## *BIOMECHANICAL FACTORS IN SPRINT TRAINING*

## *- WHERE SCIENCE MEETS COACHING.*

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**Ireland**

# Acknowledge contributions

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- Staff and Postgraduates of University of Limerick Biomechanics Research Unit
  - Ian Kenny: Computer model analysis
  - Kim Siekerman: video acquisition and preparation for editing
  - Athletes of Limerick International Athletics Squad

## Bridging the science and coaching divide

- The ISBS emphasises the importance of ‘bridging the gap between scientists and practitioners’
- Despite a large body of scientific knowledge on the biomechanics of sprinting, Jones et al, (2009) found a dearth of knowledge amongst expert coaches on the technical constructs of 100m event
- Quality of training ⇒ quality of performance



## Outline of Presentation

- Evolution of Technical Knowledge in sprinting
- Biomechanical models of sprinting
  - Descriptive and observation based models
  - Deterministic model
- Biomechanical factors in sprint training
  - Developing conditioning for sprinting
- A simple Coaching model of sprinting
  - Evidence for the model (validation)
  - Developing sprint technique (via isolation drills)
  - Application of the coaching model (case study)

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# Descriptive and observation-based models of sprint performance

***Evolution of technical knowledge***



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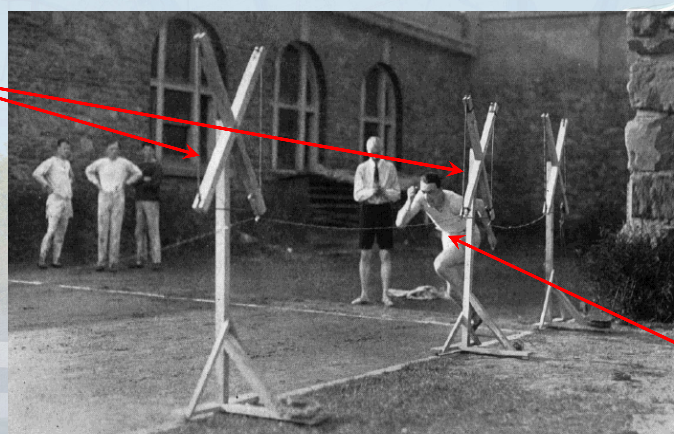
## Early observations of 100m sprint velocity




AV Hill (1927)Testing the acceleration of sprinters. From Hill's *Muscular Movement in Man* (55).

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## Velocity-time data for 100m for various classes of athlete

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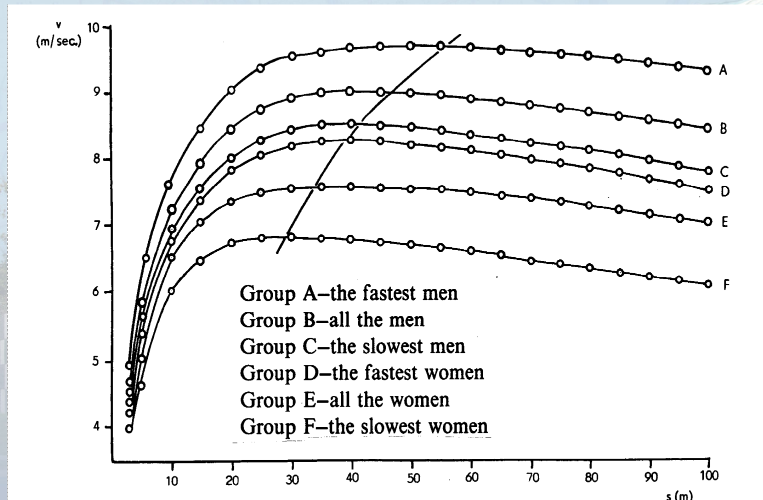


From: Schmolinsky (1983)

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## Stride rate in 100m

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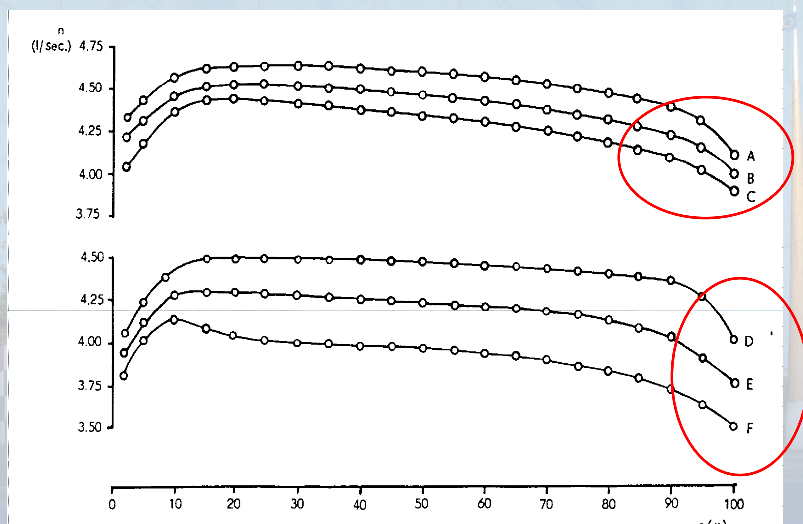


From: Schmolinsky (1983)

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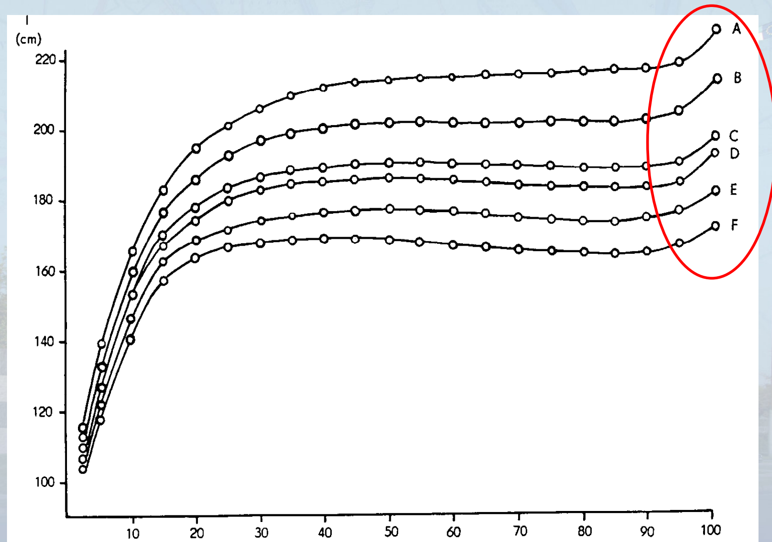
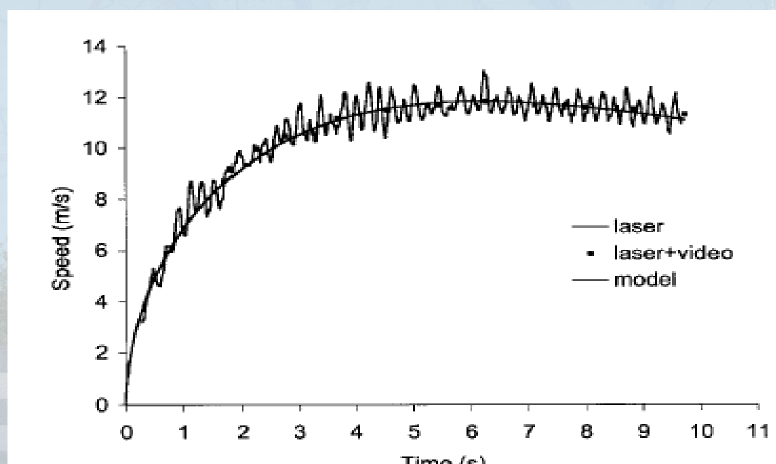
# Stride length in 100m sprint




From: Schmolinsky (1983)



# Laser 100 m speed curves




Measured and predicted speed curves of male 100-m world champion.

# Phases of the 100m

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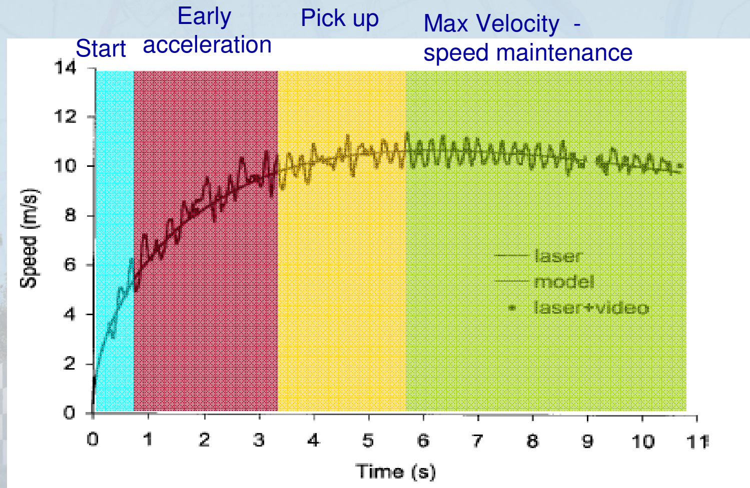


**Measured and predicted speed curves of Female 100-m world champion.**



# How fast could he have run?

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Photo montage showing Bolt's position relative to his competitors for real (left Bolt) and projected (right Bolt) world records.

Answer
< 9.50

# Deterministic model

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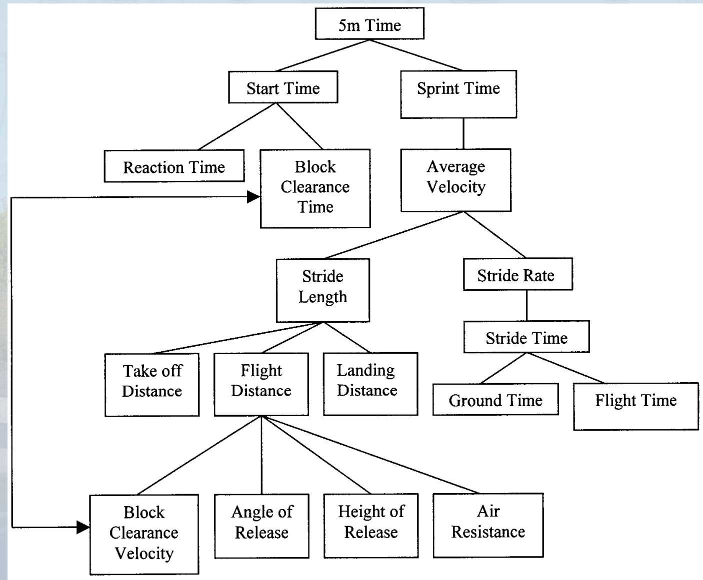




# Deterministic models

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- Strengths
  - Identify factors affecting performance
  - Hierarchical factor list linked via simple mathematical relationships
  - Strong on biomechanics
- Limitations
  - Factors not necessarily related to movement (problem for coaches)
  - No identification of *critical features*

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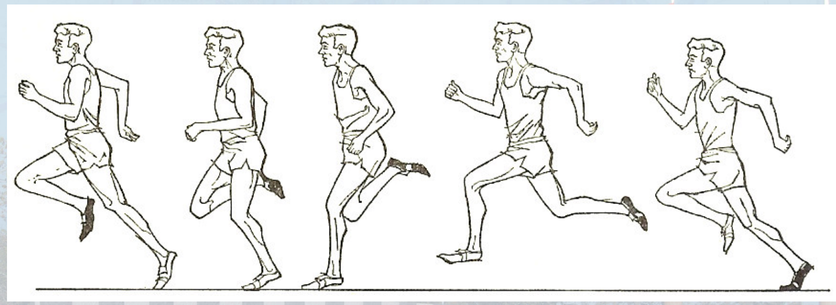
# Descriptive models of sprinting



Picture sequence for sprint running. (From Dyson, 1973)



# Training for improved early acceleration

*Use of resistance training techniques*

## Sledge towing

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Intervention study on sledge training:

- 15 Subjects measured on performance of sprinting via laser and force-sledge jumps to determine:
  - 5 m time, 10 m time, 30 m time in sprints
  - $RFD_{max}$, time to $RFD_{max}$, Starting strength, Flight time in jumps
- Control group (n=7) did normal training
- Intervention group (n=8) did normal + sledge towing training for six weeks
- Subjects tested pre and post intervention

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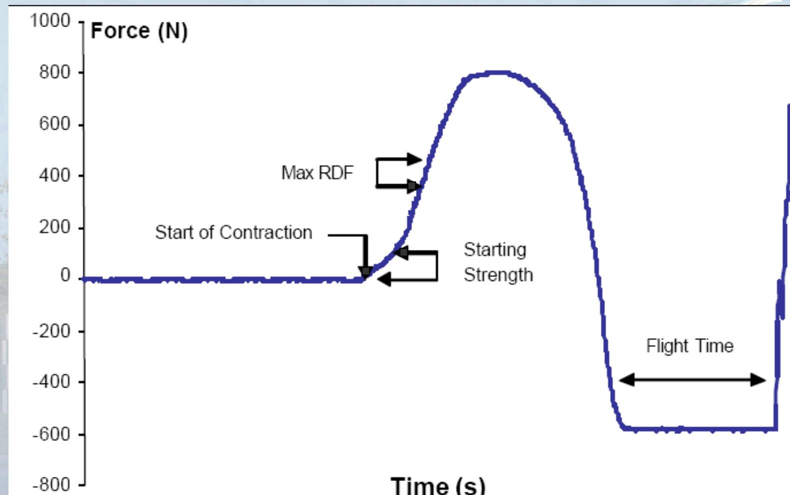
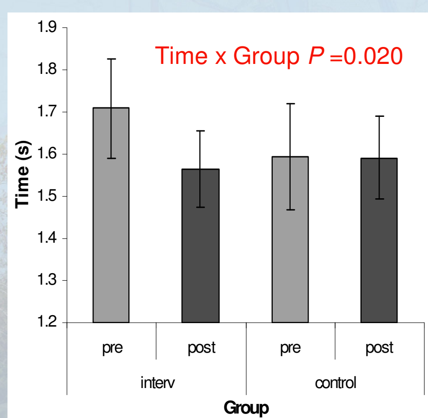
# Starting strength

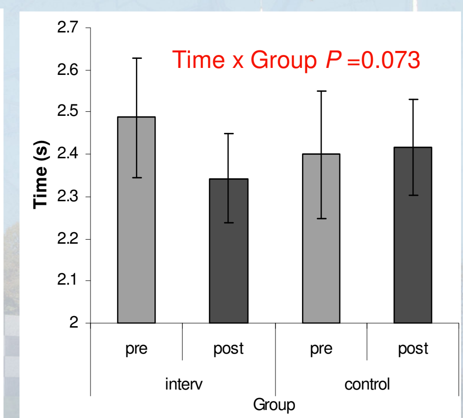




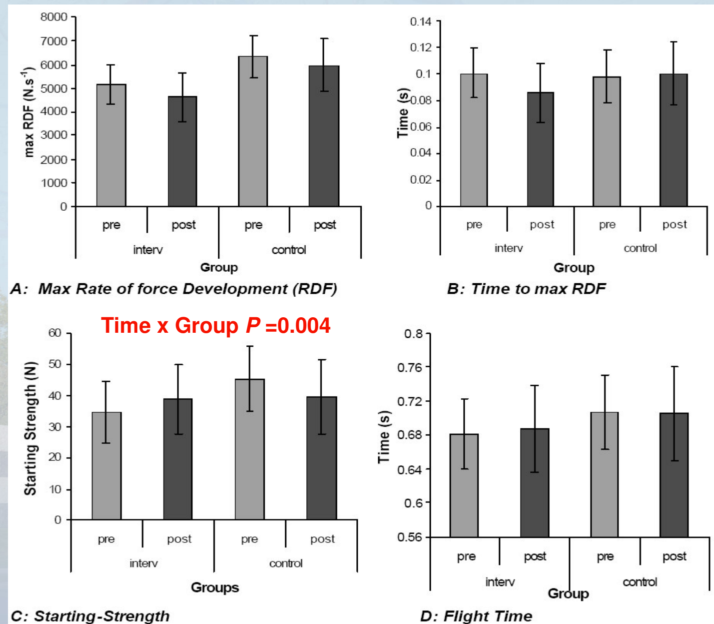

# Effects of sledge training




A: Time to 5 m




B: Time to 10 m




A: Max Rate of force Development (RDF)

B: Time to max RDF

C: Starting-Strength

D: Flight Time

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# Conclusion

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- Resistance training with sledge improves early acceleration in running
  - 5 m time
  - 10 m time (?)
  - Starting strength
- Similar conclusions in other studies
  - Cronin et al (2006); Cronin et al (2008)

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# Improving Maximum Speed in Sprinting

***The role of leg-spring stiffness ($k_{leg}$)***



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## Concepts related to stiffness

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- **Stiffness** and **compliance** refer to the amount deformation of a object in relation to the amount of force acting on the object.
  - Stiff materials require lots of force to bring about small deformations
  - Compliant materials deform easily with the application of relatively small forces

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**Stiffness is not…**

- The subjective feeling of the muscles that can be experienced after a hard workout.
- A lack of flexibility (i.e. range of motion) in the muscles or joints

**Stiffness can involve**

- Active state of muscle: concentric/ eccentric activity
- Passive actions of the tendon and muscle tendon unit or joints



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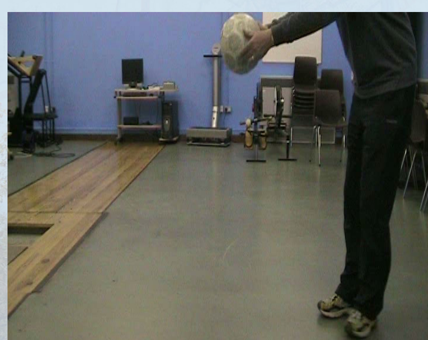
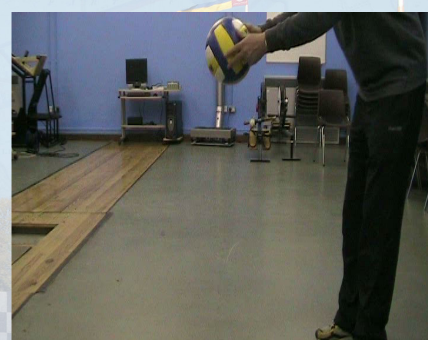
# Soft and medium spring-like bouncing





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# Stiff spring-like action (golf ball)

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# Leg-spring changing progressively from ‘soft’ to stiff

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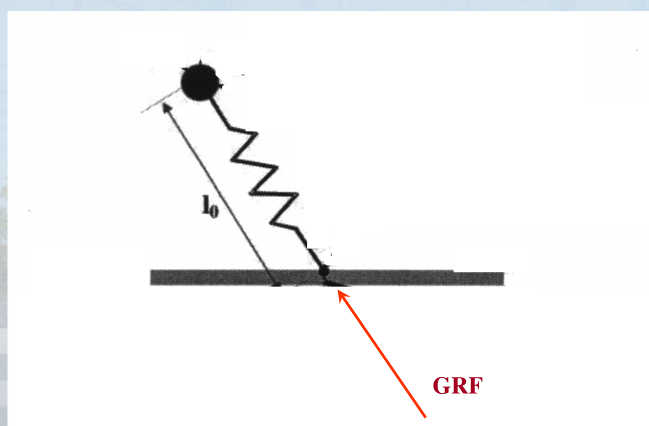
## What characterises the stiffer leg-spring?

- Increased stiffness ⇒ increased cadence or bouncing frequency
- Increased stiffness ⇒ decreased ground contact time
- Increased stiffness ⇒ decreased range of motion in legs
- Increased stiffness ⇒ possible increased rate of force development
- Increased stiffness ⇒ reduced impulse



## Spring-like leg action in sprinting



## Spring-like leg action in sprinting (McMahon & Cheng, 1990)

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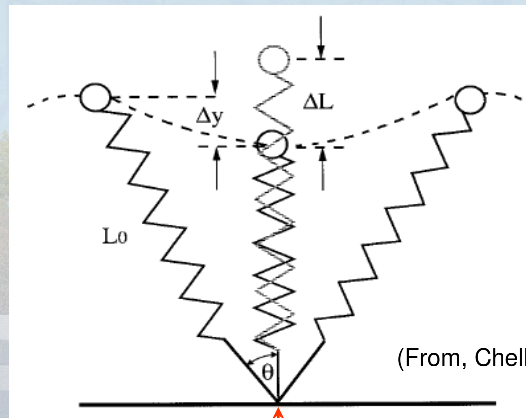


(From, Chelly and Denis, 2001)

$$K_{leg} = \frac{GRF}{\Delta l}$$

GRF

$$K_{vert} = \frac{GRF}{\Delta y}$$



## Leg-spring stiffness

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- In vertical hopping and jumping activity:
  $\Delta l = \Delta y$ ; $\Rightarrow K_{vert} = K_{leg}$
- *"In general the passive joint stiffness, the intrinsic muscle stiffness and stretch reflexes each contribute significantly to the net joint stiffness"* **Arampatzis et al, (2001).**

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# Reactive strength Index (RSI)

- Reactive Strength Index (RSI)

  RSI = height jumped÷ground contact time

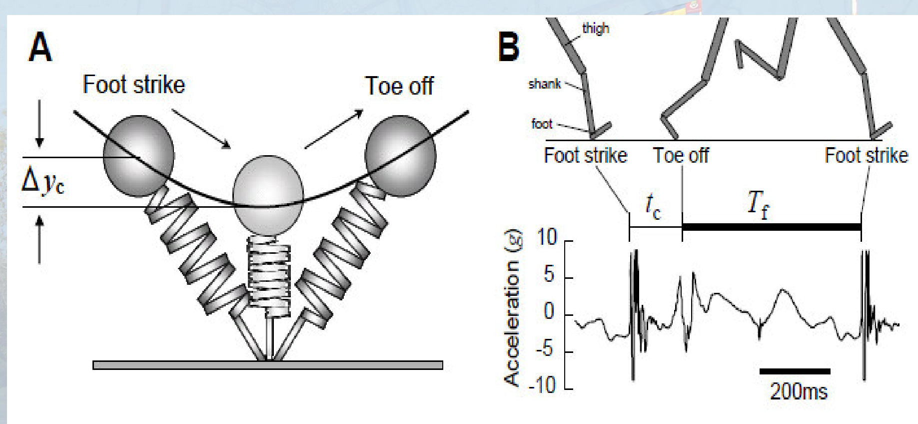
  Height Jumped $\alpha$ flight time

⇒ RSI is determined by flight time ÷ contact time

⇒ RSI and leg-spring stiffness are closely associated.

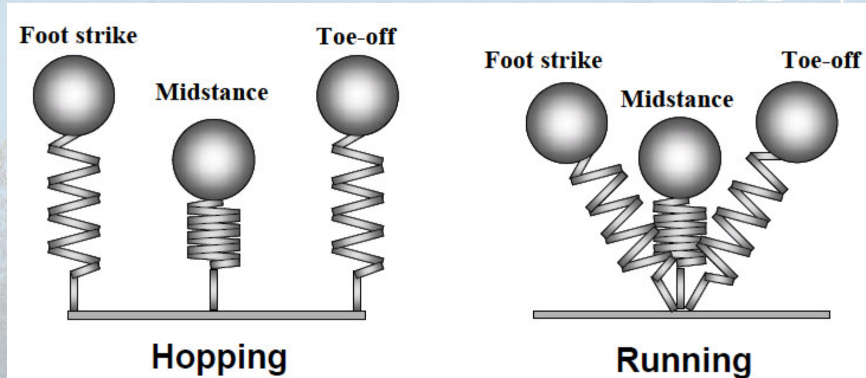


# The spring mass model in running (Hobara, 2008)




From: Hobara, 2008

## Calculating leg-spring stiffness




$$K_{vert} = [m \cdot \pi\, (t_f + t_c)] \,/\, \{ t_c^2\, [(t_f + t_c) / \pi - t_c / 4]\}$$

**Where $K_{vert}$ = vertical leg-spring stiffness;**
**m = mass; $t_f$ = flight time; and $t_c$ = ground contact time**



## Muscle-tendon and leg-spring stiffness

- High Leg-spring stiffness has been linked to sprint performance, **McMahon & Cheng (1990)**
  - Cadence in sprinting is directly proportional to leg-spring stiffness $K_{leg}$
  - Hopping frequency is proportional to $K_{vert}$
- Leg-spring stiffness has a contractile component (limited by contractile strength and contraction velocity) and a structural component (tendon compliance/stiffness)

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## Leg-spring stiffness differentiates sprinter/jumpers from endurance runners

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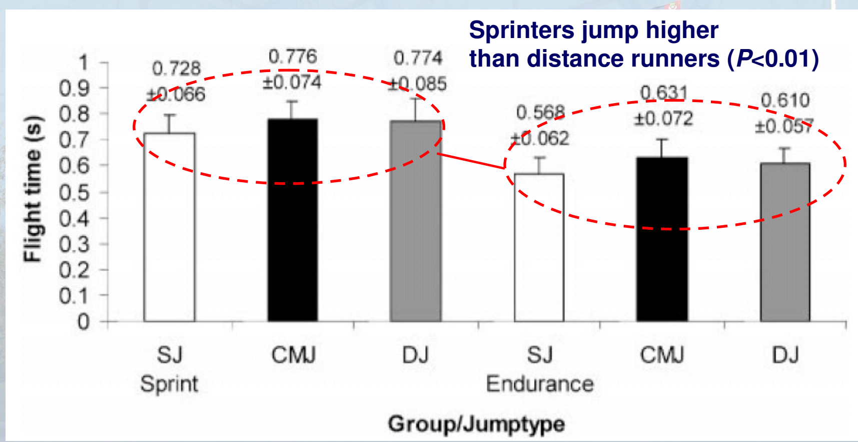
## Comparing jumping in speed and endurance athletes




Harrison et al, (2004)

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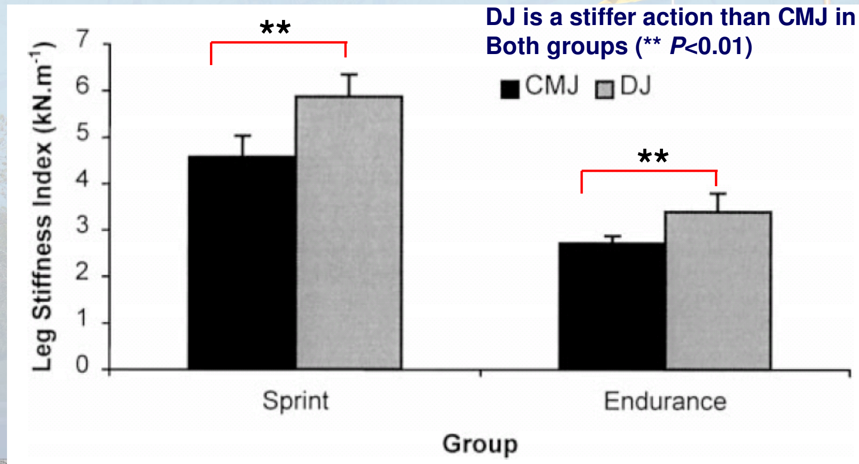
# Leg stiffness in endurance and sprint athletes

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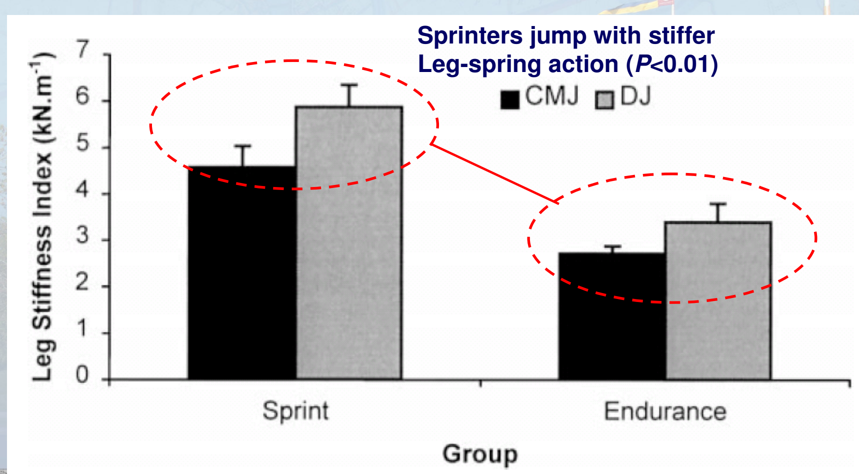
# Leg stiffness in endurance and sprint athletes

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# Acute training responses on leg-spring stiffness

*The Application of Complex Training Research*



# Complex training

- Combination of weight lifting and plyometrics has been referred to as complex training **(Ebben and Watts, 1998).**
- For example, back squatting followed by the completion of a biomechanically similar plyometric exercise, such as squat jumps.

# Complex Training

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Heavy resistance component

Plyometric component

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# Previous Knowledge complex training

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- Research in complex training provided no clear indication of beneficial or detrimental affects on performance
- Most studies focused on performance enhancement
- Few studies examined the processes underlying performance (biomechanics)

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# Previous Knowledge complex training

- Research in complex training provided no agreement on time between resistance exercise and plyometric component
- Few studies agree on optimal loading of resistance component
- Contradictory results on effects
  - ⇒Not much help to coaches athletes players



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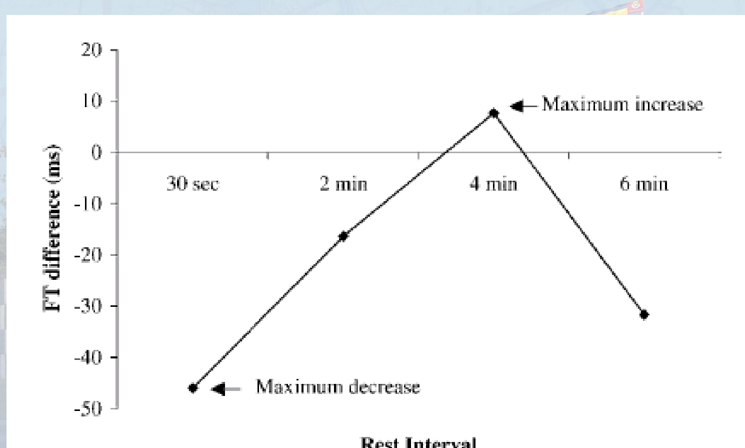
# Exemplar fatigue & potentiation response

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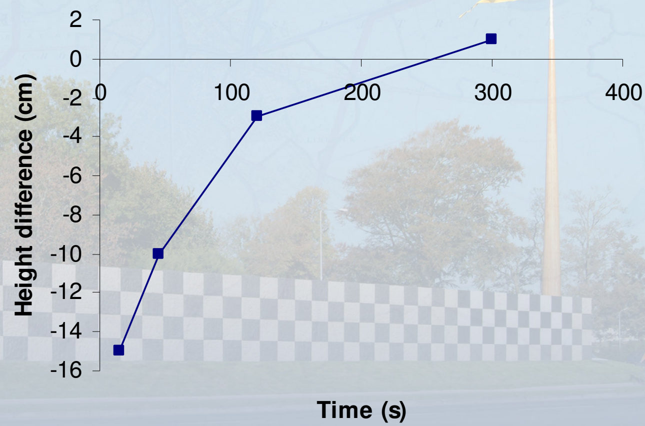
# CMJ performance after fatigue

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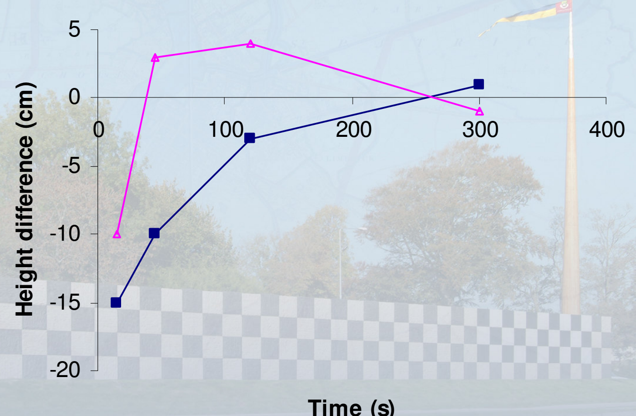
# CMJ after fatigue 2 subjects

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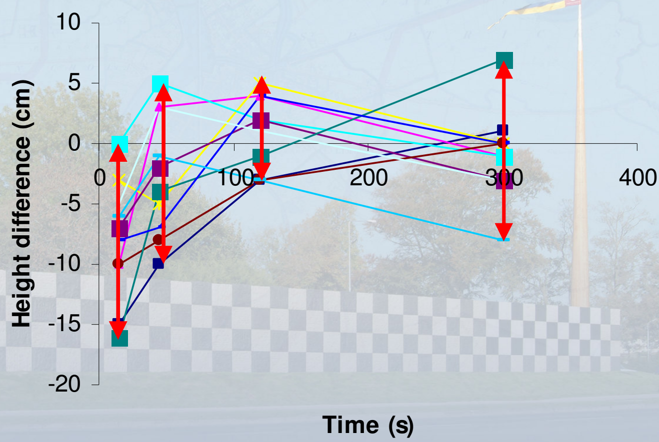
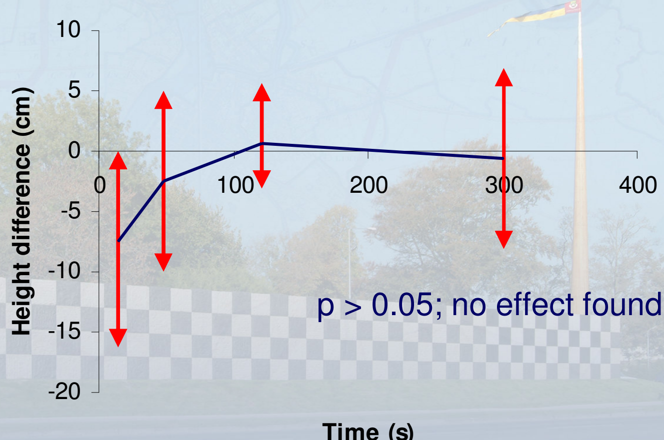
## Multiple subjects

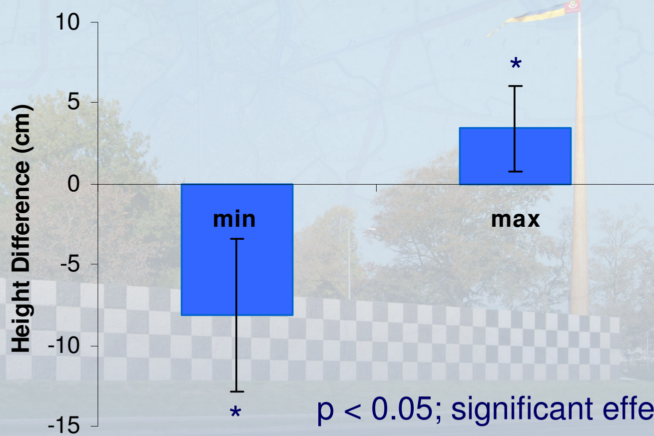





## Multiple subjects



# Showing potentiation?




$p < 0.05$; significant effects found



# Complex training experiments using force-sledge apparatus

1. How much load is required in the heavy resistance component?
2. How much recovery time between heavy resistance and plyometric components?
3. What role does fatigue play in complex training type activities?
4. Is the potentiation response generalisable?
5. How can the potentiation response be applied in the training environment?

# Sledge Drop Jump

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## *Identifying the Optimal Complex Training resistive load*

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# Change in Flight Time

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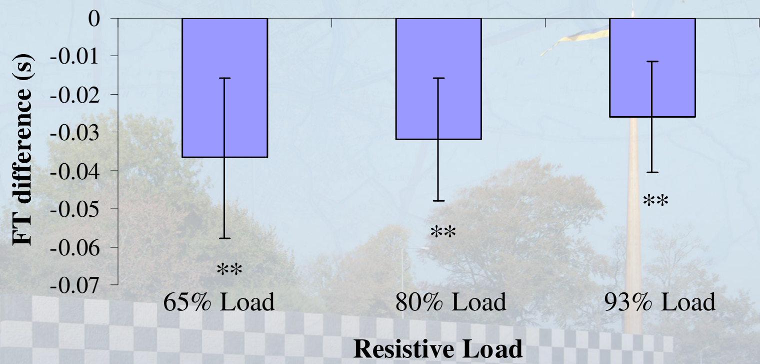


** Significant difference ($p < 0.01$)

No significant performance benefit

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# Change in $k_{vert}$

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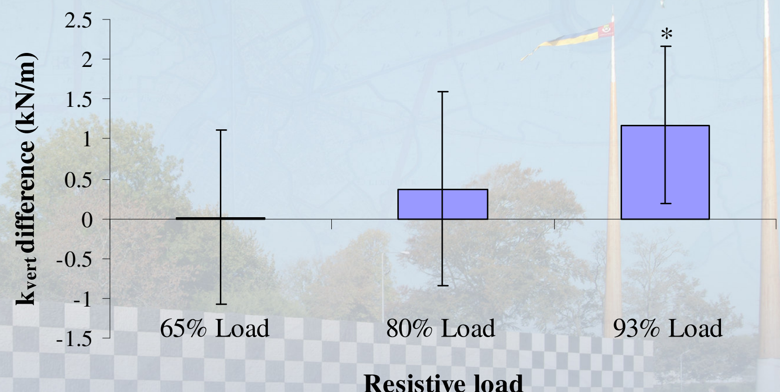


*Significant difference ($p < 0.05$)

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# Conclusions

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- The 93% load altered the biomechanics of performance of the DJ resulting in an increase in $k_{vert}$.
- It is recommended to perform heavy lifting (93%) prior to fast SSC exercises.
- In addition, the study has highlighted the over-reliance on performance outcome measures in complex training research.



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# Understanding the processes of fatigue and potentiation

# Methods: Data capture

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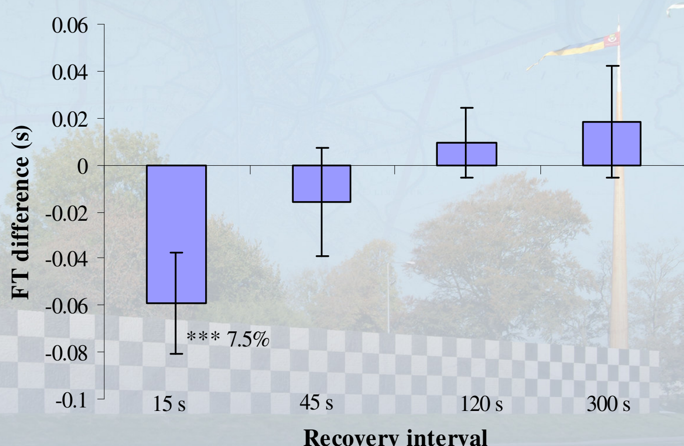
# Flight Time Fatigue and potentiation

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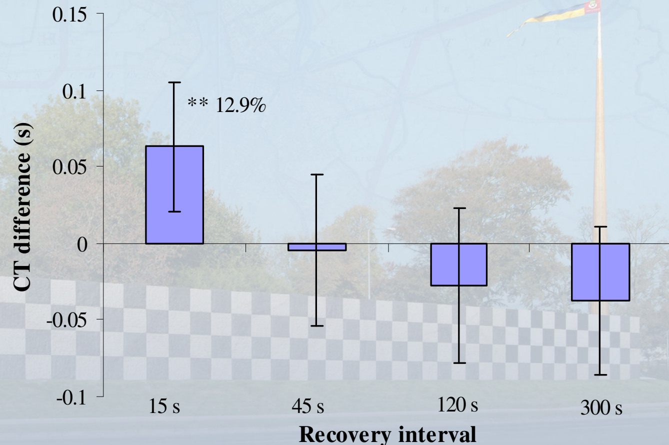
# CT Fatigue and potentiation

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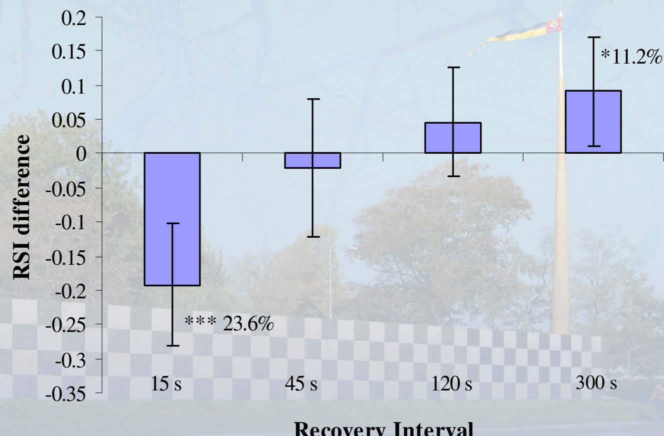
# RSI Fatigue and potentiation

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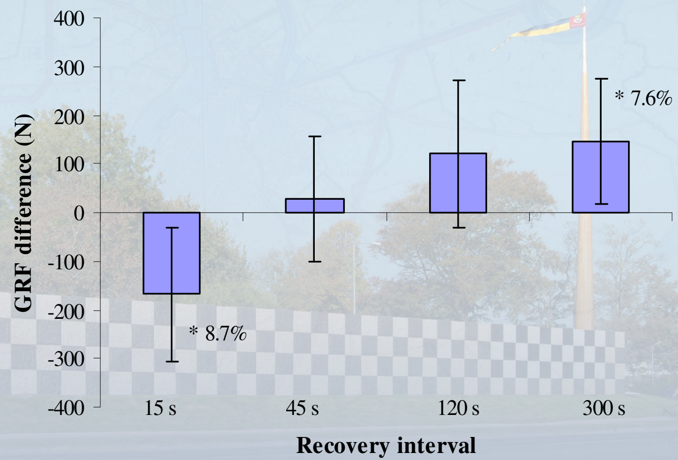
# GRF Fatigue and potentiation

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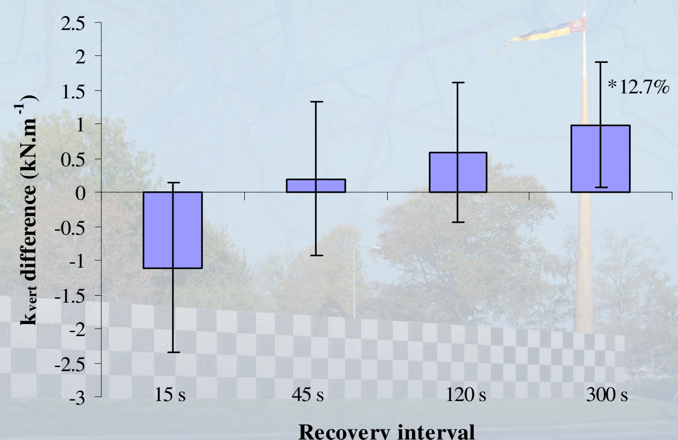
# $k_{vert}$ fatigue and potentiation

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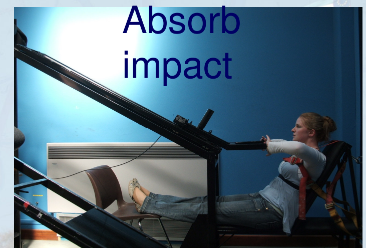
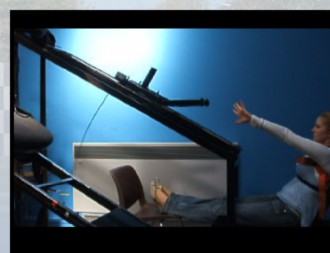
# The Rebound Throw

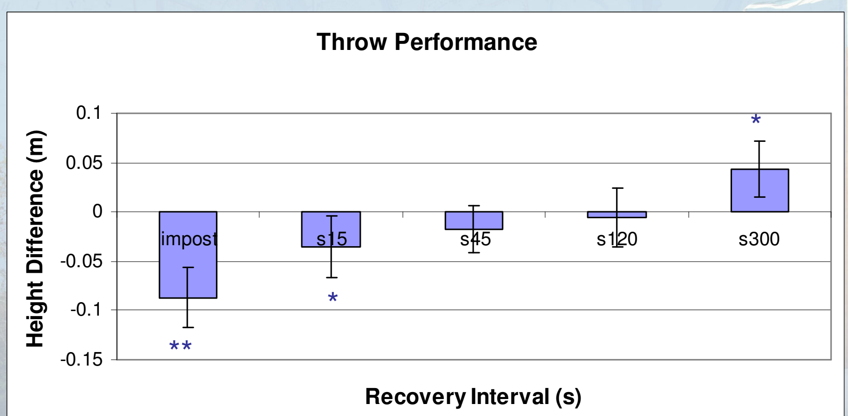




Throw





# RBT Fatigue & Recovery




**Mean ± 95% CI. height difference between the baseline RBT and the throws done at the different recovery intervals.**

# RBT Fatigue & Potentiation

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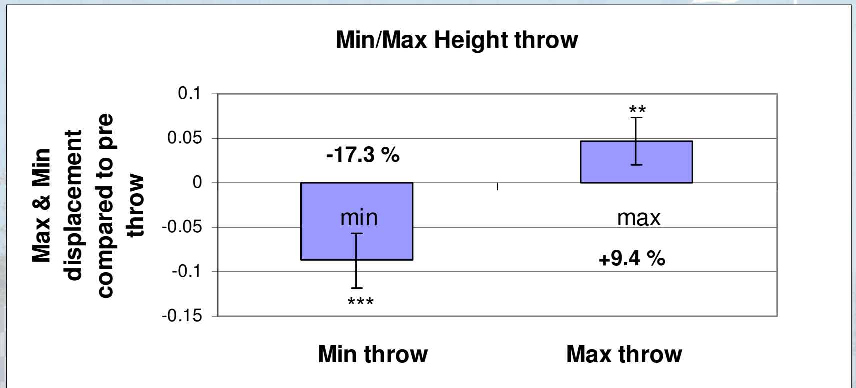


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# CT Fatigue & Recovery

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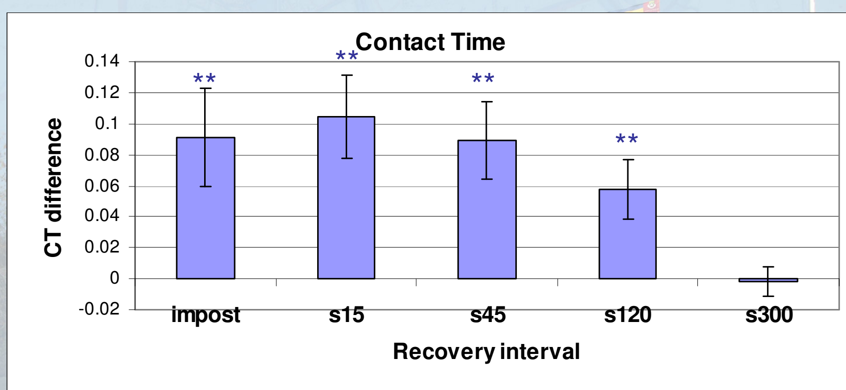


**Mean ± 95% CI. Contact time difference between the baseline RBT and the throws done at the various recovery intervals.**

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# Fatigue & potentiation (CT)

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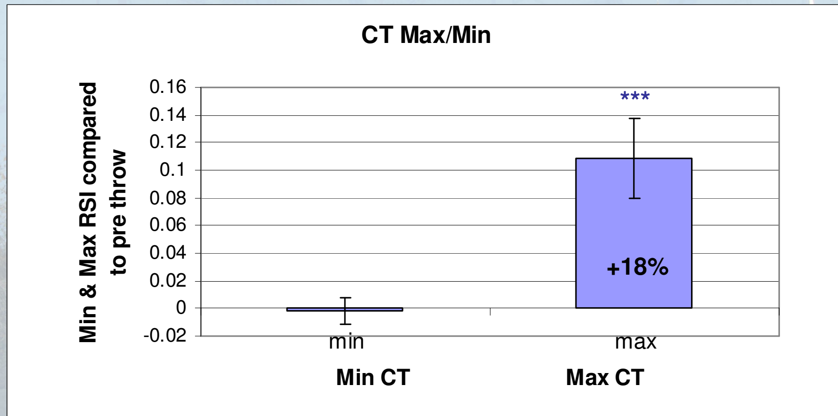




# RSI Fatigue & Recovery

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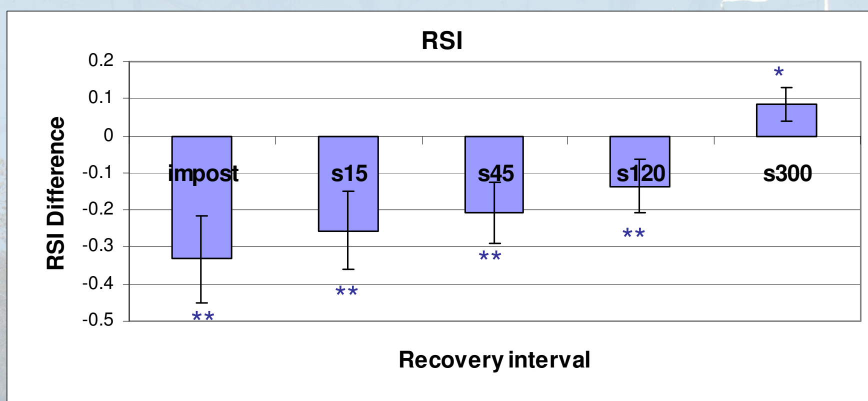
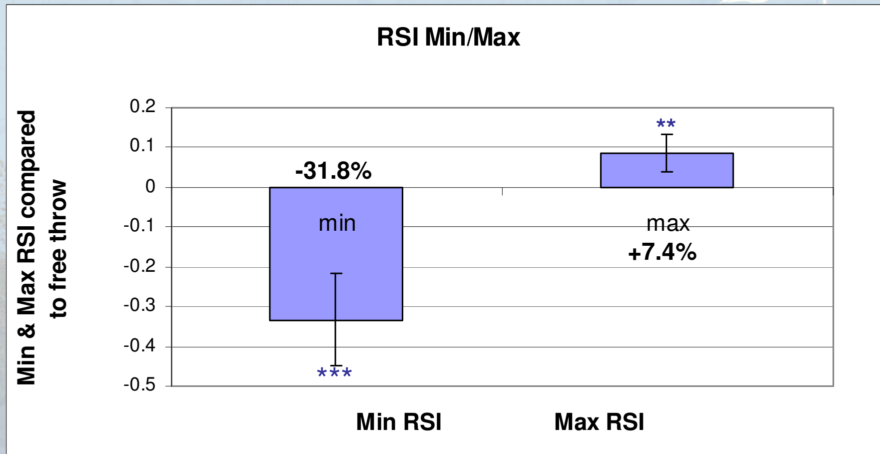



Mean ± 95% CI. differences in RSI between the baseline RBT and the throws done at the various recovery intervals.

# Fatigue-Potentiation (RSI)






# Discussion

- Flight time (FT) data (performance measure) suggests that performing back squat (or bench press) with either a 65, 80 or 93% load will have a negative affect.
- Is maximising the performance (FT) the goal of a fast SSC activity, such as drop jumping?
- Butler et al. (2003) and McMahon et al. (1987) showed that optimising a performance measure, such as stride length, is more beneficial than maximising it.
- $k_{vert}$ data gave us greater understanding of effect of loads on biomechanical performance of DJs.

# Discussion contd.

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- Increases in $k_{vert}$ are associated with increases in leg cadence (Arampatzis et al., 1999) and faster hopping frequencies (Farley et al., 1996).
- Increases in $k_{vert}$ are associated with shorter ground contact times during DJs (Arampatzis et al., 2001)
- Sprinters have high leg spring stiffness (Harrison et al., 2004).
- The increase in $k_{vert}$, such as one seen after 93% load, will be more beneficial than an increase in FT on DJ performance.



# Conclusions

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- PAP (or fitness-fatigue) is a real and repeatable phenomenon that can be used in complex training regimes
- The phenomenon seems to generalise to differing populations and different muscle groups, although with some inconsistencies
- Care is required in measuring the effect due to variations in the time course of the effect

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## How do we train for enhanced leg-spring stiffness?

- Encourage shorter ground contact times
- Elastic “quiet” (stiffer) ground contacts
- Encourage small ranges of knee flexion
- Be aware that these steps could induce high forces and increase risk of injury (we need criteria for optimal stiffness)
- Therefore, gradual progressive loading is required
- Consider Post Activation Potentiation (PAP) e.g. Complex training strategies (more work to do!)



## Towards a simple coaching model of sprint performance

***Description of the model***

## The application of drills

- ***Goal:*** Establishment of optimal movement and coordination patterns
- The predominant coaching model derives mainly from descriptive movement sequences and critical features
- Coaches often use a variety of running drills (isolation drills).
- It is assumed that the drills are the parts of a whole-part-whole learning strategy or variable practise approach



## Practise considerations

- Practises (drills) should be consistent with the *movement state* of the activity
  - Similar muscle activation movement patterns
- Leg movement patterns are anti-phase
- Variability of practise can be used:
  - But variations must be within the same *movement state*
  - Variations of speed, force are appropriate (application of DST)
  - Same activation patterns or use of in-phase or anti-phase motion

# The simplified model

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- This model assumes that the arms play a subordinate, counterbalancing role in sprinting.
  - little emphasis on correction of arm actions unless they are demonstrably destabilising the overall movement of the sprinter.
- The primary emphasis on the action of the Pelvis, hips and legs
  - each leg moves alternately (anti-phasic) from hip-knee-ankle extension to hip-knee- ankle flexion



# First movement: A→B

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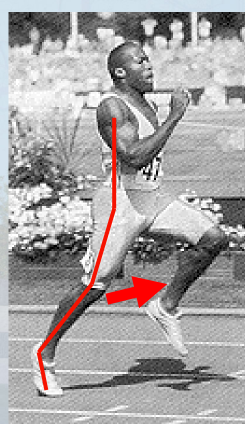
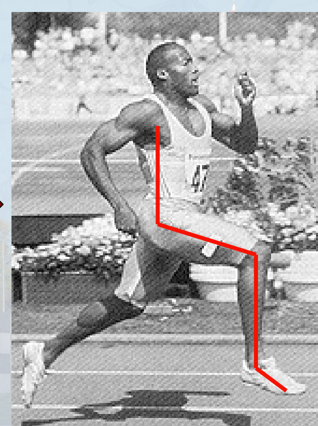
A



B



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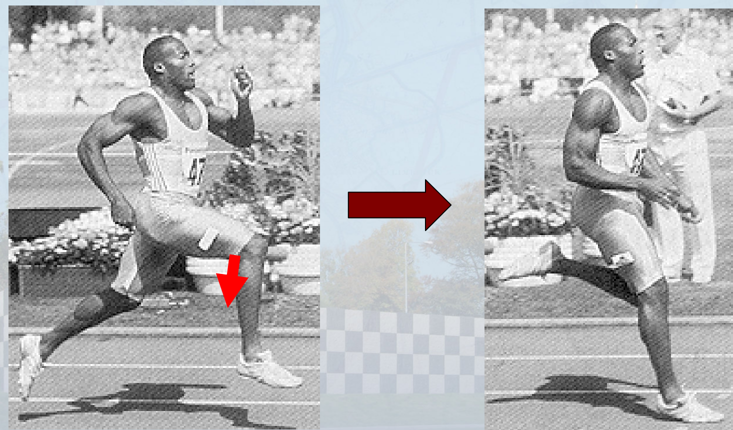
# Second movement: B→C

B C



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# Posture control exercises

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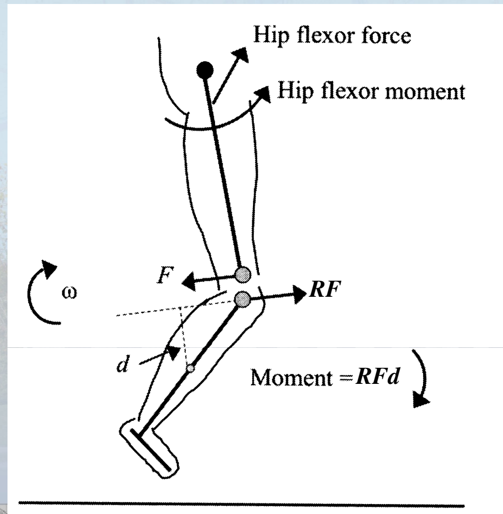
# Forces and moments accompanying hip flexion

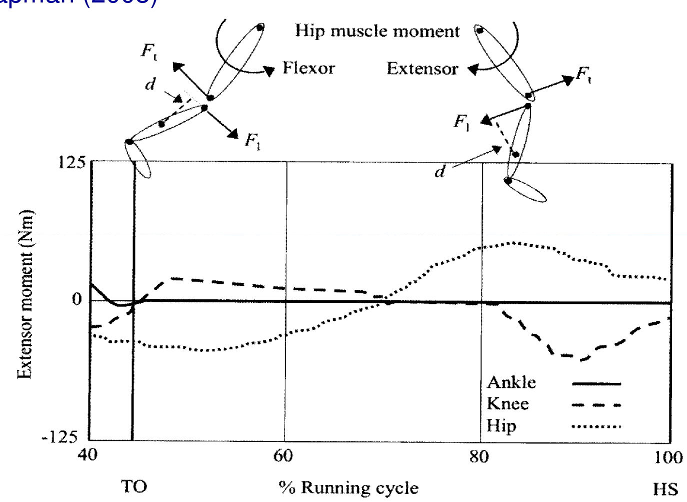



From: Chapman (2008)

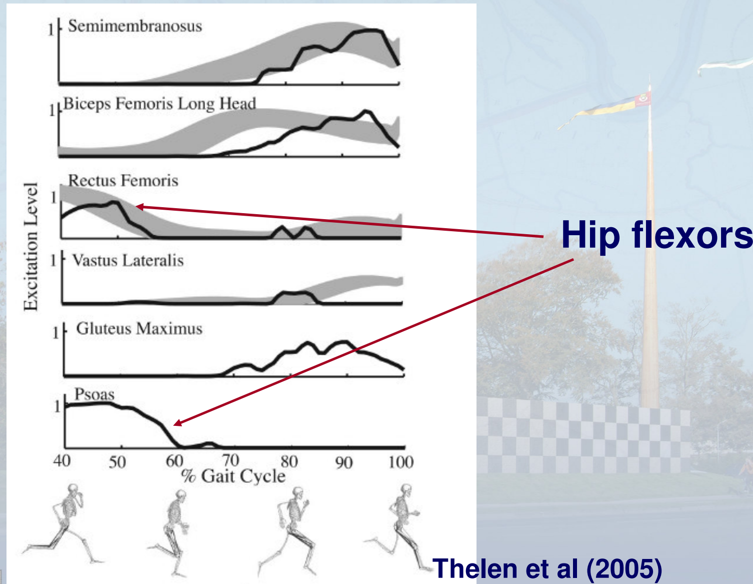


# Forces, moments and movements in swing phase of running

From Chapman (2008)



# Hamstring activity in sprinting




Thelen et al (2005)

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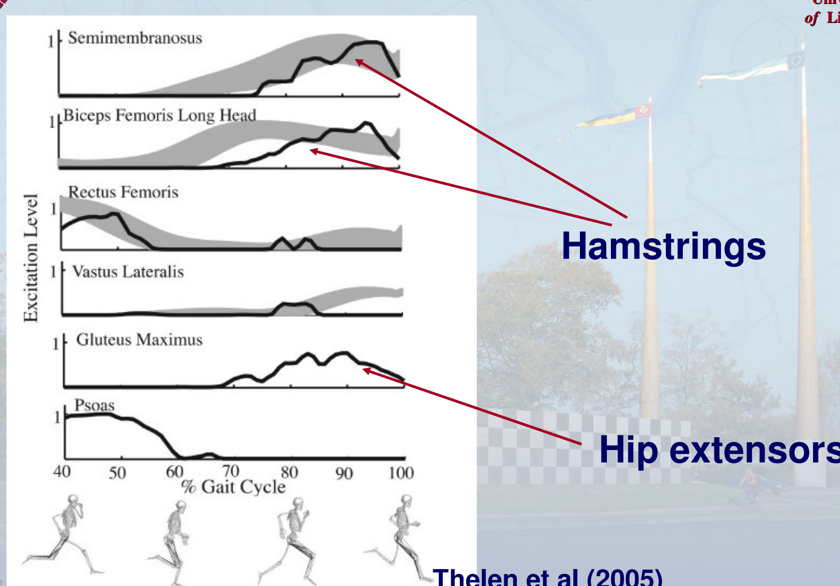
# Hamstring activity in sprinting




Thelen et al (2005)

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# Computer simulation

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- Kinematic data obtained during maximum speed phase in sprinting
  - 6 camera (Eagle) MAC system operating at 500 Hz
  - Calibrated volume – approx 6 x 3 x 2.5 m
  - Marker clusters on right side: pelvis, thigh, shank and foot.
  - Kinematic and anthropometric data exported to ADAMS/LifeMOD (v2007.0.0) software to validate model



# Computer Model

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- 4 segments (pelvis, femur, shank and foot)
- 6 degrees-of-freedom
- 17 muscles
  - soleus, gastrocnemius 1 & 2 inserts,
  - tibialis anterior,
  - bicep femoris 1 & 2 inserts,
  - semitendinosus, vastus lateralis, vastus medialis,
  - rectus femoris, iliacus, gluteus minimus, gluteus medius,
  - gluteus maximus 1 & 2 inserts,
  - psoas major, adductor longus

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# Computer Model

- Computer model used to match observed kinematics
  - Computer model provided forward dynamic simulation of sprinting
  - Subject specific anthropometric data and kinematic data
  - Optimised muscle forces derived using ADAMS/Lifemodeler



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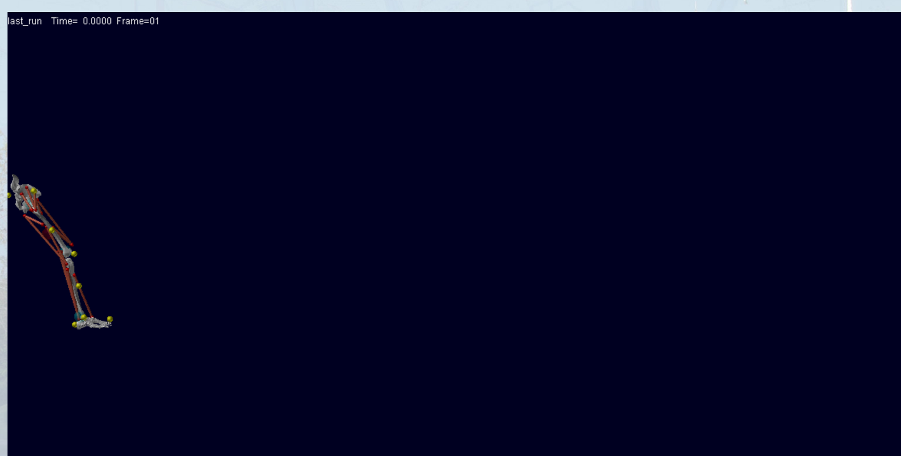
# Computer simulation

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# Computer Simulation (slow)

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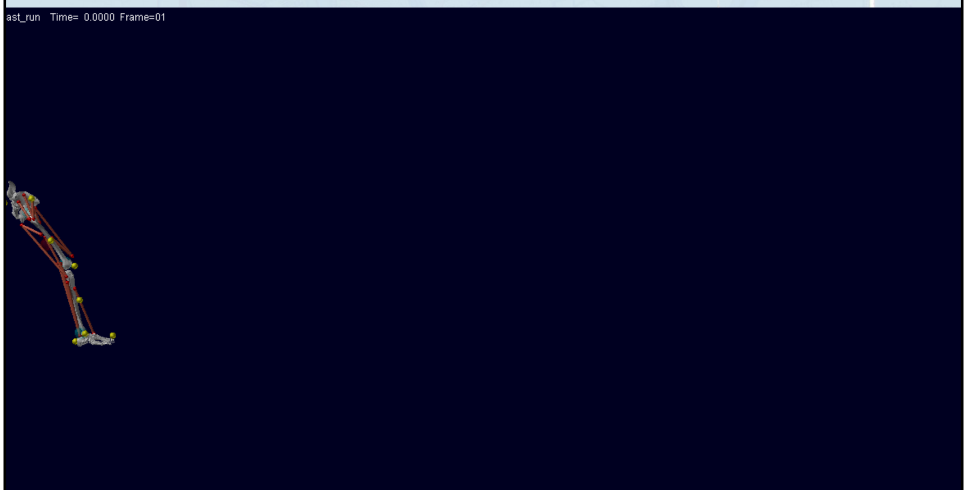




# Lateral view

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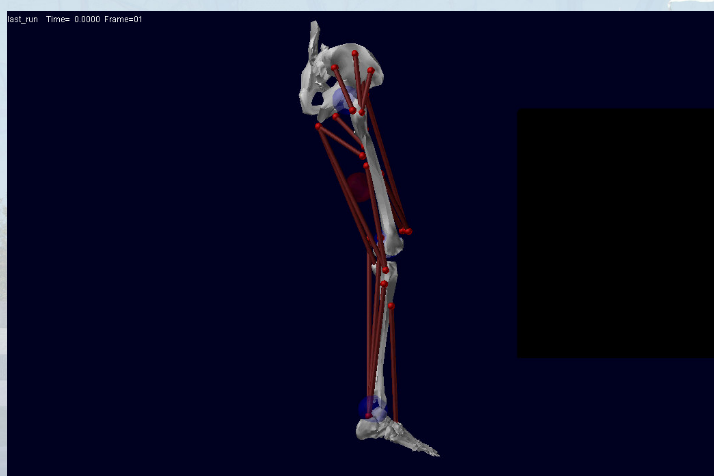

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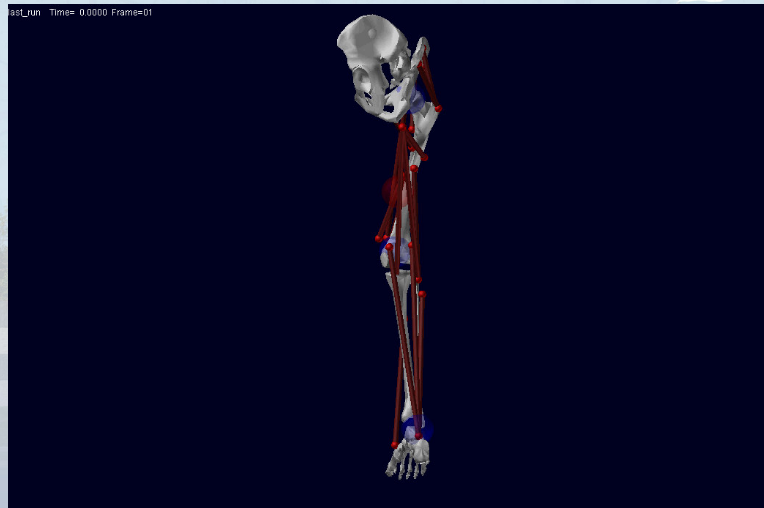
# Posterior view

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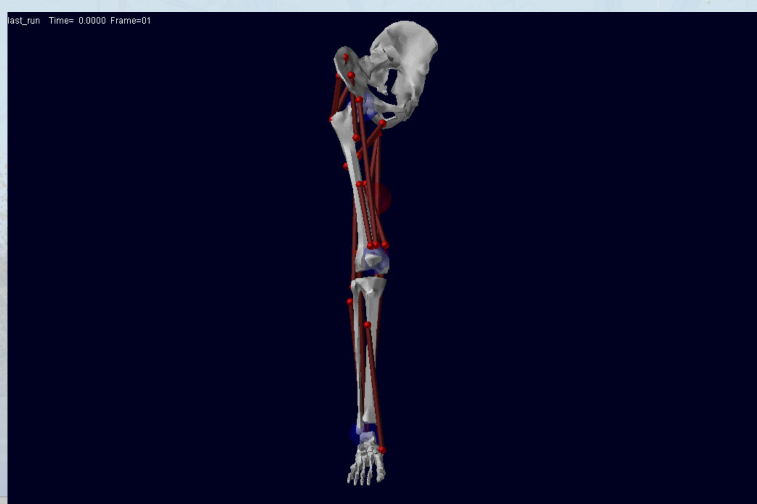
# Anterior view

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# Validation of model

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- Model/experimental validation of kinematic motion to a very high level
- X/Y/Z for ASIS, Lateral Knee, Malleolus Pearson's r = 0.993
- RMSD between model and observed data (kinematic trajectories) = 0.0244 m
- Kinetic GRF data compared to normative data for running



# Muscle Activation Patterns

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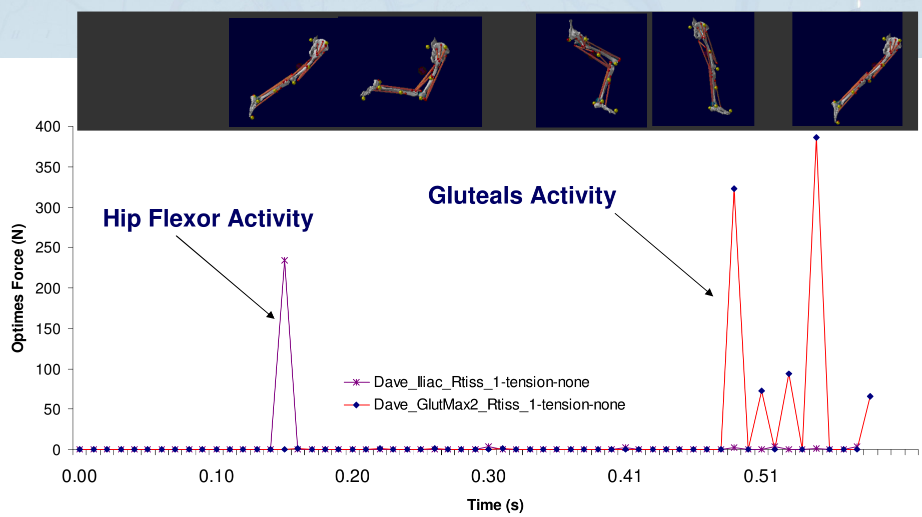


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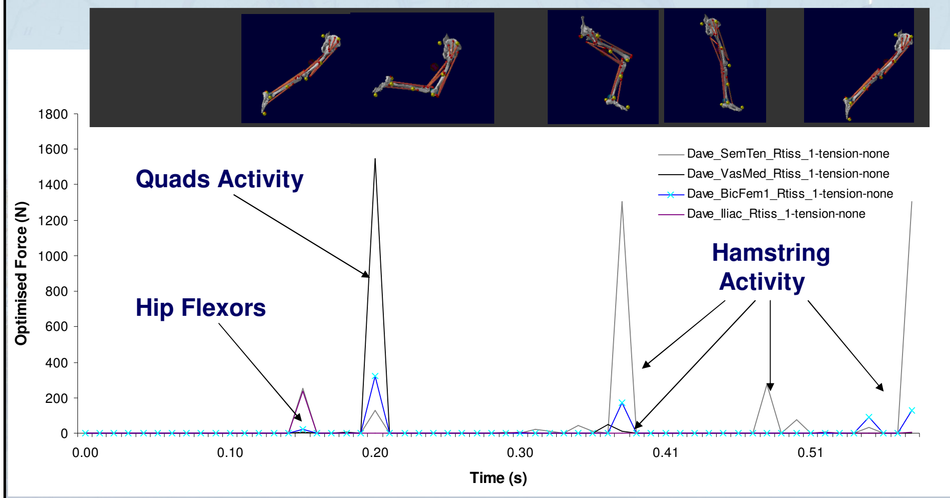
# Muscle Activation Patterns

University of Limerick






# Computer model findings

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- The first movement (A→B) in sprinting is initiated by hip flexors/quads
- There in minimal hamstring activity in the first movement.
- The Gluteals and Hamstrings are active in the second movement (B→C)

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