Lecture 1: Introduction to Advanced Biomechanics

Landing Biomechanics - ACL Injuries

Anterior/posterior part of cruciate ligaments refers to the muscle attachment site on the tibia = anterior attaches to anterior side of tibia crossing backwards to the intercondular notch of the femur.

Approx. 70% of ACL injuries occur during non-contact situations e.g. landing, cutting, deceleration, changing direction, (Griffin et al, 2000) 6-8 times greater incidence in females than males in the equivalent amount/duration of sport.

Risk factors in Females:

Anatomical
Smaller cross sectional area of joint
Narrower intercondural notch (in femur) = limited space for ACL to move around
Greater Q angle = angle at which the femur meets the tibia, an approximation of the angle that the quads pull on the tibia, determined between the ASIS to the centre of patella to the tibia tuberosity. Women have a wider pelvis, bigger hips = greater Q angle. Greater Q angle = quads pull at a greater angle = increased force and twisting on the knee. Smaller Q angle = pulls in a straighter line

Physiological
Hormonal differences - oestrogen & progesterone receptor sites found in female ACL cells (1996), suggests hormones may play a role in ACL structure. Research suggests at different times in a women’s menstrual cycle ACL strength and the amount of pressure it can withstand may vary.

Greater quadriceps: hamstring ratio - females tend to have stronger quads relative to hamstrings. Greater contraction of the quads compared to the hamstrings can cause anterior displacement of the tibia (abnormal movement of the tibiofemoral joint = increased loading on the knee. The hamstrings work to prevent anterior dislocation of the tibia relative to the femur

Biomechanical
Greater max knee valgus angle & ROM of knee valgus, knees come together = ↑ load on ACL
Trunk extension - more upright position. Trunk flexion can reduce the load on ACL and stretches the hamstrings and gluteus maximus = increases the muscles ability to exert force = increased force production of GM and H = increased hip extension moment, reduced knee extension moment and reduced knee valgus moment. Also trunk flexion causes COM to move forward slightly = COM closer to the knee and further from the hip = increased moment of the trunk about the hip but reduced moment of the trunk about the knee (Moment = force x perpendicular distance)

If trunk tilts sideways, GRF would have to come out to the side which will increase loading on the knee
Knee extension - land with straighter legs = exert greater forward force through patella tendon. If knees are flexed, the patella shifts backwards = more vertical patella tendon = smaller force through patella tendon = more vertical force than forward force = less strain on ACL. Suggests female’s quads produce greater force relative to the force of the hamstrings

*Non-contact ACL injury reported to occur frequently when the knee is close to full extension and exhibit a valgus movement
Rupture is caused when the load applied exceeds strength of the ACL

Environmental
Little evidence on how this may vary as injuries in females

Different footwear might affect landing/ different surf conditions
Decision making – greater knee valgus moment during unanticipated single leg landings than anticipated

<table>
<thead>
<tr>
<th>Kinetics</th>
<th>Kinematics</th>
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<tbody>
<tr>
<td>(description of forces related to motion - distance, displacement, speed, velocity, acceleration)</td>
<td>(description of motion without reference to forces - work, power, impulse, momentum, torque)</td>
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<tr>
<td>Females tend to exhibit:</td>
<td>Females tend to land:</td>
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<tr>
<td>- greater knee valgus moment</td>
<td>- with greater knee extension/ less knee flexion</td>
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<tr>
<td>- greater knee extension moment</td>
<td>- greater hip extension</td>
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<tr>
<td>- reduce hip extension moment</td>
<td>- greater knee valgus movement</td>
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<td>Pollard et al, 2010 reported female subjects who exhibited low peak knee and hip flexion angle displayed significantly greater peak knee valgus angles</td>
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Hughes, 2014

What muscle/muscle group is important in the prevention of ACL injury?

Hamstrings – reduced mechanical advantage of BF, SM, ST and Gracilis in females = increased risk of overloading them resulting in abnormal movement in the frontal plane (BF attaches on lateral side of knee; ST, SM, Sartorius and Gracilis attach on medial side) = can control valgus movement, straighten knee in frontal plane. The hamstrings work to prevent anterior dislocation of the tibia relative to the femur

Gastrocnemius - crosses the knee joint, runs straight through the centre of the knee = keeps knee straight in the sagittal plane but not in the frontal plane.

Glutes - stronger glutes (mainly medius and maximus) can prevent valgus movement (knee moving inwards)
Lecture 2: Advanced Motion Analysis

3D motion analysis
Used to record position and orientation of the body in 3-dimensional space
Usually integrated with 1 or 2 force plates enabling recording of kinetic variables, ideally one force plate for each leg
Sometimes integrated with EMG to show muscle activity (the term integrated means time synchronised)

Benefits
Highly accurate and all movement captured as the cameras are permanently set in position
It is becoming easier to use with advancing technology - quicker, more accurate, less technical problems with modern systems

Drawbacks
Expensive and complex
Fixed indoors - controlled environment but less ecologically valid, too much light to be used outside - system finds it difficult to locate markers

Applications
Mainly used for research purposes:
- Performance enhancement - running, golf, cricket, baseball, rowing - mainly sports to improve technique
- Injury prevention - both mechanisms of injury and risk factors
Also used for diagnostics:
- Gait labs in hospitals
- To inform surgical procedures e.g. if a child is not walking properly, it can be used to identify which muscles are causing the problem (e.g. may be constantly contracting) and can then perform surgery (e.g. to turn the muscle activity off)

Research Strategy
Applied focus:
- Further knowledge of human movement for performance enhancement/injury prevention
- To identify variables of interest and then measure those (e.g. come up with a rationale, identify biomechanical risk factors relating to the problem - then measure the risk factors)

Technology led:
- Large amounts of data can be collected (joint angles, forces, moments, powers in all planes of motion) and relationships between them can be determined
- Sometimes easier to measure everything so as not to waste data and then makes sense of it e.g. to find out which variables relate to the problem
- However, this can lead to data dredging = lack of a rationale, hard to relate back to rationale due to overwhelming data

Systems
Hardware/Active marker systems:
Linked through wires
Used to record movement in small volume that doesn’t require multiple rotations/twists
Pros - no markers are lost, all markers will be tracked
Cons - may hinder movement due to lots of wires
Passive marker systems:
Markers are not connected
Highly reflective - relies on reflection of infra-red light by reflective spherical markers
Requires more cameras - between 1 and 4 markers (synchronised)
No. of cameras required = 1 + (no. of markers divided by the capture volume)
Passive marker systems are more common

How the system works
Tracks 3D coordinates of markers placed on the body
A series of LED lights surround the camera emitting infra-red light
Markers are covered in retro-reflective material
Light is reflected back to the camera exactly where it came from so the marker can be located
Each marker must be seen by at least 2 cameras in order to show distance and position (all planes for 3D view)

Data Collection Procedures
1. Hardware Set up
Camera lens settings:
F-stop:
The amount of light allowed through to the lens, should be set to the optimum light for reflection of markers
Larger F-stop (f-16 f-2) allows less light through
Allowing too much light through the lens means it will pick up every reflection e.g. from wall/background - less focus on markers
Focal length:
Usually set to infinity so will focus on anything that is in view for maximum depth of field

Location and dimensions of capture volume – a trade-off between size and precision (resolution) - should set up for smallest capture volume possible but ensure it captures all of the movement - more accurate when the object is as big as possible in the field of view so it picks up as many pixels as possible.
Place cameras around chosen area - evenly spaced using tripods or wall mountings - pros and cons of each, e.g. tripods limit space in the room for movement, may be knocked and have to redo calibration. However the fixed position of wall mounts can be limit optimal positioning for all movements.
Ensure dead-space is minimised (space where no movement is happening).
Select appropriate sampling rate (higher sampling rate = reduced resolution (usually 120-240Hz)).
Synchronise other hardware e.g. force plate

Why might the study of isolated joints not provide an effective analysis of more complex movements?
In a kinetic chain, the motion of one segment influences the motion of an adjacent segment, meaning the study of isolated joints does not effectively capture the complexity of the coordinated motion of components of the body.

When is movement variability considered a good thing and when is it considered a bad thing?
Movement variability is important in skills where the adaptability of complex motor patterns is necessary within dynamic performance environments. However, there is a reduced requirement for adaptability in skills where tight task constraints are imposed or in closed kinetic chain activities (e.g., cycling) — any variability in the system may be indicative of an inconsistent performance.

Do you believe that an optimal pattern of movement exists that all individuals should aim to reproduce?
I agree to a degree that an optimal pattern of movement exists as a way to reach optimal performance. However, when considering Olympic athletes, many have different movement patterns but all compete and perform to a same level.

What are the aims of the study?
To investigate how lower extremity intra-limb coordination variability varies in cyclists of differing experience. To investigate the intra-limb coordinative adaptations that occur in response to a change in cadence and work rate.

What work rates and cadences were tested?
Three cadences: 60, 90, and 120 revs per minute (rpm)
Three work rates: 120, 210, 300W

How long was data recorded for and how much of this data was subsequently analysed?
Data was recorded for a minimum of 20 secs (30 secs for trials at cadences of 60 revs per minute) to ensure a minimum of 10 revolutions were recorded. 10 consecutive revolutions within ±2 rpm of the required cadence were selected for analysis.

What analysis method was used to assess coordination and why?
Coordination was analysed using continuous relative phase analysis (CRP) — due to the cyclical nature of the movement and the inclusion of temporal data, which has been deemed to be more sensitive to changes in coordination.

What joint couplings were assessed?
CRP was assessed over 2 intra-limb couplings of interest:
1. Knee flexion/extension - Ankle plantarflexion/dorsiflexion (KA)
2. Hip flexion/extension - Knee flexion/extension (HK)
Propulsive phase - pushing down on the pedal; Recovery - coming back up.

How was coordination variability calculated?
Calculated as the standard deviation at each time point across the 10 revolutions in each condition for each participant.

Key results
For both KA and HK couplings, trained participants displayed significantly lower CRP variability than untrained participants.
More in-phase motion during the propulsive phase than the recovery phase for trained athletes.
For KA coupling, higher CRP displayed during recovery phase than propulsive = less consistent, potentially less stable movement pattern.
More KA and HK in-phase motion at higher cadences - more in-phase motion as you go faster.
No significant differences found for the HK coupling.
Less variability at higher cadences - suggesting the faster you go you develop a more stable and efficient movement pattern.
No significant differences in CRP or CRP variability between work rate conditions for KA or HK.

Based on the results of this study, when might coordination patterns be most economical?
The more stable a movement pattern, the lower the metabolic cost required to maintain the pattern at a given level of stability.
Coordination patterns at higher cadences for a fixed work rate are most economical.
This is attributed to lower motor unit recruitment.

What are the conclusions of the study?
Coordination variability is detrimental to cycling performance.
Changes in cadence influence changes in coordination and its associated variability.

What are the main limitations of the study?
Work rates investigated in this study were limited and greater ranges may be required to identify any differences that exist.
Participants used a cycle ergometer — limits ecological validity as it does not replicate the variable environmental condition of road cycling.
Limited to intra-limb coordination — future work needed to investigate inter-limb coordination.

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Transition to Barefoot Running
Changing running technique/training/footwear will likely load muscles, joints and tendons beyond their usual functional range. Gradually loading structures beyond the range they are used to will allow them to adapt, however going from years of shoes straight into minimal shoes or barefoot will likely cause injury.

Transition should therefore be done gradually:
- e.g. reduce rigid shoe and heel cushioning, wear minimalist shoes, walking barefoot and increase speed, practice FFS in shoes with a shorter stride length, increase time/distance running BF, start on softer surfaces. Consult with a footwear specialist, coach, or a health professional first.
- People may underestimate time required to transition successfully to barefoot running.

Removing rigid shoe and cushioning removes initial shock absorption by shoe and absorption of impact forces - entirely down to musculoskeletal structures.
- Initial heel strike impact force is very high and is transferred from heel bones through ankle towards knee, hip and lower back.
- Sensorimotor system will realise damaging effects of those high impact forces.
- Individuals adapt towards midfoot or forefoot landing – automatic response, results in disappearance of impact force associated with heel landing.
- This adaptation usually happens quickly although varies between individuals.

Barefoot footstrike
- Forefoot strike = flatter foot, greater plantarflexion and knee flexion
- Distribute impact force over greater area than heel alone – force spread across the base of the foot to reduce pressure on parts of the foot (mainly heel), cushioning impact.

Figure 1 – GRFs,
- a) Barefoot RFS – greater initial force – steeper initial slope
- b) Shod RFS – less steep due to shoe cushioning
- c) Barefoot FFS – less steep initial force, but still reaches the same peak force (~2.4 times body weight)

Figure 2
- GRF vector (τGRF) rotates ankle in dorsiflexion direction in BF FFS – contract plantarflexors to resist this.
- Greater PF torque (τankle) required when barefoot – increasing the loading of calf muscle and Achilles tendon.

Knees flex at landing – absorption of impact energy now done by muscle-tendon structures.
- Quadriceps are used to eccentric loading – occurred during heel landing.
- Calf muscles are not used to eccentric loading – can cause extensive micro damage leading to muscle soreness.
- Likely to recover in around three days.
- If runners do not allow adequate recovery could lead to accumulative damage issues.
- Achilles tendon may not be able to withstand high stresses – could result in ruptures.
- Planta fascia on base of foot may experience micro damage – plantar fasciitis.

Changing to mid-foot or forefoot landing will change how external forces act on bones and joints.
- Bones slowly adapt to external loads in how they are built – internal bone scaffold rebuilds according to location, direction and magnitude of repetitive forces.
- Adaptations occur mainly during childhood – ability to reconstruct bone reduces with age.
- Sudden change from heel striking to forefoot landing may result in severe stresses on bones – possible development of stress fractures.

Stride Length and Stride Rate
A main change in barefoot running is altered stride length and stride rate.
- Heel strike = straighter leg, forces tend to travel up the leg and acts along the length of the bone. Can cause stress fractures of tibia and lower back pain.
- FFS = have to flex knee more and plantarflex more = reduced stride length. To compensate for this you increase stride rate to get to the same velocity.

Reduced mass of feet from taking off shoes = reduced moment of inertia of leg.
- Moment of inertia (I) = m.k^2 = mass x radius of gyration.

Performance Enhancement
- Findings still unclear.
- Barefoot running associated with improved running economy – reduction in mass, mechanical alterations of the lower limbs (elastic compliance from the foot, greater elastic energy storage and release).
- Lighter shoes may be more economical than barefoot.

Injury Prevention (Tam et al., 2014; Liebermann, 2012)
- Faster repositioning of legs during swing phase?
  1. Inertial and deformation advantages? – Prosthetic limb slighter & at end of leg = reduced moment of inertia
  2. Unique motor control processes?

For amputee sprinters, primary function of prosthetic is to match gait of remaining leg
- Limited opportunity to enhance performance of prosthetic as would unbalance the runner (James, 2012)
Small number of elite bilateral amputees where such constraints are not applicable
- Single-blade runners have an advantage over bilateral amputees when covering shorter distances as they have to compensate for an imbalance between the lighter more energy efficient prosthetic and the heavier biological limb.
- As distance increases double amputees have the advantage

Running Time Analysis
Difficult to argue an advantage for single amputee athletes over able-bodied athlete (‘normal’ leg will always be the limiting factor) – same cannot be said for double amputee athletes
Analysing 100m split times of a 400m race reveals that able-bodied athletes follow similar pattern:
- Accelerating in first 100m, maintaining speed for second 100m and losing speed over remainder of the race (Fig 1)
Differentials of time taken to run first and second 200m of a 400m race illustrate able-bodied athletes are slower in second half of the race – build-up of lactic acid in athletes muscles – metabolic cost
Fig 2. Shows time difference between first 200m and second 200m – outlier is OP
In contrast, OP is able to run faster second half of the race by a large margin – slower off the blocks as cannot produce the same force (no muscles), build up speed as prosthetic limbs store and release energy at no metabolic cost to him

Energy at the start of a race
Double limb amputee = passive, does not generate energy
Able bodied = active, generates energy at a metabolic cost

Energy at full speed
Double limb amputee = passive, has very a no metabolic cost
Able bodied = active, generates energy at a metabolic cost
Doesn’t necessarily mean double limb amputee has an advantage – disadvantaged at the start

Running Inertial Properties
Mass of leg segment is small
Since moment of inertia (I) = m.k^2 – blades have low resistance to angular motion
Able to generate fast angular velocity of legs

Prosthetic blades may allow for more efficient running placing less demand on the athlete
Over 400 m, Pistorius uses 30% less oxygen than able-bodied competitors (James, 2012)
Detailed analysis of Pistorius revealed:
  1. Lower mechanical work during stance phase
  2. Lower joint moments and power at hip and knee
  3. Higher joint power at (prosthetic) ankle
  4. Reduced swing time and aerial time (key point)
  5. Ability to achieve maximum speed at lower metabolic costs (key point)
  6. Decreased average & peak vertical force compared against able-bodied athletes running at same speed (Brüggeman et al. 2008; Weyland et al. 2009)
OP claimed Oliveira’s longer prostheses allowed greater stride length - OP strides were actually ~8% longer – it was a faster stride rate that gave Oliveira an advantage
Pistorius’ competed in IPC and IAAF events - based on IPC regulations Pistorius allowed to compete at height of 1.93m but in IAAF and Olympic events was restricted to 1.84m
Oliveira only competed in IPC events
  - Required to be less than 1.85m
  - Lengthened his blades from 1.77m to 1.81m which significantly enhanced performance
Pistorius is amputated just above ankle, while Oliveira’s is just below knee
  - 0.15m difference in height without prostheses
No single ratio or formula proclaiming correct leg length - clarification of rules needed
Small changes in mass, stiffness, thickness and curvature of blades affect different aspects of performance