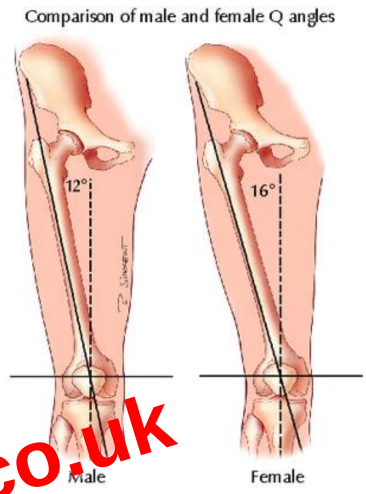
Lecture 1: Introduction to Advanced Biomechanics

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 injures 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 intercondular 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.
Less muscle strength in proportion to bone size than men – weaker ligaments
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 hamstring

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

Environmental
Little evidence on how this may impact ACL injuries in females
Different footwear males vs females wear/ different surfaces they play on
Decision making – greater knee valgus moment during unanticipated single leg landings than anticipated

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

Hughes, G. (2014). A review of recent perspectives on biomechanical risk factors associated with anterior cruciate ligament injury. *Research in Sports Medicine, 22*(2), 193-212.
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)

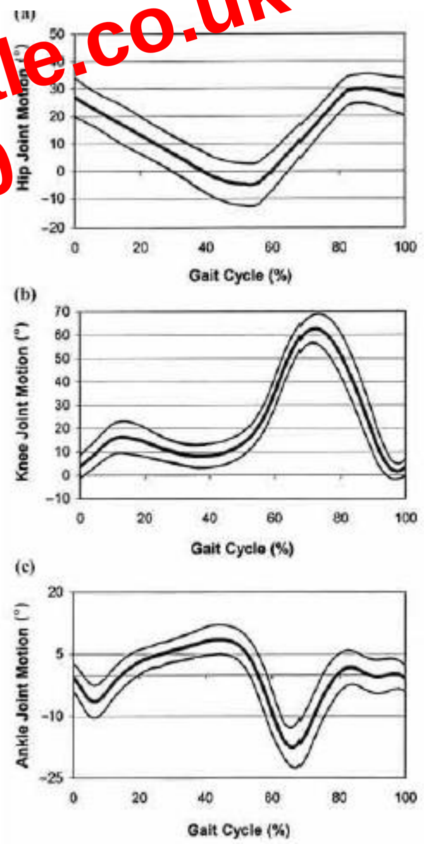
Benefits
Highly accurate and all movement captured as the cameras are permanently set in position
It is becoming easier to use with advancing technology - quicker, more accurate, less technical problems with modern systems

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
Hardwire/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 2 and 12 cameras (synchronised)
No. of cameras required depends on no. of markers and capture volume (bigger capture volume = more cameras needed)
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 positon (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 v 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

Sides, D & Wilson, C. (2012). Intra-limb coordinative adaptations in cycling. *Sports Biomechanics, 11*(1), 1-9.
Sides & Wilson, 2012

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 constrains 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

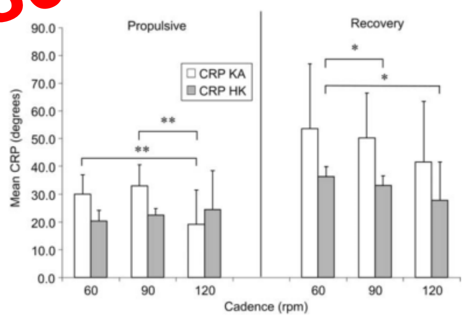
How long was data recorded for and how much of this data was subsequently analysed?
Data was recorded for a minimum of 20secs (30secs for trials at cadences of 60rpm) to ensure a minimum of 10 revolutions were recorded.
10 consecutive revolutions within ±2rpm of the required cadence were selected for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

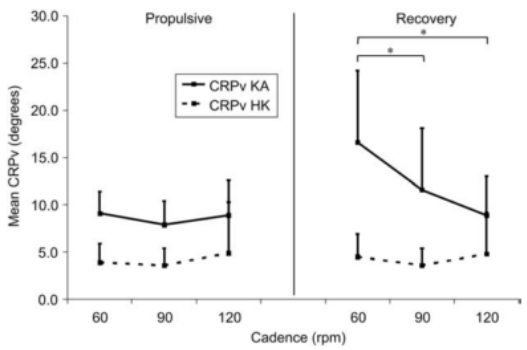
What joint couplings were assessed?
CRP was assessed over 2 intra-limb couplings of interest:
1. Knee flexion/extension - Ankle plantarflexion/dorsiflexion (KA)
2. Hip flexion/extension - Knee flexion/extension (HK)
Propulsive phase - pushing down on the pedal; Recovery - coming back up

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

Key results
For both KA and HK couplings, trained participants displayed significantly lower CRPv (variability) than untrained participants
More in-phase motion was displayed during the propulsive phase than the recovery phase for trained athletes
For KA coupling, higher CRPv 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 CRPv 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

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

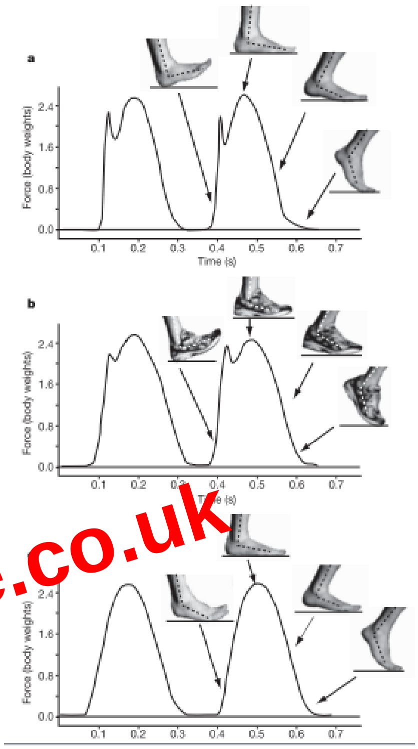


Figure 1 – GRFs,
a) Barefoot RFS – greater initial force – steeper initial slope
b) Shod RFS – less steep due to shoe cushioning
c) Barefoot FFS – less steep initial force, but still reaches the same peak force (~2.4 times body weight)

Figure 2
GRF vector (τ_{GRF}) rotates ankle in dorsiflexion direction in BF FFS – contract plantarflexors to resist this.
Greater PF torque (τ_{ankle}) 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 scaffolding aligned according to location, direction and magnitude of repetitive forces
Adaptations occur mainly during childhood – ability to restructure bone reduces with age
Sudden change from heel striking to forefoot landing may incur adverse 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)
More common – ankle/Achilles tendon/calf muscle injuries, lacerations, splinters, punctures, stress fractures of metatarsals (land on 4th & 5th metatarsal)
Less common – stress fractures of tibia and calcaneus, patellafemoral pain syndrome (PFP), plantar fasciitis, lower back pain

- 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

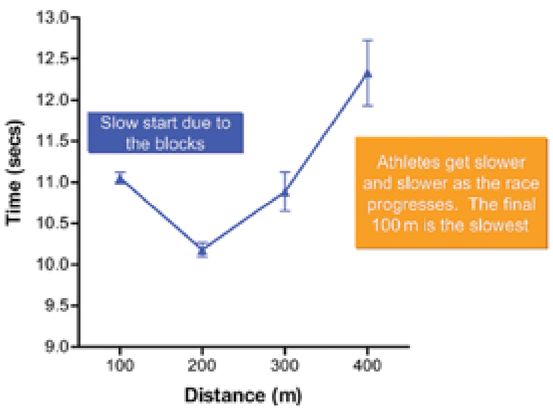
Difficult to argue an advantage for single amputee athletes over able-bodied athlete ('normal' leg will always be the limiting factor) – same cannot be said for double amputee athletes

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 a full speed

Double limb amputee = passive, returns energy a no metabolic cost

Able bodied = active, returns 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