A Biomechanical Analysis of the Golf Swing

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Introduction

- The golf shot is one of the most difficult biomechanical motions in sport to execute [Vaughn, 1979] Work and Power
- The golf swing employs 90% of peak muscle activity in amateur golfers and 80% of peak muscle activity in professional golfers [Hosea and Gatt (1996)] Lumbar spinal loads

Introduction

- The main objective of the golf swing is to maximize the club head linear velocity at the point of impact with the ball
- Through basic physics this is modelled through conservation of energy and momentum at the time of impact
- $\frac{1}{2}m_{\text{club}}v_{\text{club}}^2 = \frac{1}{2}m_{\text{club}}V_{\text{club}}^2 + \frac{1}{2}m_{\text{ball}}v_{\text{ball}}^2$ KE transfer
- $m_{\text{club}}v_{\text{club}} = m_{\text{club}}V_{\text{club}} + m_{\text{ball}}v_{\text{ball}}$ Elastic Collision

Introduction

- In a perfectly elastic collision, this can be modelled as:

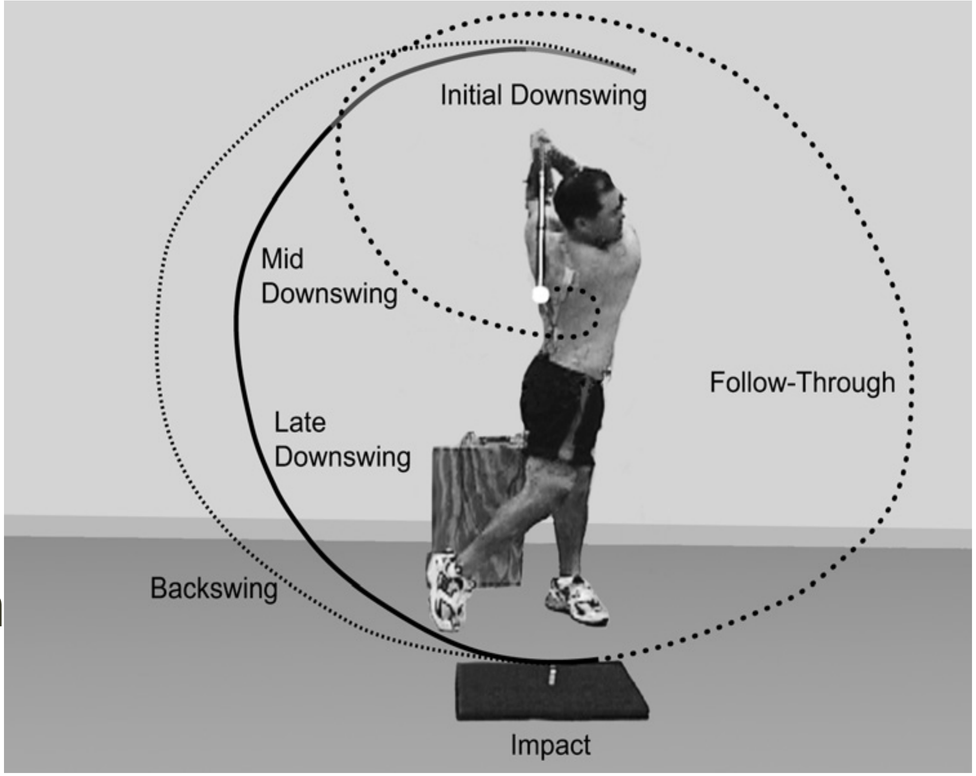
$$v_{\text{ball}} = v_{\text{club}} \frac{2m_{\text{club}}}{m_{\text{club}} + m_{\text{ball}}} = v_{\text{club}} \frac{2}{1 + m_{\text{ball}}/m_{\text{club}}}$$

- In reality, some energy is lost due to the deformation of the golf ball:
  - $$v_{\text{ball}} = \frac{(1 + c_R)v_{\text{club}}}{1 + m_{\text{ball}}/m_{\text{club}}}$$

The Fundamentals of the Golf Swing

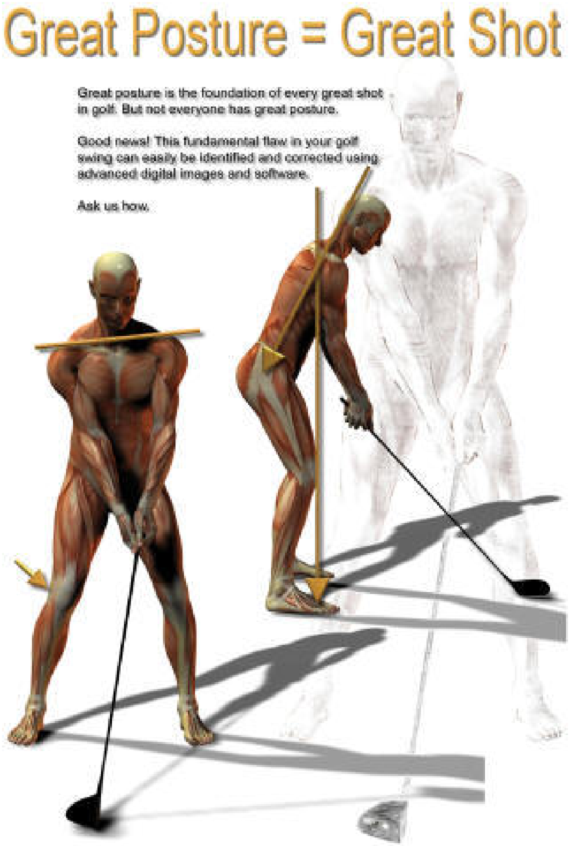
- There are four main phases of the golf swing:
- 1) Set-up or Approach
- 2) Backswing
- 3) Downswing
- 4) Follow through

[6]



The Set-up or Approach

- Aligns golfer properly with ball, while establishing static and dynamic balance of golfer
- 50-60% of the golfer’s weight should be on the back foot [27].
- Truck flexed to 45 deg at hips [2]
- Right lateral shoulder tilt of 16 deg [2]
- An effective grip that allows the golfer to control the club-face, and allows the club to hinge and unhinge during the swing



The Backswing

- Properly stretches muscles and joints responsible for generating power on backswing
- "X Factor" of approx. 50 deg [Meister]
- Left elbow extended while right arm abducted to 75-90 deg
- Left hand is firmly gripping while right hand is passive, wrists are cocked

The Downswing

- Returns the club head to the ball in the correct plane with maximum velocity
- Hips and Trunk muscles initiate downswing
- Right arm adducts and the elbow extends
- To attain maximum velocity, wrists should be un-cocked later in the downswing, accounting for as much as 9% addition of club head velocity

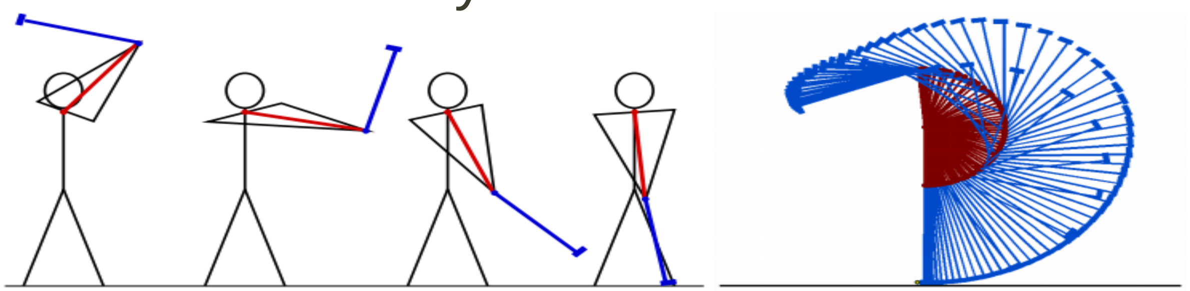


FIGURE 2. The double pendulum model of a golf swing.

The Follow-Through

- Decelerates the body and club head by using eccentric muscle actions [43]
- Hand and wrists follow the plane of the swing path
- Postural stability is maintained and swing is finished in a balanced position

Work on Joints

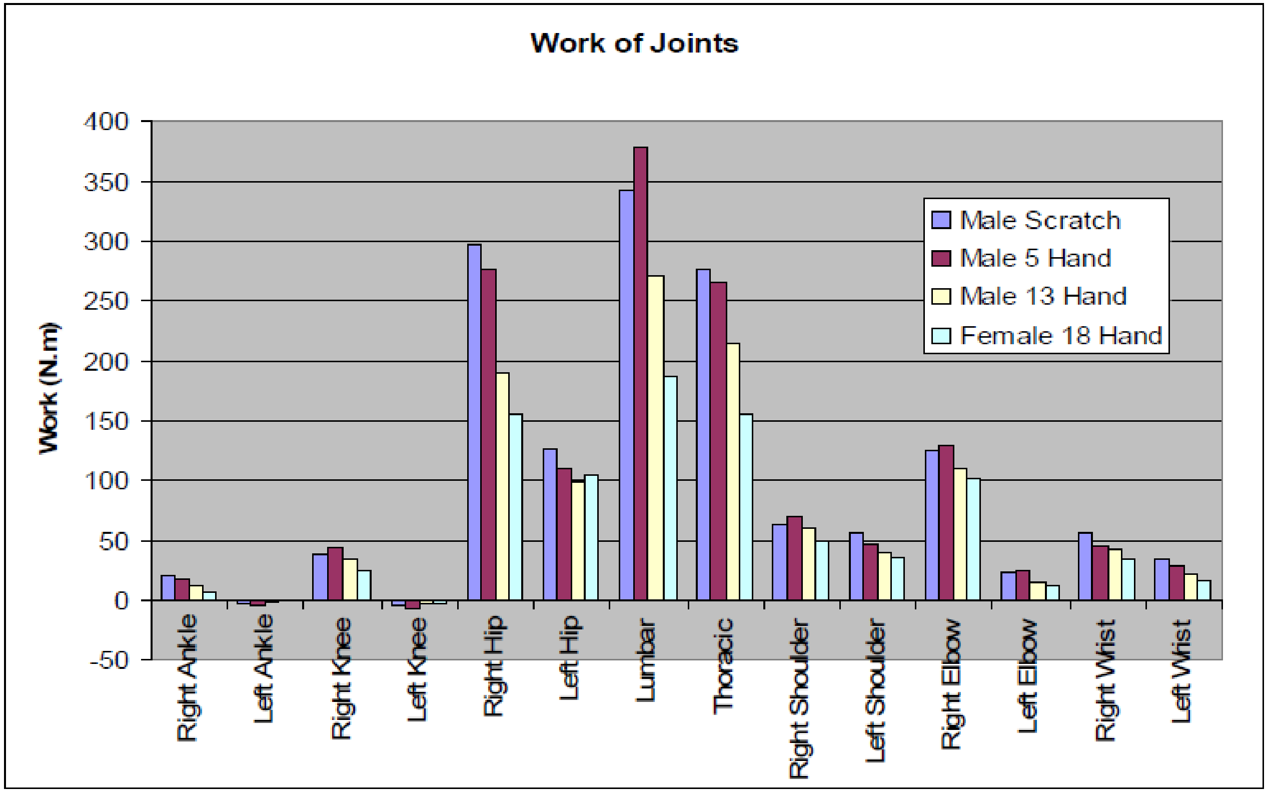
- W = Tθ

$$Work_{joint} = \int_{t_2}^{t_1} (\vec{\omega}_i \bullet \sum \vec{T}_i) dt$$

- α, β, γ = X, Y, Z axis rotations respectively

$$Work_{joint} = \sum_0^n T_\alpha(\alpha_{t+\Delta t} - \alpha_t) + \sum_0^n T_\beta(\beta_{t+\Delta t} - \beta_t) + \sum_0^n T_\gamma(\gamma_{t+\Delta t} - \gamma_t)$$

- n is the number of numerical time steps



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- Total Work on all Joints ~1500N*m

Data Type	Units	Male Scratch	Male 5H	Male 13H	Fem 18H
Club Head Vel	$m \cdot s^{-1}$	52.0	49.7	46.3	42.1
Max Torque	Nm	42.1	36.8	24.6	24.0
Max Force	N	512	453	390	304
Total Work	Nm	355	289	288	235
Max Lin Work	Nm	206	155	140	114
Max Ang Work	Nm	146	134	148	121
Lin/Ang Work	Ratio	1.41	1.16	.95	.94
Peak Power	$Nm \cdot s^{-1}$	3875	3005	2310	1720
Peak Lin Power	$Nm \cdot s^{-1}$	2775	2316	1402	1188
Peak Ang Power	$Nm \cdot s^{-1}$	1150	890	1078	698
Lin/Ang Power	Ratio	2.41	2.60	1.30	1.70
Peak Kinet Engy	Nm	334	302	264	216
Peak Strain Engy	Nm	3.7	3.4	2.9	2.5
Swing Efficiency	%	24.5	20.2	26.1	26.8

[5]

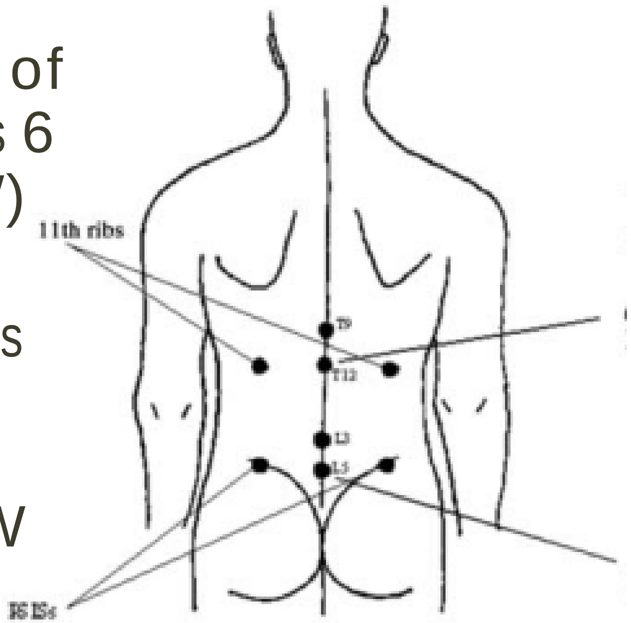
Injuries

- Approximately 80% of golf-related injuries are reported to occur in the lower back, the elbow and the wrist [2, 8,17,18].

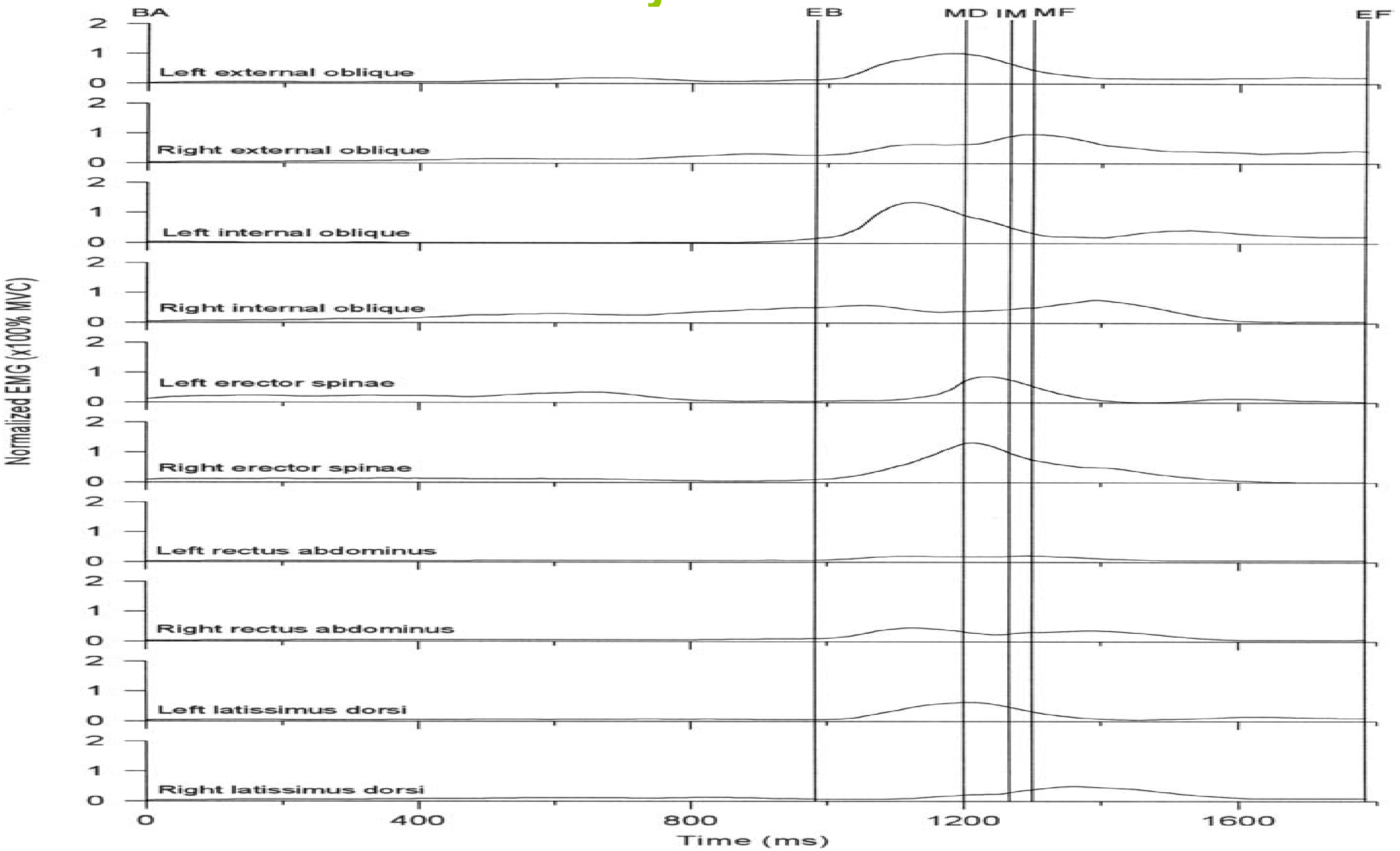
Type of Injury	% of Amateur	% of Pro
Wrist [2, 8,17,18]	13-20	20-27
Elbow [16, 18 – 20]	25-33	7-10
Lower back [1, 8,17 – 20]	15-34	22-24

Lower Back Injuries

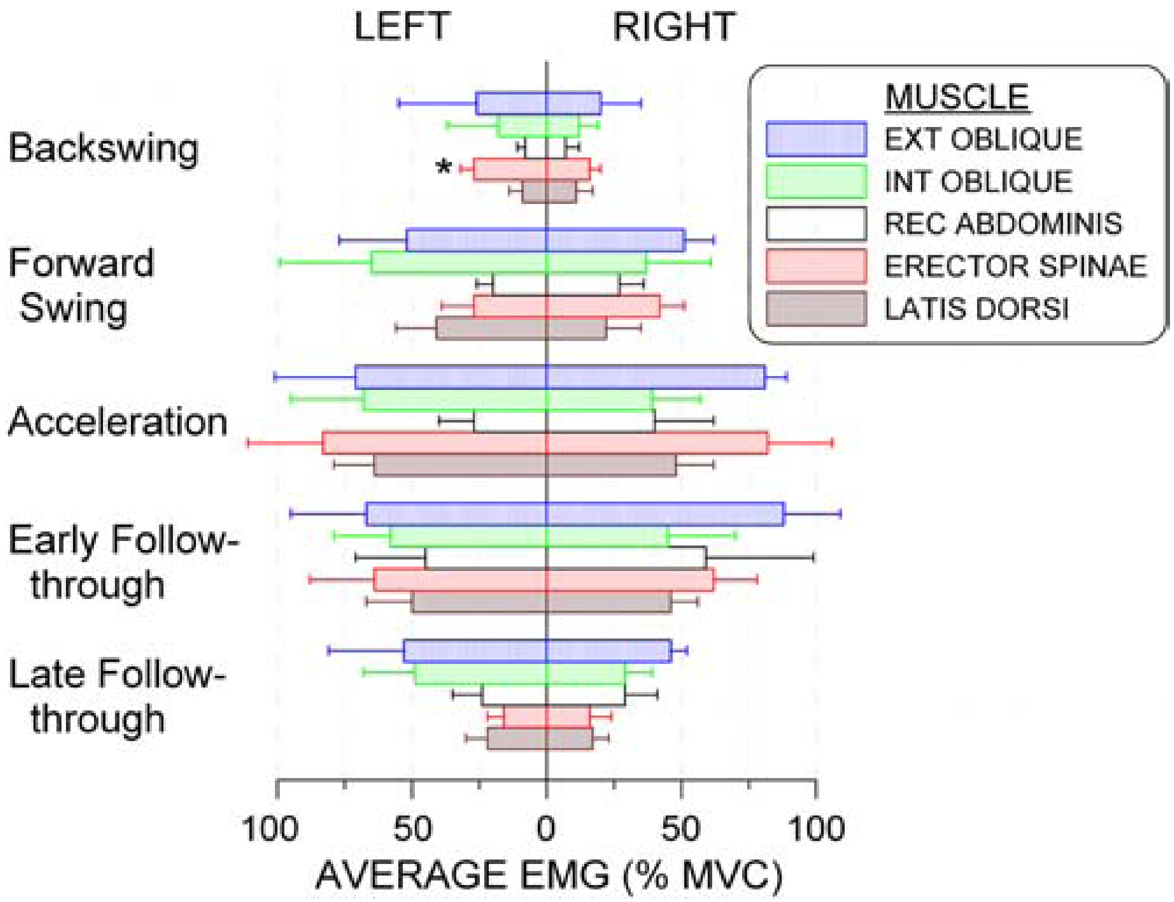
- Lower back injuries are one of the most prevalent injuries in golf
- The L4-L5 (pictured) section of the lower back experiences 6 times their body weight (BW) during the downswing
- This section also experiences mean peak anterior and medial shear loads approaching 1.6 and 0.6 BW during the follow-through phases



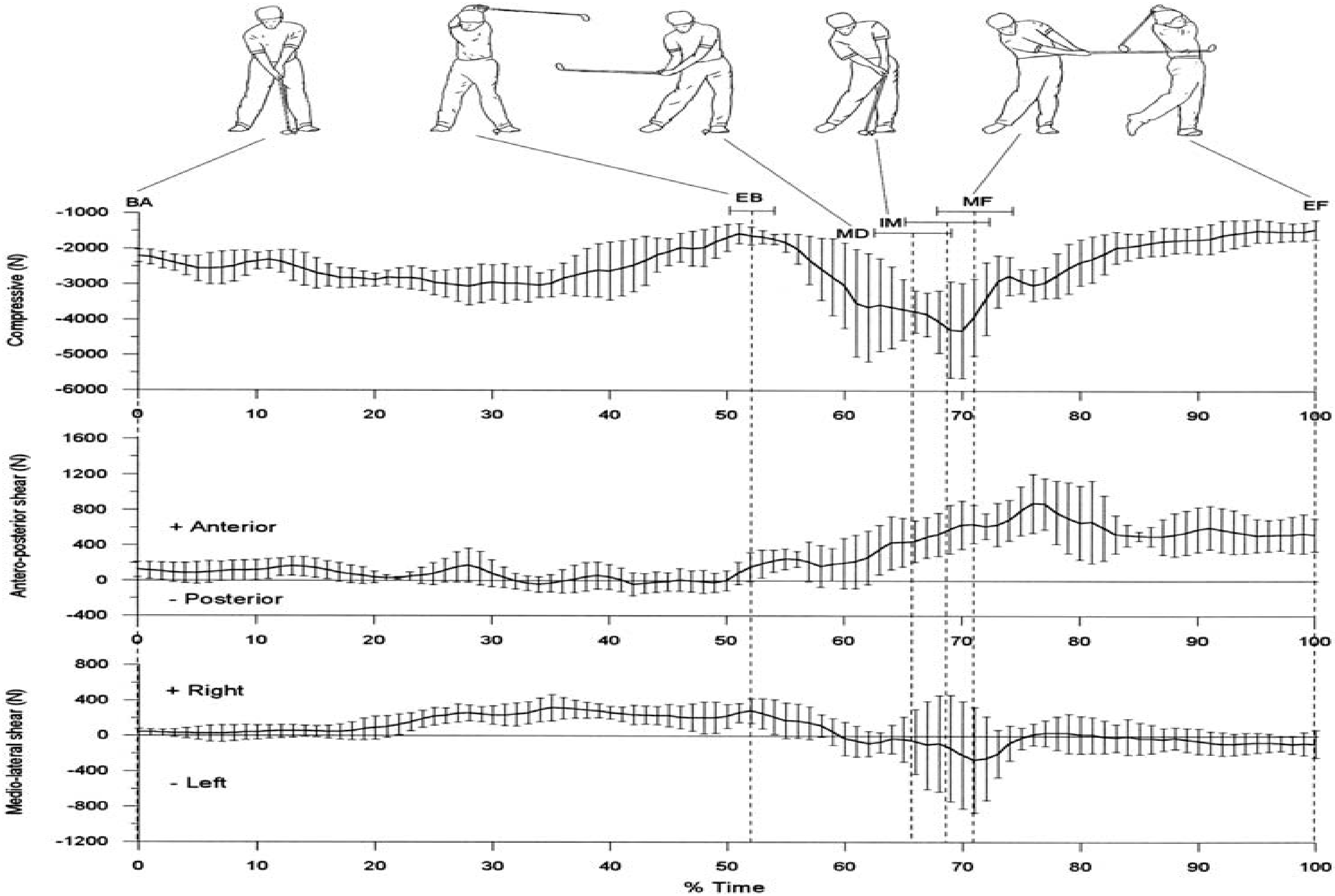
Lower Back Injuries



Lower Back Injuries

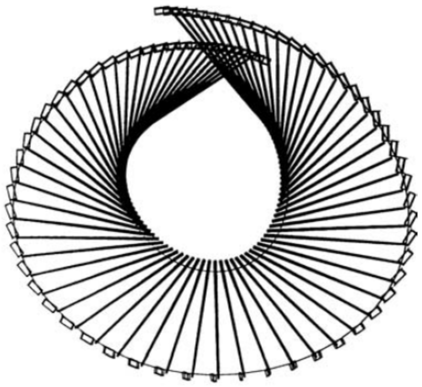


Lower Back Injuries



Work on Club

$$Work_{Golfer \to club} = \int_{t_2}^{t_1} \left(\sum \vec{F}_i \bullet \vec{V}_i + \sum \vec{T}_i \bullet \vec{\omega}_i\right) dt$$



- $\vec{F}$ is the external applied force
- $\vec{V}$ is the linear velocity
- $\vec{T}$ is Torque
- $\vec{\omega}$ is angular velocity
- i is the x,y,z and α,β,γ components respectively

Work - Energy

$$Work_{Golfer \rightarrow club} = \Delta KE_{club} - \Delta SE_{shaft}$$

- KE = Kinetic Energy of the club and can be broken down into the shaft and head
- SE = Strain Energy stored by the bending and torsion of the shaft
- We want to reduce SE when designing clubs

Energy of Club

$$KE_{shaft} = \sum_{j=1}^{n}\left(\frac{1}{2}M_jV_{gj}^2 + \frac{1}{2}(I_{xj}\omega_{\alpha j}^2 + I_{yj}\omega_{\beta j}^2 + I_{zj}\,\omega_{\gamma j}^2)\right)$$

$$KE_{head} = \sum_{j=1}^{n}\left(\frac{1}{2}M_hV_{gh}^2 + \frac{1}{2}(I_x\omega_\alpha^2 + I_y\omega_\beta^2 + I_z\omega_\gamma^2 + 2I_{xy}\omega_\alpha\omega_\beta + 2I_{yz}\omega_\beta\omega_\gamma + 2I_{xz}\omega_\alpha\omega_\gamma)\right)$$

$$SE_{shaft} = \sum_{j=1}^{n}\left(K_{xj}\delta_{xj}^2 + K_{yj}\delta_{yj}^2 + K_{\gamma j}\delta_{\gamma j}^2 + K_{Aj}\delta_{Aj}^2\right)$$

[5]

Energy Transferred to Ball

- The Velocity of the ball can be modelled by

$$v_{\text{ball}} = \frac{(1 + c_R)v_{\text{club}}}{1 + m_{\text{ball}}/m_{\text{club}}}$$

- Cr was experimentally determined to be around 0.78 [4]

Ball-Club Collision

- *Damped Spring-Mass System*
- $F = KX - C\frac{dx}{dt}$
- *Impact Model* [kinematics paper]
- $F = KX^e - CV$
- K = Spring Stiffness (912975N*m obtained experimentally)
- X = Impact Deformation
- e = Stiffening Exponent (1.5265 obtained experimentally)
- C = Dampening Factor
- V = Impact Deformation Velocity

Conclusion

- Analysing complex systems with many Degrees of Freedom is difficult
- Having an understanding of the movements of all your joints can help perfect your swing
- There are so many variables in a golf swing and everyone's body is slightly different, so next time you take golf lessons remember there's more value in replicating your own shot than mimicking someone else's precisely

References

- [1] Vaughn, 1979 Work and Power
- [2] [Hosea and Gatt (1996)] Lumbar spinal loads
- [3] Kinematic analyses of the golf swing hub path and its role in golfer/club kinetic transfers - Steven M. Nesbit and Ryan McGinnis
- [4] The Science of a Drive – Douglas N. Arnold
- [5] WORK AND POWER ANALYSIS OF THE GOLF SWING - Steven M. Nesbit and Ryan McGinnis
- [6] Hume, Patria A., Justin Keogh, and Duncan Reid. "The Role of Biomechanics in Maximising Distance and Accuracy of Golf Shots." *Sports Medicine* 35.5 (2005): 429-49. Print.