Relationship of Club Handle Twist Velocity to selected Biomechanical Characteristics of the Golf Drive

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PhD Dissertation Defense
Arizona State University
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Interesting to See What World Class Golfers Do During the Downswing

• They:
  – Maintain a Fixed Wrist Angle and,
  – Release the Wrist Angle Late,
  – Then Roll Arms and Twist Club Handle, to
  – Square the Club Face into Impact

• Some Twist the Handle Slowly
  – Low Handle Twist Velocity
  – As Low as ~600 °/s

• Some Twist the Handle Fast
  – High Handle Twist Velocity
  – As High as ~2400 °/s

• Which is Better?
• What are the Biomechanical Characteristics?
Define Mechanical Factors using a Deterministic Model

Dr. James Hay
Hay and Reid (1988)

How Does Handle Twist Velocity Affect the Outcome?

Final Ball Resting Position
Model from Club Handle to Ball Landing

- Club Handle Twist Velocity
  - Angular velocity about the long axis of the handle
Literature Review
2D Pendulum Models

Double Pendulum
- Williams (1967)
- Cochran and Stobbs (1968)
  - Search for the Perfect Swing
- Lampsa (1975)
- Budney and Bellow (1979)
- Campbell and Reid (1985)
- Milne and Davis (1992)
- Jorgensen (1999)
  - The Physics of Golf
  - Pickering and Vickers (1999)

Triple Pendulum
- Sprigings and Neal (2000)
- Sprigings and Mackenzie (2002)

Club would hit ball with heal?
3D Models

Nesbit (2007)
- Commissioned by the USGA
- Full-Body 15 Segment Model
- Club Shaft can rotate in all 3-axes
- Alpha, Beta, Gamma
- Gamma is Handle Twist
- Can add 1.5m/s to Swing Speed

MacKenzie and Sprigings (2009)
- Six Segment Model
- Arm can Rotate around Long Axis
- Allows the face to square up at impact

Image from:

Image from:
Cochran and Stobbs (1968), Search for the Perfect Swing
Rollers, Squares and Pushers

Roller Method
- High HTV
- Open Faced

Pusher Method
- Low HTV
- Closed Faced

Open Face Method
- High HTV
- Rollers

Closed Face Method
- Low HTV
- Pushers

Methods
System and Software

Capture, Calculations and Display

Protocol, Database and Reports
AMM3D Electromagnetic

- Polhemus, Inc.
  - Liberty Hardware
- Transmitter
  - Stationary 4” Cube
  - 3 Orthogonal Coils
  - Global Coordinate System
- Sensors
  - On Body and Club
  - Wired Moving ½” Cubes
  - 3 Orthogonal Coils
  - Local Coordinate Systems

**Advantages**
- 12 Sensor Full-Body Model
- Fast 240 Hz
- Real-Time
- 6 DOF (x, y, z, pitch, yaw, roll)
- Accurate Anatomical Alignment

**Disadvantages**
- Don’t have clubhead directly
- Compute it from rigid shaft model
Anatomical Alignment

• Local coordinate systems created in every body segment and club
  – Digitizing at least 3 bony landmarks on each segment and the club.
  – Medial/Lateral, Anterior/Posterior and Superior/Inferior axes in each segment
  – Using the Cross Product Method

• Shin is an easy example
Analysis Layout for Our Study
# Comparison Table and Database

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Adr</th>
<th>HB</th>
<th>Top</th>
<th>HD</th>
<th>Imp</th>
<th>HF</th>
<th>Fin</th>
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</thead>
<tbody>
<tr>
<td>Pelvis Rotation (Open-Closed)</td>
<td>deg</td>
<td>2.5 O</td>
<td>17.5 C</td>
<td>55.8 C</td>
<td>30.4 O</td>
<td>41.4 O</td>
<td>50.6 O</td>
<td>113.2 O</td>
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<td>23.8 F</td>
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<td>17.2 F</td>
<td>14.3 F</td>
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<td>14.5 F</td>
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<td>Pelvis Side Bend (Trail-Lead)</td>
<td>deg</td>
<td>0.3 L</td>
<td>3.7 L</td>
<td>8.5 L</td>
<td>11.7 T</td>
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<td>1.6 A</td>
<td>0.8 A</td>
<td>2.4 T</td>
<td>2.5 T</td>
<td>3.4 T</td>
<td>8.4 T</td>
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<td>Pelvis Thrust (Fwd-Back)</td>
<td>in</td>
<td>0.0</td>
<td>0.5 B</td>
<td>1.8 F</td>
<td>2.1 F</td>
<td>2.8 F</td>
<td>3.3 F</td>
<td>2.9 F</td>
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<td>Pelvis Lift (Up-Down)</td>
<td>in</td>
<td>0.0</td>
<td>0.0</td>
<td>1.8 D</td>
<td>1.1 U</td>
<td>1.5 U</td>
<td>1.3 U</td>
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<td>Thorax Sway (To-Away)</td>
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<td>1.4 A</td>
<td>1.2 A</td>
<td>0.0</td>
<td>2.0 A</td>
<td>4.5 A</td>
<td>5.8 T</td>
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<td>0.0</td>
<td>0.1 F</td>
<td>2.4 F</td>
<td>0.5 B</td>
<td>0.9 B</td>
<td>0.6 B</td>
<td>2.5 F</td>
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<tr>
<td>Thorax Lift (Up-Down)</td>
<td>in</td>
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<td>0.8 D</td>
<td>2.3 D</td>
<td>1.7 U</td>
<td>2.2 U</td>
<td>0.9 U</td>
<td>1.3 U</td>
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<td>13.9 C</td>
<td>47.9 C</td>
<td>27.9 C</td>
<td>20.5 C</td>
<td>5.8 C</td>
<td>31.5 O</td>
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<td>Spine (Flex-Ext)</td>
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<td>20.0 F</td>
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<td>51.0 E</td>
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<td>9.8 L</td>
<td>32.3 L</td>
<td>1.0 T</td>
<td>15.0 T</td>
<td>37.8 T</td>
<td>2.0 T</td>
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<td>13.7 C</td>
<td>19.5 C</td>
<td>4.5 C</td>
<td>0.6 C</td>
<td>3.8 O</td>
<td>77.4 O</td>
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<tr>
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<td>46.3 F</td>
<td>42.3 F</td>
<td>33.2 F</td>
<td>49.1 F</td>
<td>52.0 F</td>
<td>49.8 F</td>
<td>8.8 B</td>
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<tr>
<td>Head Side Bend (Trail-Lead)</td>
<td>deg</td>
<td>1.0 L</td>
<td>9.7 L</td>
<td>10.0 L</td>
<td>6.9 T</td>
<td>8.6 T</td>
<td>11.0 T</td>
<td>29.7 T</td>
</tr>
<tr>
<td>Head Sway (To-Away)</td>
<td>in</td>
<td>0.1 T</td>
<td>2.8 A</td>
<td>3.7 A</td>
<td>2.1 A</td>
<td>3.1 A</td>
<td>4.6 A</td>
<td>12.3 T</td>
</tr>
<tr>
<td>Head Thrust (Fwd-Back)</td>
<td>in</td>
<td>0.0</td>
<td>0.2 B</td>
<td>0.8 F</td>
<td>0.2 B</td>
<td>0.7 B</td>
<td>0.7 B</td>
<td>2.6 B</td>
</tr>
<tr>
<td>Head Lift (Up-Down)</td>
<td>in</td>
<td>0.0</td>
<td>0.5 D</td>
<td>0.2 D</td>
<td>0.5 D</td>
<td>0.3 D</td>
<td>0.7 D</td>
<td>8.2 U</td>
</tr>
<tr>
<td>Neck Rotation (Open-Closed)</td>
<td>deg</td>
<td>18.1 C</td>
<td>15.7 O</td>
<td>80.7 O</td>
<td>10.8 C</td>
<td>28.5 C</td>
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<td>71.3 C</td>
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<td>Neck (Flex-Ext)</td>
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<td>6.7 E</td>
<td>39.8 E</td>
<td>14.7 E</td>
<td>27.8 E</td>
<td>47.3 E</td>
<td>27.8 E</td>
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<td>Neck Side Bend (Trail-Lead)</td>
<td>deg</td>
<td>17.1 T</td>
<td>3.8 L</td>
<td>30.8 L</td>
<td>5.7 T</td>
<td>18.5 T</td>
<td>37.2 T</td>
<td>20.0 L</td>
</tr>
</tbody>
</table>
Databases of Swings

• Swings Captured at TPI in Oceanside, CA
  – 94 Male Professional Golfers from European and PGA Tour
  – 70 PGA Tour Professionals with Driving Statistics from www.pgatour.com
  – Two groups of 32, Lo-HTV and Hi-HTV
  – Also have 52 PGA Tour Winners
Statistics

• Correlations
  – Pearson Product-Moment Correlations on full groups
  – 70 for Driving Accuracy Test
  – 94 for All other Selected Parameters
  – With Handle Twist Velocity

• Analysis of Variance
  – Two groups of 32 golfers from the 70 and 94 groups
  – Lo-HTV and Hi-HTV
  – Compare means of Hi-HTV and Lo-HTV groups for each parameter using single factor ANOVAs
  – Family-wise significance level of $p < .05$
  – Bonferroni corrected for the number of tests done in each study to avoid Type 1 Errors
Limitations

• AMM3D measures club handle not clubhead

• Two Assumptions
  – Handle Twist Velocity is highly correlated with Clubhead Closing Speed
  – Rigid Clubhead Speed is highly correlated with Actual Clubhead Speed
Clubhead Closing Velocity

- **CCV > HTV for Driver**
  - Combination of both HTV and SPV
- **Vertical Shaft**
  - All HTV
  - Like Putting
- **Horizontal Shaft**
  - All SPV
  - Like Baseball

\[
\text{CCV} = \text{HTV} \sin (\theta) + \text{SPV} \cos (\theta)
\]

where \( \theta \) is the Lie Angle
e.g. 58° for a driver
Handle Twist Velocity and Clubhead Closing Velocity

- ENSO Motion Analysis System at Ping
- 150 players, 5 swings each
- \( CCV/HTV = 1.6 \)
- CCV is faster than HTV
- Strongly Correlated
  - \( r = 0.95 \)
  - \( R^2 = 0.89 \)

P. Wood, personal communication, May 16, 2014
Clubhead Speed - Rigid v Actual

- ENSO Motion Analysis System at Ping
- 150 players, 5 swings each
- 52 mph to 120 mph
- Actual > Rigid
- 2.7 ± 1.43 mph
- Strongly Correlated
- $r = 0.99$
- $R^2 = 0.99$

P. Wood, personal communication, May 16, 2014
Data from Pre-Captured Swings at TPI

- Human Subjects Exemption
- By Independent Review Board at ASU
- Data Already in Existence
- No Subject Identification Divulged
Study 1

Handle Twist Velocity Relationship to Clubhead Speed and Driving Accuracy
Definitions

Clubhead Speed at Impact

• Magnitude of the linear clubhead velocity
• How fast in m/s or mph of the clubhead is traveling

Driving Accuracy

• Percent of drives off the tee that come to rest in the fairway
• Found for each golfer on www.pgatour.com
Study 1: HYPOTHESES

- **Clubhead Speed at Impact**
  Golfers with high HTV will have higher clubhead speed at impact

- **Driving Accuracy**
  Golfers with low HTV have better driving accuracy
### Descriptive Statistics and Correlations with HTV

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Mean</th>
<th>SD</th>
<th>r</th>
<th>$R^2$</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clubhead Speed (m/s)</td>
<td>94</td>
<td>48.4</td>
<td>2.5</td>
<td>0.14</td>
<td>0.02</td>
<td>Weak</td>
</tr>
<tr>
<td>Driving Accuracy (%)</td>
<td>70</td>
<td>62.8</td>
<td>6.4</td>
<td>-0.14</td>
<td>0.02</td>
<td>Weak</td>
</tr>
</tbody>
</table>

For Clubhead Speed (m/s) with Handle Axial Velocity (°/s):

$y = 0.0012x + 46.837$

$R^2 = 0.0208$

For Driving Accuracy (%) with Handle Axial Velocity (°/s):

$y = -0.0029x + 66.595$

$R^2 = 0.0187$
**ANOVA with Hi-HTV v Lo-HTV**

<table>
<thead>
<tr>
<th></th>
<th>Hi-HTV</th>
<th></th>
<th>Lo-HTV</th>
<th></th>
<th>F[1,62]</th>
<th>p</th>
<th>p &lt; .025</th>
<th>Sig at</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clubhead Speed (m/s)</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>2.80</td>
<td>0.100</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td></td>
<td>48.9</td>
<td>2.5</td>
<td>48.0</td>
<td>2.0</td>
<td></td>
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<tr>
<td>Driving Accuracy (%)</td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td>0.98</td>
<td>0.320</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td></td>
<td>62.2</td>
<td>6.3</td>
<td>63.9</td>
<td>7.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Single Factor ANOVA Results ($p < .025$)
- No significant difference between groups for either:

  Clubhead Speed or Driving Accuracy
Clubhead Speed Hypothesis

A weak positive correlation was found \((r = 0.14)\)
And Hi-HTV group mean was faster than Lo-HTV group
48.9 m/s to 48.0 m/s
But not enough to produce a significant difference between groups

Hypothesis is not Supported

Golfers with high HTV DO NOT have significantly higher clubhead speed at impact than low HTV golfers

Strength of Correlation as per Dancey and Reidy (2004)
HTV and Clubhead Speed Discussion

• Possible speed gain
  – $v = \omega r$
  – Contact point is separated from rotation axis

• Nesbit (2005)
  – High gamma velocity of shaft can add 1.5m/s to the linear velocity of the clubhead at impact

• Cochran and Stobbs (1968)
  – Low HTV is a weaker swing because of the loss of the “screwdriver action”

• Hi-HTV group did have mean velocity 0.9m/s higher than the Lo-HTV group.
• But not enough for significance
Driving Accuracy Hypothesis

A weak negative correlation was found ($r = -0.14$)
And Lo-HTV group had slightly higher mean accuracy than Lo-HTV group
63.9% to 62.2%
But not enough to produce a significant difference between groups

![X] Hypothesis is not Supported

Golfers with low HTV **DO NOT** have significantly better driving accuracy than high HTV golfers

Strength of Correlation as per Dancey and Reidy (2004)
HTV and Driving Accuracy
Discussion

• Cochran and Stobbs (1968) and Suttie (2011)
  – Both say high HTV less accurate due to greater chance of miss-timing contact
  – Their comments were only anecdotal; no data

• Our Results Disagree
  – We found both Hi-HTV and Lo-HTV produce similar driving accuracy
Practical Application

• Instructors can teach either high or low HTV method with confidence that they both give acceptable results

• But must be consistent in body and arm actions as will be seen in Studies 2 and 3
Study 2
Handle Twist Velocity Relationship to Lead Wrist Velocities and Trail Elbow Velocity
Definitions

Velocities at Impact

• **Lead Wrist Supination Velocity**
  – Rolling of forearm and wrist
• **Lead Wrist Extension Velocity**
  – Extension of lead wrist

Velocities at Maximum

• **Lead Wrist Ulnar Deviation Velocity**
  – Lateral motion of the wrist
• **Lead Wrist Release Velocity**
  – Angle between forearm and club shaft
• **Trail Elbow Extension Velocity**
  – Back elbow extending

From: Mark Papas, www.revolutionarytennis.com
Lead Wrist Set Angle

- Rapid Release
- Fixed Angle
Lead Wrist Release Velocity

- **Rapid Release**
- **Fixed Angle**
- **Zero Velocity**

Graph showing the lead wrist release velocity over time. Peaks before impact.
Lead Wrist Angle 3DOF Components

Top
- Radial Dev.
- Extended
- Pronated

Downswing
- Flexion
- Extra Pronation
- Ulnar Dev.
- Supination

Impact
- Ulnar Dev.
- Flexed
- Supinated
Lead Wrist Release
3DOF Component Velocities

- Ulnar Velocity Peaks Before Impact
- Extension Velocity At Impact
- Supination Velocity is Largest at Impact
Study 2: HYPOTHESES

Lead Wrist Supination Velocity at Impact
Will show positive correlation with HTV and Hi-HTV group will be significantly faster than Lo-HTV group

Lead Wrist Extension Velocity at Impact
Hi-HTV group will be significantly faster than Lo-HTV group

Lead Wrist Ulnar Deviation Velocity at Maximum

Lead Wrist Release Velocity at Maximum

Trail Elbow Extension Velocity at Maximum
Will show no significant difference between groups
Descriptive Statistics and Correlation with HTV

<table>
<thead>
<tr>
<th>Angular Velocity</th>
<th>Mean (°/s)</th>
<th>SD (°/s)</th>
<th>r</th>
<th>$R^2$</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead Wrist Supination (Imp)</td>
<td>1569</td>
<td>338</td>
<td>0.68</td>
<td>0.46</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

Hypothesis is Supported

**Lead Wrist Supination Velocity at Impact**

Does show a moderate positive correlation with HTV

Strength of Correlation as per Dancey and Reidy (2004)

\[
y = 0.7588x + 577.29 \\
R^2 = 0.4647
\]
ANOVAs with Hi-HTV v Lo-HTV

<table>
<thead>
<tr>
<th>Wrist/Elbow</th>
<th>Hi-HTV (°/s)</th>
<th>Lo-HTV (°/s)</th>
<th>F[1,62]</th>
<th>p</th>
<th>Sig at</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead Wrist Supination (Imp)</td>
<td>1811</td>
<td>1295</td>
<td>58.1</td>
<td>0.000</td>
<td>Yes</td>
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<tr>
<td>Lead Wrist Extension (Imp)</td>
<td>433</td>
<td>446</td>
<td>0.1</td>
<td>0.813</td>
<td>No</td>
</tr>
<tr>
<td>Lead Wrist Ulnar Dev. (Max)</td>
<td>922</td>
<td>859</td>
<td>2.6</td>
<td>0.109</td>
<td>No</td>
</tr>
<tr>
<td>Lead Wrist Release (Max)</td>
<td>1249</td>
<td>1186</td>
<td>2.5</td>
<td>0.119</td>
<td>No</td>
</tr>
<tr>
<td>Trail Elbow Extension (Max)</td>
<td>931</td>
<td>851</td>
<td>3.4</td>
<td>0.070</td>
<td>No</td>
</tr>
</tbody>
</table>

- Single Factor ANOVA Results ($p < .01$)
- Significant difference for Lead Wrist Supination with Hi-HTV > Lo-HTV
- No Significant difference for all the other tested velocities
Study 2: Additional Hypothesis Results

- **Hypothesis is Supported**
  - **Lead Wrist Supination Velocity at Impact**
    Hi-HTV group IS significantly faster than Lo-HTV group

- **Hypothesis is not Supported**
  - **Lead Wrist Extension Velocity at Impact**
    Hi-HTV group IS NOT significantly faster than Lo-HTV group

- **Hypotheses are Supported**
  - **Lead Wrist Ulnar Deviation Velocity at Maximum**
  - **Lead Wrist Release Velocity at Maximum**
  - **Trail Elbow Extension Velocity at Maximum**
    Do show NO significant difference between groups
Lead Wrist Supination Velocity at Impact

Discussion

- Cochran and Stobbs (1968)
- MacKenzie and Sprigings (2009)
  - Both research groups state that it is the arm roll that twists the club handle and squares club face for impact
- Our data suggests this is true
  - Moderate Correlation between Lead Wrist Supination Velocity and HTV
  - Mean Hi-HTV Group 40% faster than Lo-HTV Group 1811°/s v 1295°/s, certainly significant
Lead Wrist Extension Velocity

- Hi-HTV Group not significantly faster
- 446°/s to 433°/s
- Interesting that these velocities are positive
- Means that Lead Wrist is Extending at Impact
- 92 of the 94 golfers in our database show this characteristic
At Impact:
The lead wrist is in a flexed position but has an extending action.
Study 3
Handle Twist Velocity
Relationship to Pelvis and Thorax Rotation and Side Bend
Definitions

Pelvis and Thorax Rotation at Impact

Pelvis and Thorax Side Bend at Impact
What we Have Seen from 3D

- Low Handle Twist Velocity
- High Handle Twist Velocity
Study 3: HYPOTHESES

Pelvis and Thorax Rotation at Impact
Will show negative correlation with HTV and Lo-HTV group will be significantly more rotated open than Hi-HTV group

Pelvis and Thorax Side Bend at Impact
Will show negative correlation with HTV and Lo-HTV group will be significantly more side bent to trail side than Hi-HTV group
## Descriptive Statistics and Correlations with HTV

<table>
<thead>
<tr>
<th></th>
<th>Mean (°)</th>
<th>SD (°)</th>
<th>$r$</th>
<th>$R^2$</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thorax Rotation (Open)</td>
<td>27</td>
<td>9</td>
<td>-0.40</td>
<td>0.16</td>
<td>Moderate</td>
</tr>
<tr>
<td>Thorax Side Bend (Trail)</td>
<td>31</td>
<td>5</td>
<td>-0.50</td>
<td>0.25</td>
<td>Moderate</td>
</tr>
<tr>
<td>Pelvis Rotation (Open)</td>
<td>41</td>
<td>9</td>
<td>-0.36</td>
<td>0.13</td>
<td>Weak</td>
</tr>
<tr>
<td>Pelvis Side Bend (Trail)</td>
<td>9</td>
<td>4</td>
<td>-0.28</td>
<td>0.08</td>
<td>Weak</td>
</tr>
</tbody>
</table>

### Thorax Rotation (Open) vs. Handle Twist Velocity
- $y = -0.0121x + 43.327$
- $R^2 = 0.1617$

### Thorax Side Bend (Trail) vs. Handle Twist Velocity
- $y = -0.0089x + 42.54$
- $R^2 = 0.2514$

### Pelvis Rotation (Open) vs. Handle Twist Velocity
- $y = -0.011x + 55.467$
- $R^2 = 0.1323$

### Pelvis Side Bend (Trail) vs. Handle Twist Velocity
- $y = -0.0035x + 13.83$
- $R^2 = 0.0791$
Study 3: Hypotheses are Supported

**Thorax Rotation and Side Bend at Impact**
Do show a moderate negative correlation with HTV

**Pelvis Rotation and Side Bend at Impact**
Do show a weak negative correlation with HTV

Strength of Correlation as per Dancey and Reidy (2004)
## ANOVAs with Hi-HTV v Lo-HTV

<table>
<thead>
<tr>
<th>Pelvis and Thorax Angles at Impact</th>
<th>Hi-HTV (°)</th>
<th>Lo-HTV (°)</th>
<th>F[1,62]</th>
<th>p</th>
<th>Sig at p &lt; .0125</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thorax Rotation (Open)</td>
<td>23</td>
<td>7</td>
<td>31</td>
<td>9</td>
<td>15.9</td>
</tr>
<tr>
<td>Pelvis Rotation (Open)</td>
<td>37</td>
<td>6</td>
<td>43</td>
<td>7</td>
<td>9.7</td>
</tr>
<tr>
<td>Thorax Side Bend (Trail)</td>
<td>28</td>
<td>5</td>
<td>34</td>
<td>5</td>
<td>27.1</td>
</tr>
<tr>
<td>Pelvis Side Bend (Trail)</td>
<td>8</td>
<td>3</td>
<td>11</td>
<td>4</td>
<td>10.2</td>
</tr>
</tbody>
</table>

- Single Factor ANOVA Results ($p < .0125$)
- Significant difference for all body angles with Lo-HTV > Hi-HTV
Study 3: Hypotheses are Supported

Pelvis and Thorax Rotation at Impact
Lo-HTV group is significantly more rotated open than Hi-HTV group

Pelvis and Thorax Side Bend at Impact
Lo-HTV group is significantly more side bent to trail side than Hi-HTV group
HTV with Rotation and Side Bend Discussion

<table>
<thead>
<tr>
<th></th>
<th>Hi-HTV</th>
<th>Lo-HTV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rotation (Open)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thorax</td>
<td>23°</td>
<td>31°</td>
</tr>
<tr>
<td>Pelvis</td>
<td>37°</td>
<td>43°</td>
</tr>
<tr>
<td><strong>Side Bend (Trail)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thorax</td>
<td>28°</td>
<td>34°</td>
</tr>
<tr>
<td>Pelvis</td>
<td>8°</td>
<td>11°</td>
</tr>
</tbody>
</table>

Less Side Bend

More Side Bend

Less Rotation

More Rotation
Instructional Literature

Cochran and Stobbs (1968)
- Rollers
  - Use Arms More
  - Roll Club Rapidly
  - Less Body Action
- Pushers
  - Less Arm Action
  - Use Body More
  - Rotate Body Faster

Suttie (2011)
- Open-Face Method
  - Active Closing of Club Face
  - “Handsy” Swing
  - Medium to Slow Hip Speed
- Closed-Face Method
  - Less Twist of the Club needed
  - Faster Hips Needed
  - More Open at Impact
Other Studies - Rotation Values

<table>
<thead>
<tr>
<th>Rotation Angle</th>
<th>Type</th>
<th>Pelvis</th>
<th>Thorax</th>
<th>Skill Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheetham</td>
<td>Hi-HTV</td>
<td>37°</td>
<td>23°</td>
<td>Tour Pro</td>
</tr>
<tr>
<td></td>
<td>Lo-HTV</td>
<td>43°</td>
<td>31°</td>
<td>Tour Pro</td>
</tr>
<tr>
<td>McTeigue et al.</td>
<td>PGA Male</td>
<td>32°</td>
<td>26°</td>
<td>Tour Pro</td>
</tr>
<tr>
<td></td>
<td>PGA Senior</td>
<td>34°</td>
<td>28°</td>
<td>Senior Pro</td>
</tr>
<tr>
<td></td>
<td>Amateur</td>
<td>35°</td>
<td>27°</td>
<td>Amateur</td>
</tr>
<tr>
<td>Myers et al.</td>
<td>Hi Vel</td>
<td>38°</td>
<td>25°</td>
<td>Amateur</td>
</tr>
<tr>
<td></td>
<td>Med Vel</td>
<td>35°</td>
<td>23°</td>
<td>Amateur</td>
</tr>
<tr>
<td></td>
<td>Lo Vel</td>
<td>29°</td>
<td>20°</td>
<td>Amateur</td>
</tr>
<tr>
<td>Horan et al.</td>
<td>Male</td>
<td>44°</td>
<td>26°</td>
<td>Skilled</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>50°</td>
<td>29°</td>
<td>Skilled</td>
</tr>
</tbody>
</table>

- All are open at impact with both pelvis and thorax
- Pelvis is more open than thorax
- None are close to square at impact. So definitely not same as at address
Practical Applications
New Instructional Information

• Valuable to know what the elite players do
• Both handle twist techniques can be successful
• Rolling the arms more in the downswing will increase handle twist velocity and clubhead closing velocity
• Lead wrist is extending at impact

• Important to be consistent in teaching the wrist and body characteristics that match
  – Don’t force a high HTV golfer to be more open and side bent at impact
  – Unless you also change their arm and club twist action
New High Quality Databases

• Now have several high quality databases of the best golfers in the world with full-body motion capture data
  – 94 PGA and European Tour Golfers
  – 32 High HTV PGA and European Tour Golfers
  – 32 Low HTV PGA and European Tour Golfers
  – 51 PGA Tour Winners

• Quality data for future studies and education
Acknowledgments

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Mr. Dave Phillips

Dr. Paul Wood
Dr. Erik Henrikson

Thank You
Thank You