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:

\[
\begin{align*}
\frac{1}{2}m_{\text{club}}v_{\text{club}}^2 &= \frac{1}{2}m_{\text{club}}V_{\text{club}}^2 + \frac{1}{2}m_{\text{ball}}v_{\text{ball}}^2 \\
m_{\text{club}}v_{\text{club}} &= m_{\text{club}}V_{\text{club}} + m_{\text{ball}}v_{\text{ball}}
\end{align*}
\]

KE transfer

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].
- Trunk 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

- \( W = T\theta \)

\[
Work_{\text{joint}} = \int_{t_1}^{t_2} (\vec{\omega}_i \cdot \sum \vec{T}_i) dt
\]

- \( \alpha, \beta, \gamma = X, Y, Z \) axis rotations respectively

\[
Work_{\text{joint}} = \sum_{0}^{n} T_{\alpha} (\alpha_{t+\Delta t} - \alpha_t) + \sum_{0}^{n} T_{\beta} (\beta_{t+\Delta t} - \beta_t) + \sum_{0}^{n} T_{\gamma} (\gamma_{t+\Delta t} - \gamma_t)
\]

- \( n \) is the number of numerical time steps
Total Work on all Joints \( \sim 1500 \text{N} \times \text{m} \)
<table>
<thead>
<tr>
<th>Data Type</th>
<th>Units</th>
<th>Male Scratch</th>
<th>Male 5H</th>
<th>Male 13H</th>
<th>Male 18H</th>
<th>Fem 18H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Club Head Vel</td>
<td>m·s⁻¹</td>
<td>52.0</td>
<td>49.7</td>
<td>46.3</td>
<td>42.1</td>
<td></td>
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<tr>
<td>Max Torque</td>
<td>Nm</td>
<td>42.1</td>
<td>36.8</td>
<td>24.6</td>
<td>24.0</td>
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<tr>
<td>Max Force</td>
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<td>453</td>
<td>390</td>
<td>304</td>
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<tr>
<td>Total Work</td>
<td>Nm</td>
<td>355</td>
<td>289</td>
<td>288</td>
<td>235</td>
<td></td>
</tr>
<tr>
<td>Max Lin Work</td>
<td>Nm</td>
<td>206</td>
<td>155</td>
<td>140</td>
<td>114</td>
<td></td>
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<tr>
<td>Max Ang Work</td>
<td>Nm</td>
<td>146</td>
<td>134</td>
<td>148</td>
<td>121</td>
<td></td>
</tr>
<tr>
<td>Lin/Ang Work</td>
<td>Ratio</td>
<td>1.41</td>
<td>1.16</td>
<td>.95</td>
<td>.94</td>
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<td>Peak Power</td>
<td>Nm·s⁻¹</td>
<td>3875</td>
<td>3005</td>
<td>2310</td>
<td>1720</td>
<td></td>
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<tr>
<td>Peak Lin Power</td>
<td>Nm·s⁻¹</td>
<td>2775</td>
<td>2316</td>
<td>1402</td>
<td>1188</td>
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<tr>
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<td>Peak Kinet Engy</td>
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<td>302</td>
<td>264</td>
<td>216</td>
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<td>Peak Strain Engy</td>
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<td>3.4</td>
<td>2.9</td>
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<tr>
<td>Swing Efficiency</td>
<td>%</td>
<td>24.5</td>
<td>20.2</td>
<td>26.1</td>
<td>26.8</td>
<td></td>
</tr>
</tbody>
</table>
Injuries

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

<table>
<thead>
<tr>
<th>Type of Injury</th>
<th>% of Amateur</th>
<th>% of Pro</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wrist [2, 8,17,18]</td>
<td>13-20</td>
<td>20-27</td>
</tr>
<tr>
<td>Elbow [16, 18 – 20]</td>
<td>25-33</td>
<td>7-10</td>
</tr>
<tr>
<td>Lower back [1, 8,17 – 20]</td>
<td>15-34</td>
<td>22-24</td>
</tr>
</tbody>
</table>
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

\[ Work_{\text{Golfer} \rightarrow \text{Club}} = \int_{t_2}^{t_1} \left( \sum \vec{F}_i \cdot \vec{V}_i + \sum \vec{T}_i \cdot \vec{\omega}_i \right) dt \]

- $\vec{F}$ 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 $\alpha, \beta, \gamma$ components respectively
Work - Energy

\[ Work_{\text{Golfer} \rightarrow \text{Club}} = \Delta KE_{\text{Club}} - \Delta SE_{\text{Shaft}} \]

- 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

\[ KE_{\text{shaft}} = \sum_{j=1}^{n} \left( \frac{1}{2} M_j V_{gj}^2 + \frac{1}{2} \left( I_{xj} \omega^2_{\alpha_j} + I_{yj} \omega^2_{\beta_j} + I_{zj} \omega^2_{\gamma_j} \right) \right) \]

\[ KE_{\text{head}} = \sum_{j=1}^{n} \left( \frac{1}{2} M_h V_{gh}^2 + \frac{1}{2} \left( I_x \omega^2_{\alpha} + I_y \omega^2_{\beta} + I_z \omega^2_{\gamma} + 2I_{xy} \omega_{\alpha} \omega_{\beta} + 2I_{yz} \omega_{\beta} \omega_{\gamma} + 2I_{xz} \omega_{\alpha} \omega_{\gamma} \right) \right) \]

\[ SE_{\text{shaft}} = \sum_{j=1}^{n} \left( K_{xj} \delta^2_{xj} + K_{yj} \delta^2_{yj} + K_{yj} \delta^2_{yj} + K_{Aj} \delta^2_{Aj} \right) \]
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


[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

