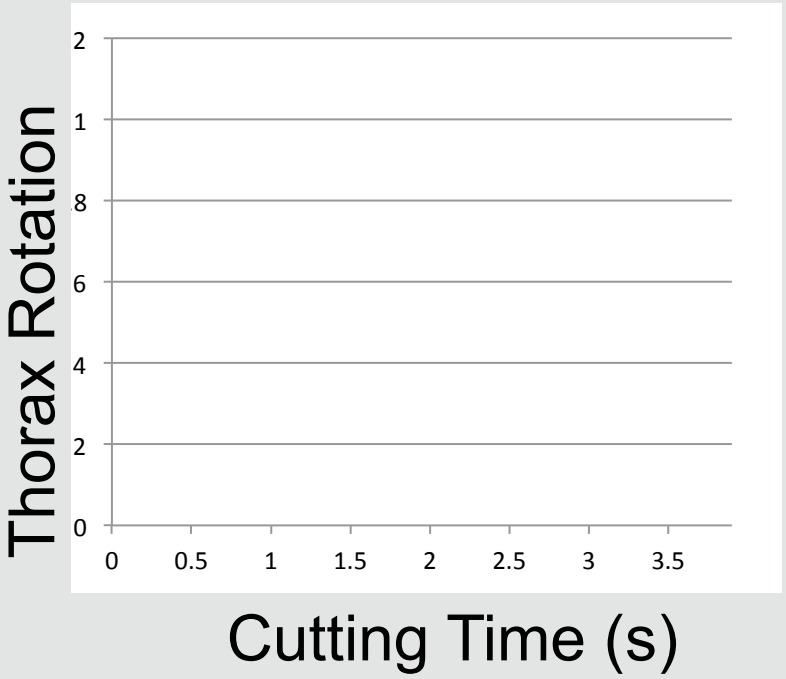
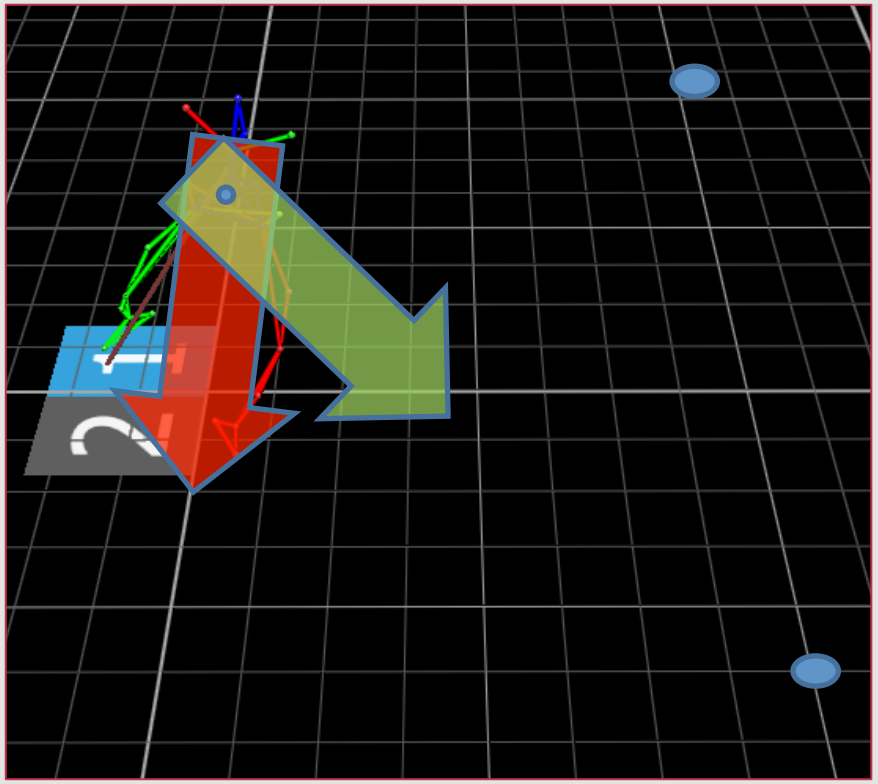
Peak thorax rotation





Rehabilitation – Linear Running

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Rehabilitation

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Marshall et al. 2015 JSR

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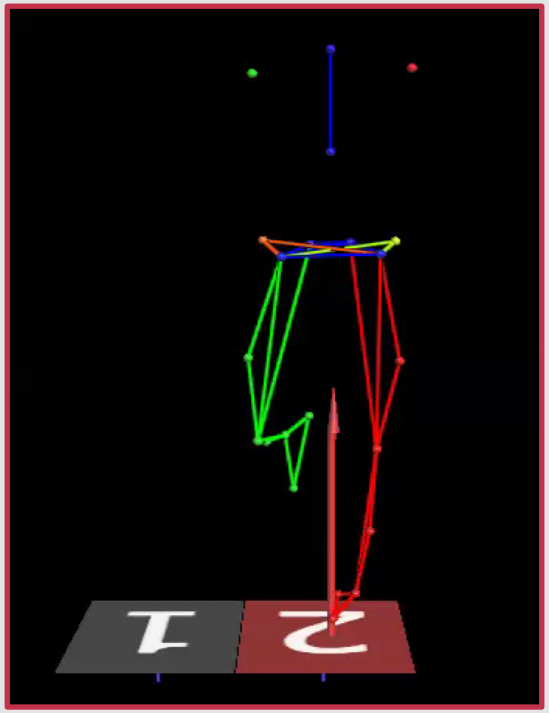
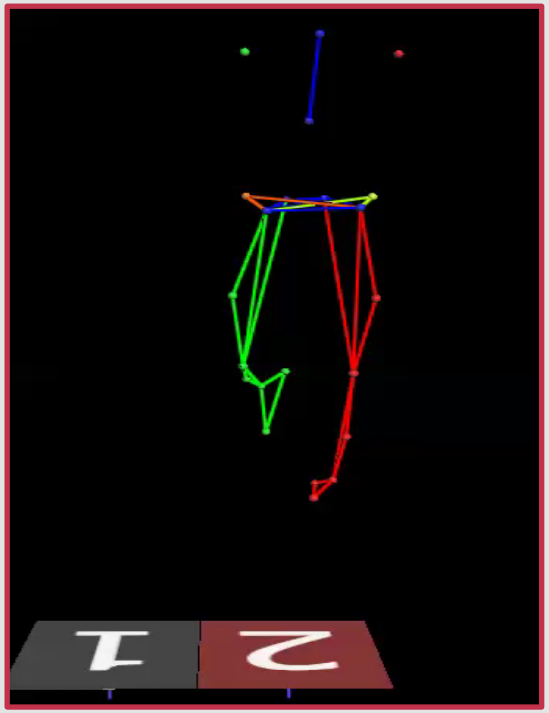
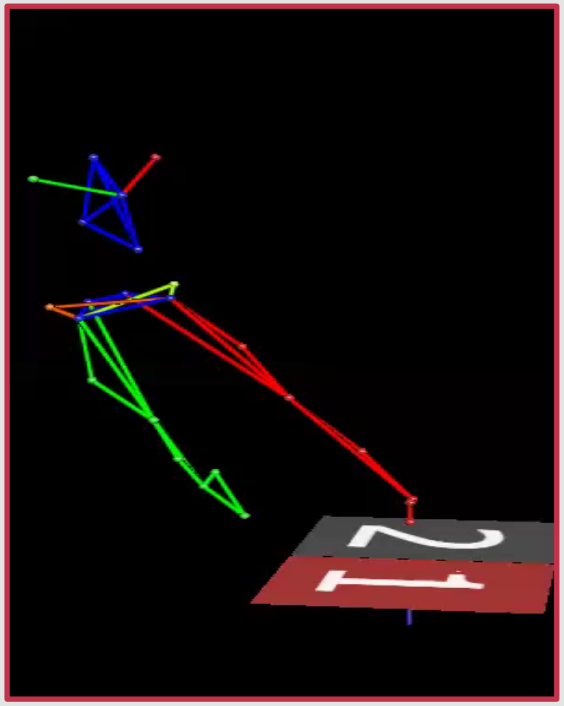


SLS



Landing



Cutting

Can a SLS provide an insight into movement control and loading in more dynamic sporting tasks?

Marshall et al. 2015 JSR

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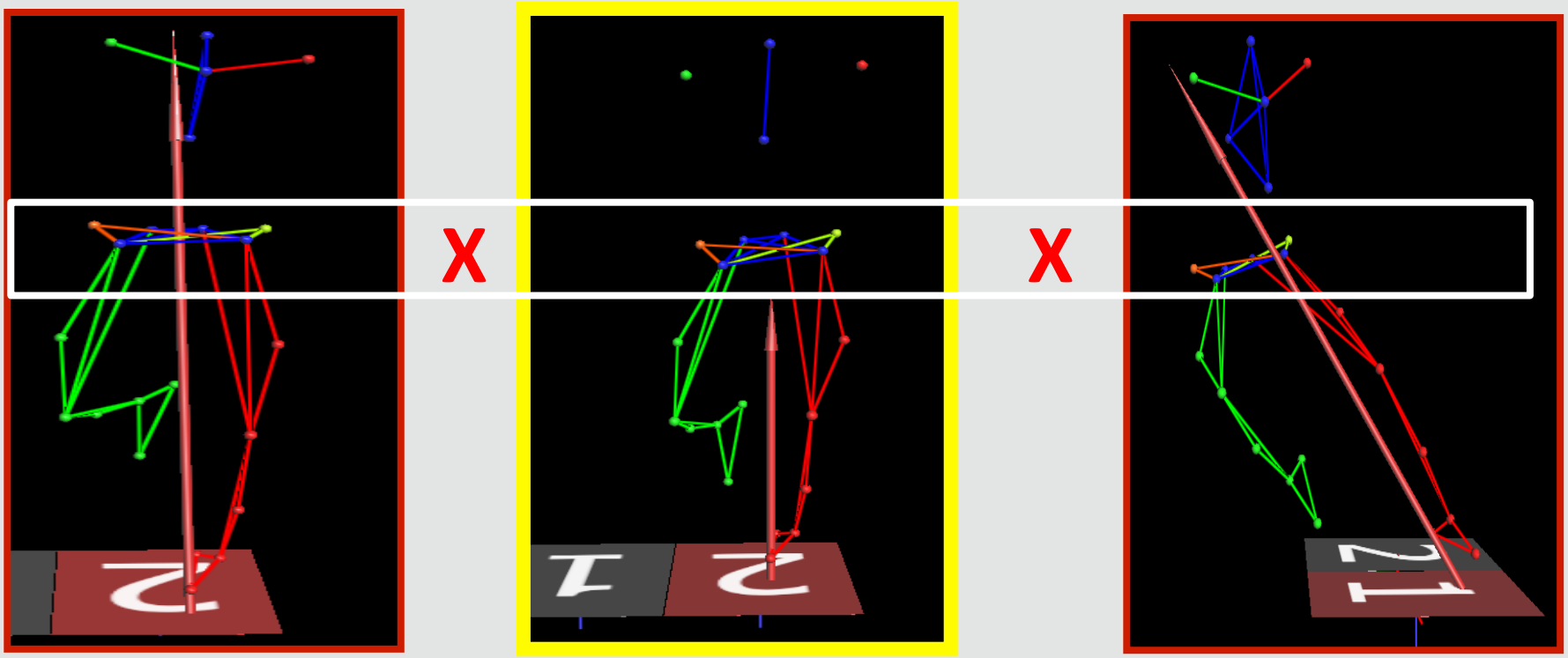

Land SLS Cut

No significant correlations between the SLS and Land or Cut for:
pelvis or hip angles or moments of force

Post Rehab Changes

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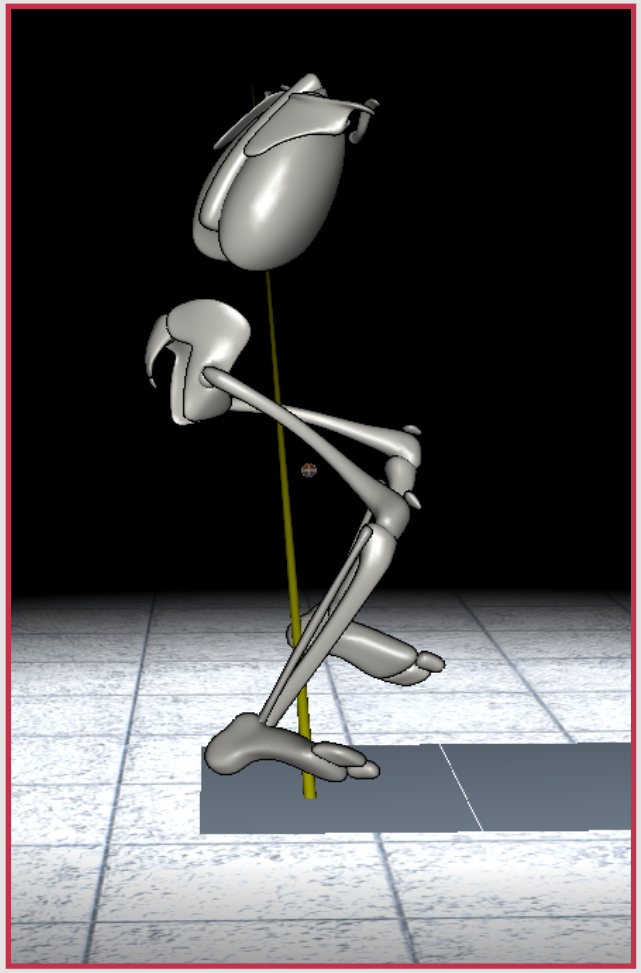
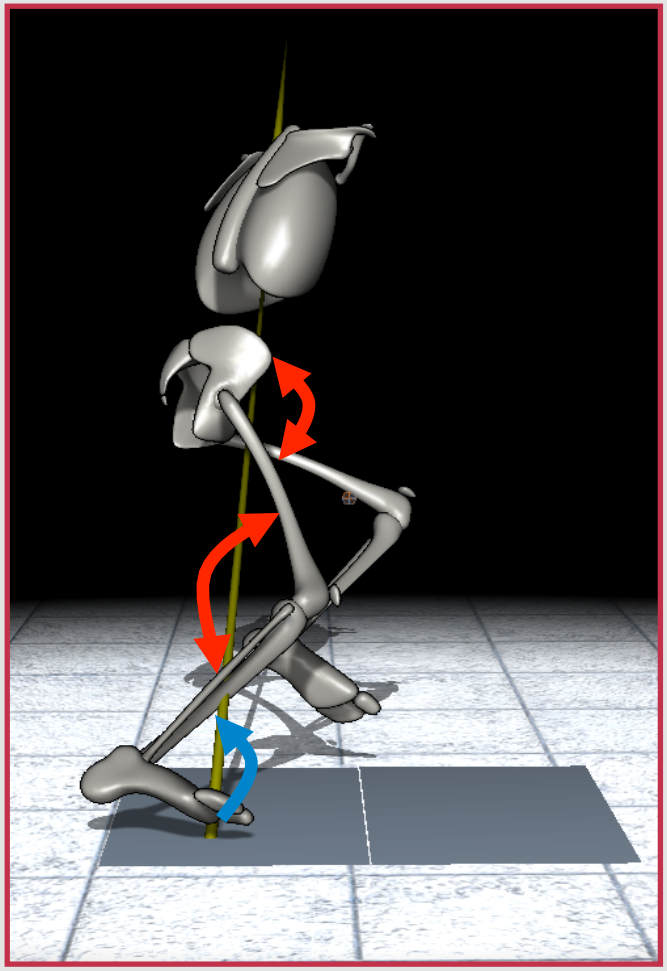


Pre Rehab



Post Rehab