

TPI 3D Biomechanics Report

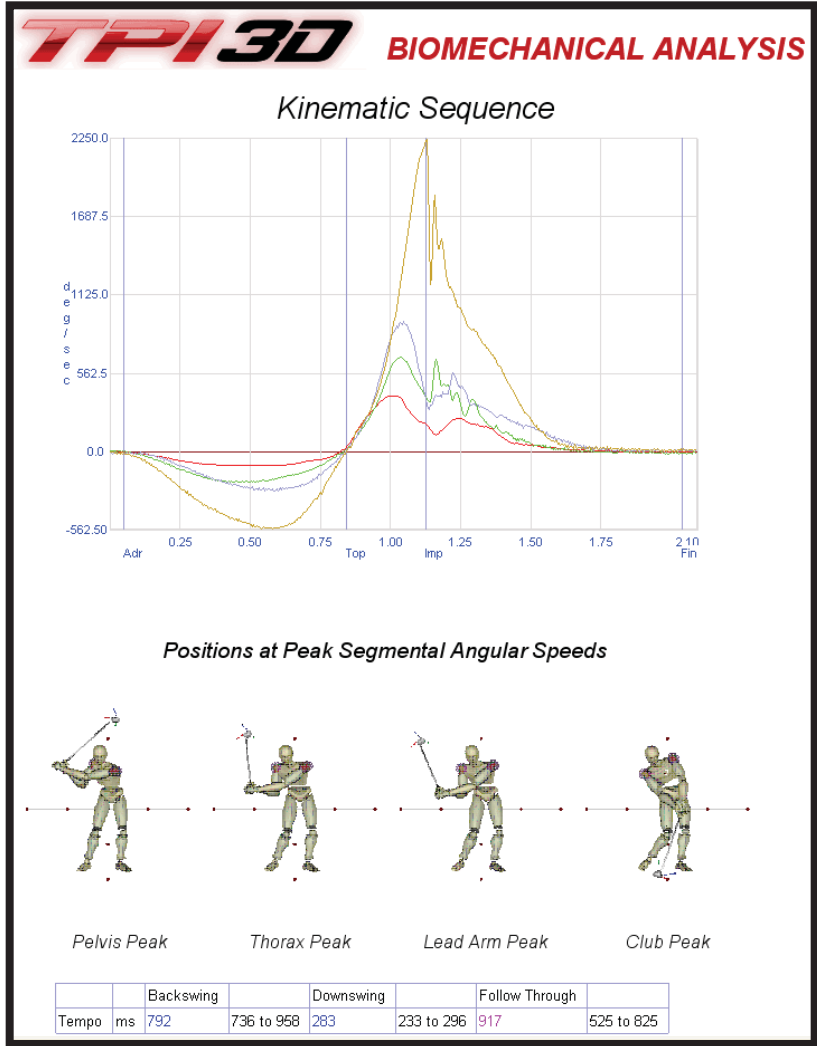
Interpreting the Data



Biomechanics Comparative Report

TPI-3D COMPREHENSIVE BIOMECHANICS REPORT REVIEW

Page 2:



On the second page we highlight the entire Kinematic Sequence and focus on the downswing phase with visual references. Notice the pictures of the golfer show the body position at each of the peak rotational speeds from left to right; pelvis peak, thorax peak, lead arm peak, and club peak. The pictures should clearly show (looking at the position of the golf club) that the pelvis peaked first, then the thorax, then the arm and then the club. The peak for the thorax and arm will be very close so these two pictures should show the club at almost the same location. There should be a larger time between the pelvis peak and thorax peak; and again between the arm peak and the club peak. The club rotational speed should peak very close to impact.

Tempo Table:

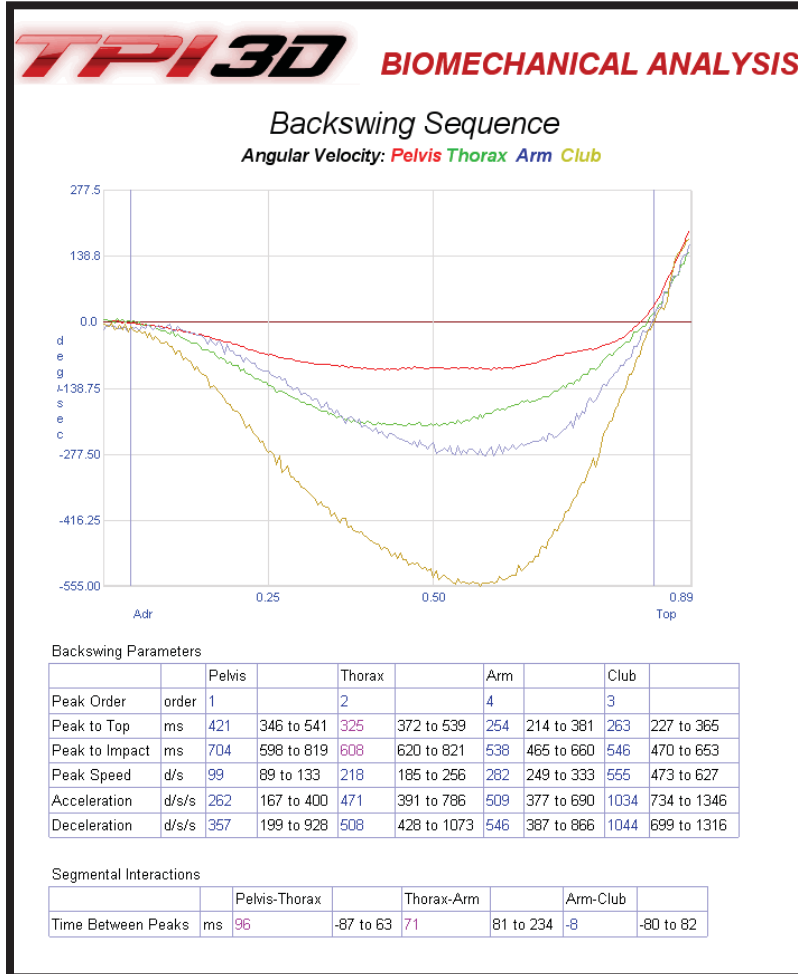
The bottom of the page shows the player's tempo - the time taken for the backswing, downswing and follow through. Backswing is from address to top, downswing is from top to impact, and follow through is from impact to finish. Tempo is measured in milliseconds. Milliseconds are thousands of a second so, for example, 250 msec is equivalent to 0.250 seconds (a quarter of a second).

Our current average PGA Tour tempos are:

- 736-958 msec for the backswing (this is the mean +/- one standard deviation)
- 233-296 msec for the downswing (this is the mean +/- one standard deviation)
- 525-825 msec for the follow through (this is the mean +/- one standard deviation)

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Page 3:



Backswing Sequence:

This page shows curves and parameters from the backswing section of the kinematic sequence graph.

Backswing Graph

The graph shows the kinematic sequence zoomed in on the backswing phase. The four curves are the angular velocity of pelvis (red), thorax (green), lead arm (blue) and club (brown). Angular velocity is measured in degrees per second.

Backswing Parameters Table

Peak Order

The order in which each body segment reaches its highest speed in the backswing.

Peak to Top

The time in milliseconds from the peak (minimum) point, for each segment, to the top of backswing (which is when the club turns around).

Peak Speed

The peak value in degrees per second for each body segment. The value is shown on the graph as negative which means it is the backswing.

Acceleration

This is the average acceleration (speed up) of each segment during the first part of the backswing. It is the slope of a line from each segment's address point to its peak in the backswing. The units are degrees per second per second (d/s/s).

Deceleration

This is the average deceleration (slow down) of each segment during the latter part of the backswing. It is the slope of a line from each segment's peak to top. The units are degrees per second per second (d/s/s).

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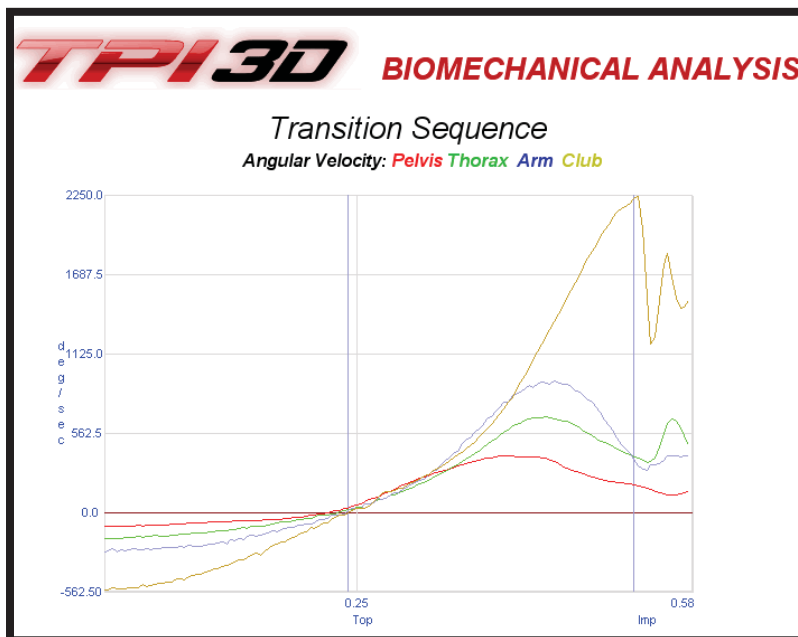
Page 3 cont.:

Segmental Interactions Table

Time between Peaks

This is the time in milliseconds between the peak speeds of each segment; pelvis to thorax, thorax to arm, and arm to club. If the time is negative then the distal segment peaked first.

Page 4:



Transition Sequence:

This page shows the kinematic sequence information specifically around the Transition Phase of the golf swing.

Transition Sequence Graph

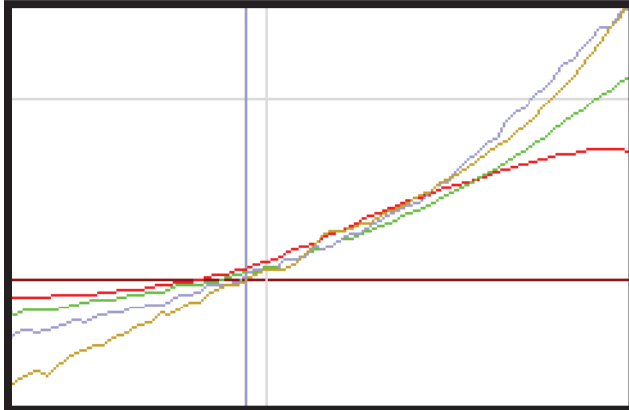
The graph on this page shows the kinematic sequence zoomed in on the transition phase. The four curves are the angular velocity of pelvis (red), thorax (green), lead arm (blue) and club (brown). The transition phase is the time from the first segment turn around to the last segment turn around. The biomechanically efficient

sequence of transition is pelvis, thorax, lead arm, club.

Any part of the curve below the black horizontal zero line is in the backswing, any part that is above this line is in the downswing. For the example above, starting from the left of the graph we see that the red (pelvis) line crosses zero first, then the green (thorax) line, then the blue (lead arm) and finally the brown (club). The club crosses exactly at top of backswing because this is our definition of top; the point at which the club shaft changes direction. Since the x-axis of the graph is time, the distance from when the red curve crosses zero to when the brown line crosses zero is the time from when the pelvis changed direction to when the club changes direction. The transition sequence show above is considered a good one as far as the order is concerned, that is, a good transition order is pelvis, thorax, lead arm, and club.

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Page 4 cont.:



The amount of time that the red curve is on top of the green curve after it has crossed the zero line gives an indication of how much transitional spine stretch (X-Factor Stretch) is occurring, since when the red is on top of the green it means that the pelvis is rotating faster than the thorax and hence the spine stretch is increasing. This same rule can be applied to each curve or body segment. Look at when the green crosses the zero line. The time that it is on top of the blue line after crossing zero indicates that shoulder stretch is

occurring, because the thorax is rotating faster than the lead arm and the shoulder angle must therefore be closing.

Finally after the blue curve has crossed zero means that the lead arm is in the downswing. So the time it stays on top of the brown curve after crossing zero indicates how much wrist stretch is occurring.

Due to the structure of muscles and connective tissue, it is advantageous to cause the muscle and joint to get this extra stretch during the transition period. It helps transmit more energy and speed to the following body segment. If the transition sequence described above is not optimal, elastic energy from the muscles and joint is lost.

Transition Parameters Table

Transition Parameters									
		Pelvis		Thorax		Arm		Club	
Transition Order	order	1		2		3		4	
Transition to Top	ms	21	17 to 94	13	4 to 58	4	-6 to 30	0	0 to 0
Transition to Peak	ms	175	187 to 263	208	185 to 264	208	170 to 237	283	232 to 294
Transition to Impact	ms	304	286 to 355	296	259 to 333	288	244 to 308	283	233 to 296
Transition Acceleration	d/s/s	1530	757 to 1682	1628	1026 to 2340	2694	1893 to 3958	3540	2724 to 5730

Transition Order

The order in which each body segment turns around from backswing to downswing.

Transition to Peak

The time from the transition of each segment to the peak speed of the same segment. Measured in milliseconds.

Transition to Impact

The time from the transition of each segment to impact; measured in milliseconds.

Transition Acceleration

The average acceleration of each body segment during its transition from backswing to forward swing, (measured 25ms either side of transition). This measurement gives an idea of the torque that is applied to that segment during transition.

TPI-3D COMPREHENSIVE BIOMECHANICS REPORT REVIEW

Page 4 cont.:

Segmental Interactions Table

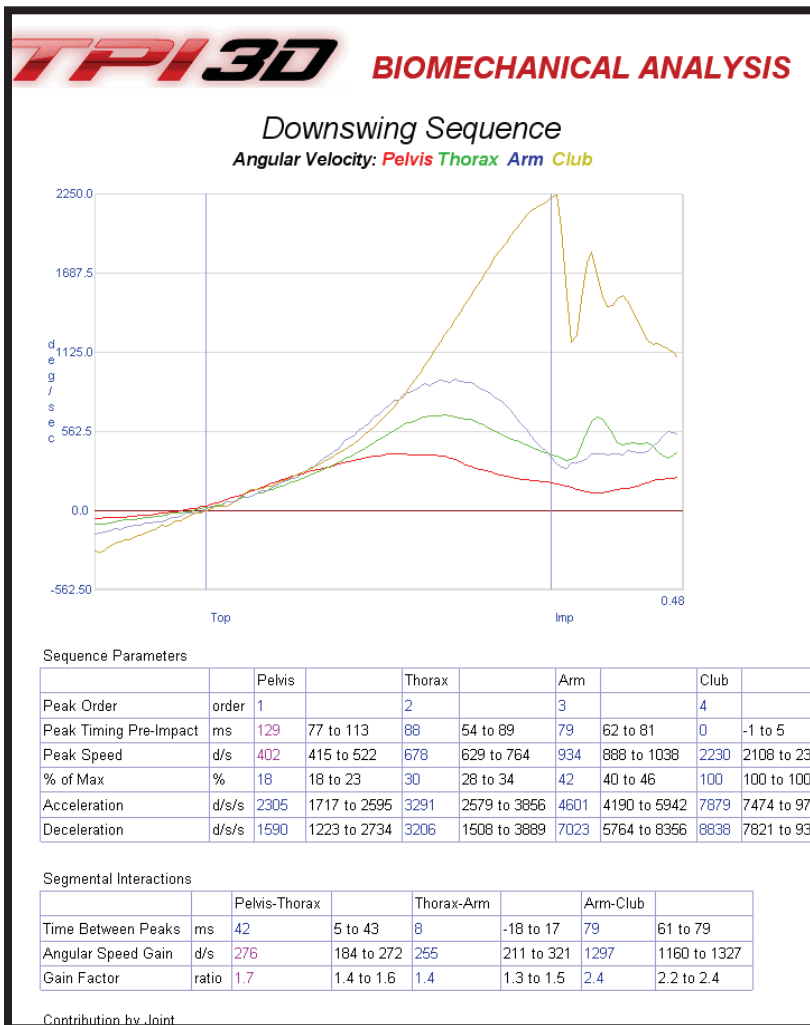
Segmental Interactions							
		Pelvis-Thorax		Thorax-Arm		Arm-Club	
Time Between Transitions	ms	8	-6 to 55	8	-1 to 40	4	-6 to 30

Time between Transitions

This is the time in milliseconds

between the transitions of each segment; pelvis to thorax, thorax to arm and arm to club. If the time is negative then the distal (outside) segment peaked first.

Page 5:



Downswing Sequence:

This page shows curves and parameters from the downswing section of the kinematic sequence graph (the area from top to impact). This is the key section of the graph so review page 14 for a full explanation of the Kinematic Sequence.

Downswing Sequence Graph

This is a graph of pelvis (red), thorax (green), lead arm (blue) and club (brown) angular speeds. It is zoomed in between top of backswing and impact. It shows the relationships of the peaks and the acceleration-deceleration characteristics of each segment during the downswing.

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Page 5 cont.:

Sequence Parameters Table

Sequence Parameters									
		Pelvis		Thorax		Arm		Club	
Peak Order	order	1		2		3		4	
Peak Timing Pre-Impact	ms	129	77 to 113	88	54 to 89	79	62 to 81	0	-1 to 5
Peak Speed	d/s	402	415 to 522	678	629 to 764	934	888 to 1038	2230	2108 to 2306
% of Max	%	18	18 to 23	30	28 to 34	42	40 to 46	100	100 to 100
Acceleration	d/s/s	2305	1717 to 2595	3291	2579 to 3856	4601	4190 to 5942	7879	7474 to 9734
Deceleration	d/s/s	1590	1223 to 2734	3206	1508 to 3889	7023	5764 to 8356	8838	7821 to 9375

This table shows values for each body segment in the downswing sequence, including pelvis, thorax, lead arm and club.

Peak Order

This is the order in which the segments reach their highest rotational speed after which they should decelerate before impact. The biomechanically efficient sequence is pelvis, thorax, lead arm and club. This would be shown as 1,2,3,4. The numbers show the order in which the segments peak.

Peak Timing

This is the time that the peak of each segment occurs, measured in milliseconds before impact. If the sequence is in the expected order, then the numbers will get progressively smaller from pelvis to club, that is, the larger the number the earlier it is before impact. The numbers should always be positive.

Peak Speed

This is the maximum rotational speed that each segment reaches during the downswing. It is measured in degrees per second.

% of Max

This is the speed of each segment (pelvis, thorax and lead arm) with respect to the club peak speed, presented as a percentage. The calculation is (segment peak) / (club peak) * 100.

Acceleration

This is the average acceleration (speed up) of each segment during the initial part of the downswing. It is the slope of a line from each segment’s transition point to its peak. The units are degrees per second per second (d/s/s).

Deceleration

This is the average deceleration (slow down) of each segment during the latter part of the downswing before impact. It is the slope of a line from each segment’s peak to impact. The units are degrees per second per second (d/s/s).



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Page 5 cont.:

Segmental Interactions Table

Segmental Interactions							
		Pelvis-Thorax		Thorax-Arm		Arm-Club	
Time Between Peaks	ms	42	5 to 43	8	-18 to 17	79	61 to 79
Angular Speed Gain	d/s	276	184 to 272	255	211 to 321	1297	1180 to 1327
Gain Factor	ratio	1.7	1.4 to 1.6	1.4	1.3 to 1.5	2.4	2.2 to 2.4

Time Between Peaks

This is the time in milliseconds between each of the peak angular velocity points of each of the body segments

and the club, specifically between pelvis and thorax, thorax and lead arm, lead arm and club. If the value is negative then the second segment peaked first. For an effective sequence the values should all be positive, meaning that the distal segment peaked after the proximal one.

Angular Speed Gain

This is the angular speed gain from each proximal segment to the distal one, taken in pairs. It is measured in degrees per second and gives an indication of how much that "joint" contributed to the increase in speed from segment to segment.

Gain Factor

This is the ratio of the second segment's peak speed to the first one's. It shows how much speed gain occurred across each joint; for example; 1.5 for Pelvis-Thorax means that the peak thorax speed was 1.5 times faster than the pelvis peak speed.

Contribution by Joint Table

Contribution by Joint									
		Legs		Core		Shoulder		Wrist	
% Contribution	%	18	18 to 23	12	8 to 12	11	9 to 14	58	53 to 59

% Contribution

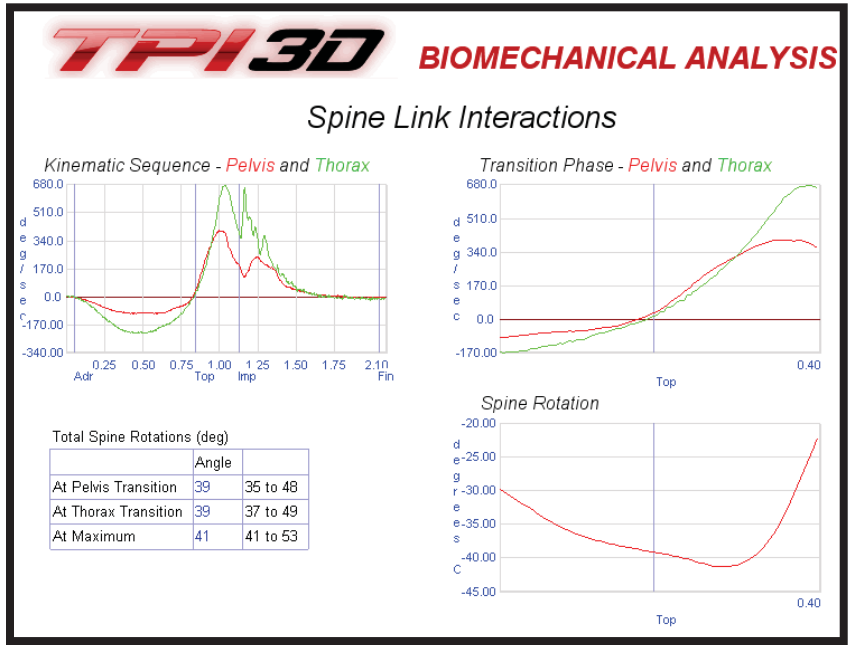
This measurement gives an indication of the percent contributed by each joint to

the angular velocity of the club at impact. The calculation is (speed gain across the joint) / (peak club speed) * 100. For the pelvis it is just (pelvis speed) / (peak club speed) * 100. Note that this should just be used as an indicator since the velocities don't peak at the same time and are measured around different axes. It is still, however, a very useful measurement.

Notes:

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Page 6:



Spine Link Interactions:

This page provides information on the interactions between the pelvis and thorax. It breaks out the pelvis and thorax kinematic sequence graphs and also shows the spine rotation curve.

Kinematic Sequence – Pelvis and Thorax Graph

The rotation speed of the pelvis and thorax segments for the whole swing.

Transition Phase – Pelvis and Thorax Graph

The rotational speed of the pelvis and thorax segments zoomed in around the top of backswing area.

Spine Rotation Graph

The rotation of the thorax with respect to the pelvis; this has been commonly known as the X-Factor, Separation or Coil. This is an angle and is measured in degrees.

Total Spine Rotations Table

These are the values of the spine rotation (X-Factor) as specific instances during the transition phase.

At Pelvis Transition

Spine rotation value at the instant that the pelvis turns from backswing to downswing. This point is the beginning of the transitional spine stretch (X-Factor Stretch).

At Thorax Transition

Spine rotation value at the instant that the thorax turns from backswing to downswing. This point is the end of the contra-directional stretch portion of the transitional spine stretch (X-Factor Stretch).

At Maximum

Spine rotation value at the instant that the pelvis and thorax are rotating in the downswing at the same speed. This point is the end of the ipsi-directional stretch portion of the transitional spine stretch (X-Factor Stretch) and, in fact, the end of this stretch period all together.



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Page 6 cont.:

Transitional Spine Rotation (Stretch)						
	Angle (deg)		Time (ms)		Rate (d/s)	
Contra-Directional	0	0 to 3	8	5 to 50	24	7 to 73
Ipsi-Directional	2	0 to 6	113	30 to 140	20	6 to 65
Total Stretch	2	0 to 9	121	47 to 179	21	8 to 68

Transitional Spine Rotations Table

This table expands the Transitional Spine Stretch into several portions; Contra-Directional Stretch, Ipsi-directional Stretch and the Total Stretch (X-Factor Stretch). It also reports these as the angle of stretch,

time of stretch and rate of stretch. For a comprehensive discussion of these measurements and a little bit about backswing also, see the "Spine Rotation from the Kinematic Sequence Graph" discussion at the end of this section.

Transitional Timings Table

Transitional Timings (ms)				
	Pelvis		Thorax	
To Club Transition	21	17 to 94	13	4 to 58
To Impact	304	286 to 355	296	259 to 333

Transitional Accelerations (d/s/s)				
	Pelvis		Thorax	
Acceleration	1530	757 to 1682	1628	1026 to 2340

To Club Transition

Time from pelvis or thorax turn around to when the club turns around; measured in milliseconds. Note that club turn around is also the definition of top of backswing.

To Impact

Time from pelvis or thorax turn around to impact; measured in milliseconds.

Transitional Accelerations

The average acceleration of pelvis and thorax during its transition from backswing to downswing, (measured 25 msec either side of transition). This measurement gives an idea of the torque that is applied to each segment during transition; measured in degrees per second per second.

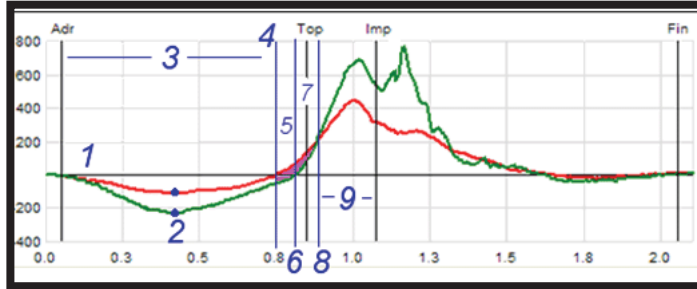
Notes:



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Page 6 cont.:

Spine Rotation from the Kinematic Sequence Graph



Y-Axis: Pelvis (red) and thorax (green) angular velocity components about an inferior/superior (down/up) axis in each segment (note the axis follows the segment), measured in degrees per second.

X-Axis: Time in Seconds.

Vertical Black lines: These represent times of Address, Top, Impact and Finish.

Events and Phases

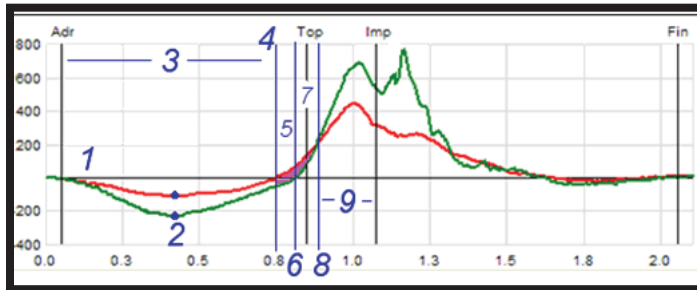
Blue numbers are now described in detail and assume we are looking down on a right handed golfer:

1. Pelvis and thorax begin to rotate clockwise in the backswing; thorax quickly outpaces the pelvis; opening up the spine rotation angle (X-Factor). Since the slope of both curves is negative (until point 2) they are both accelerating backwards, which implies there is a clockwise torque acting on both the thorax and the pelvis.
2. This is the point of maximum backswing speed of both the pelvis and thorax. Here, (in this case) both pelvis and thorax begin to slow down and the slope of the curves becomes positive. This implies that a counterclockwise torque is now acting on both segments, but their momentum and the momentum of the arms and club carry them through to their respective transition points (points 4 and 6).
3. This is the whole backswing phase; during this phase both pelvis and thorax are traveling clockwise and the spine angle is opening. The amount of turn of the pelvis could be measured by summing the area between the red curve and the horizontal zero line (black); similarly for the thorax using the green line. The area between the red and green lines represents the amount of spine opening (X-Factor) at point 4.
4. This point is the time at which the pelvis speed is zero and the pelvis begins the forward swing, so it is the transition point or top of backswing for the pelvis. The counterclockwise torque mentioned in point 2 has finally stopped the pelvis and is now twisting and accelerating it into the down swing. The slope of the curve here gives a measure of the amount of acceleration. Notice that the thorax is still going backwards, so the spine angle is still opening even though the pelvis is turning forward.
5. During phase 5 the pelvis is rotating forwards (counterclockwise) while the thorax is still rotating backwards (clockwise); they are both rotating in different directions; this is creating extra rotational spine stretch; We call this portion of the transitional spine stretch, the "contradirectional stretch" since both the pelvis and thorax on either side of the lumbar and lower thoracic spine are turning in opposite directions; note that this concept works on any joint.

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Page 6 cont.:

Spine Rotation from the Kinematic Sequence Graph cont.



6. At this point the thorax rotation speed is zero and the thorax turns around into the downswing. The torque mentioned in point 2 has finally overpowered the momentum of the thorax and is now turning and accelerating the thorax into the forward swing. The slope of the green curve here gives a measure of the amount of acceleration. From now

both the pelvis and thorax are turning forward in the downswing but the spine rotation angle is still increasing and the X-Factor is still stretching because the pelvis is rotating faster than the thorax (the red curve is higher than the green curve). We call this ipsi-directional stretch since the joint is still stretching open but the segments on either side are moving in the same direction.

7. During phase 7 both pelvis and thorax are rotating in the downswing; pelvis is still out running the thorax and the spine separation is still increasing, but the thorax speed is catching the pelvis speed (slope of green curve is increasing). This is the ipsi-stretch period.

8. At this point the pelvis and thorax have the same speed, but the thorax has not caught up with the pelvis, in fact, this is the point of maximum spine rotational separation (maximum X-Factor). So the area between the red and green curves from point 4 to point 8 gives the total value of the spine rotational stretch (X-Factor Stretch). This is the increase in the spine separation from the point that the pelvis turns around till the point that the spine separation begins to close. The purple area on the graph.

9. A lot happens during phase 9. The thorax is now rapidly closing the gap with the pelvis. The pelvis peaks in speed before the thorax and begins to decelerate. The thorax then peaks and it begins to decelerate. When the area between the green and red curves from point 8 on equals the area between them before point 8 then the thorax has finally closed the gap on the pelvis. In most cases this happens slightly after impact in the follow through.

Phases

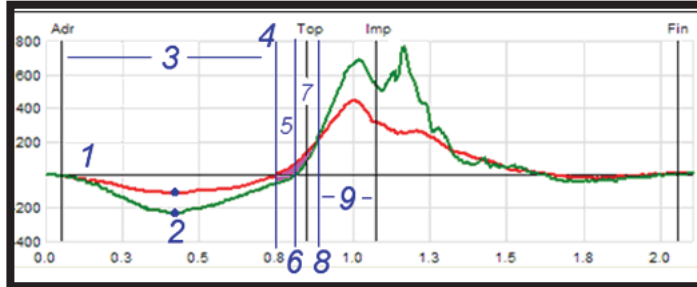
Backswing (3): This is the spine rotation opening phase; pelvis and thorax both turning backwards; thorax turning faster than pelvis; larger negative value; X-Factor increasing.

Contra-Directional Stretch (5): This is the spine contra-directional stretch phase; pelvis in downswing, thorax still in backswing, spine rotation angle opens more; first part of the X-Factor Stretch.

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Page 6 cont.:

Spine Rotation from the Kinematic Sequence Graph cont.



Phases cont.

Contra-Directional Stretch (5): This is the spine contra-directional stretch phase; pelvis in downswing, thorax still in backswing, spine rotation angle opens more; first part of the X-Factor Stretch.

Ipsi-Directional Stretch (7): This is the spine ipsi-directional stretch; ipsi means "the same"; both pelvis and thorax are turning in the same direction; spine rotational stretch continues even though both are turning forward because pelvis is turning faster than thorax.

Transitional Spine Stretch (5+7): This is the total spine rotational stretch or X-Factor Stretch; it is the extra opening of the spine angle (X-Factor) after the pelvis turns from backswing to downswing; note that it is not after the club turns around but after the pelvis turns around.

Closing the Gap (9): This is the spine closing phase; the thorax is catching the pelvis and the X-Factor is closing.

Stretch-Shorten Cycle Rational

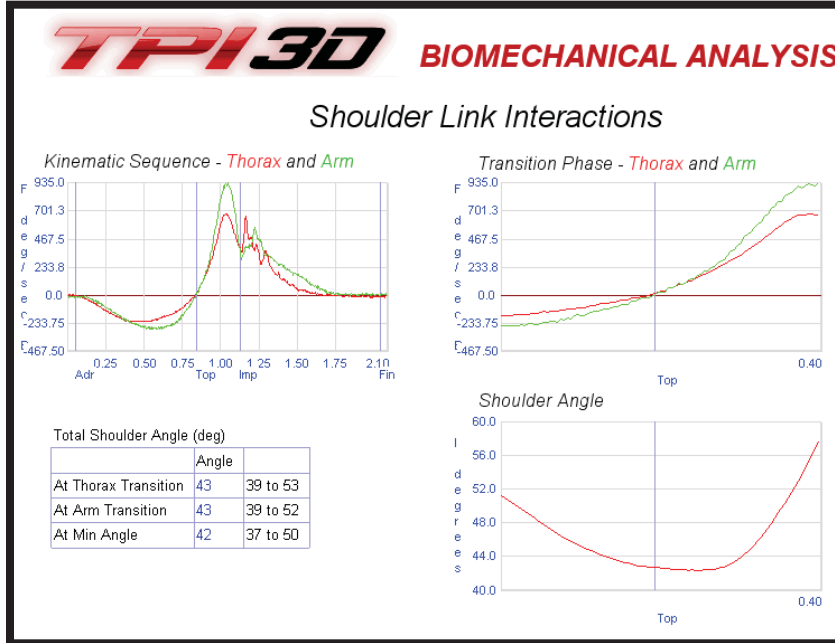
Eccentric Phase – Includes three phases of the graph above: Phase 3 – the backswing until the pelvis turns around, Phase 5 – the contra-directional stretch where pelvis and thorax are moving in opposite directions, Phase 7 – the ipsi-directional stretch where pelvis and thorax are moving in the same forward direction

Amortization Phase - There is none if the golfer doesn't stop at the top.

Concentric Phase - Phase 9 the downswing after the pelvis and thorax speeds become equal, until the gap is closed and the spine rotation angle becomes zero. Note that this is not usually exactly at impact it is usually after impact, early in the follow through phase.

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Page 7:



Shoulder Link Interactions

This page breaks out the thorax and lead upper arm kinematic sequence graphs and also shows the shoulder angle curve.

Kinematic Sequence – Thorax and Arm Graph

The rotation speed of the thorax and lead upper arm segments for the whole swing.

Transition Phase – Thorax and Arm Graph

The rotation speed of the thorax and lead upper arm segments zoomed in around the top of backswing area.

Shoulder Angle Graph

The angle between the thorax and the lead upper arm measure between a line along the lead upper arm and its projection onto the frontal plane of the thorax; the smaller the angle the closer the lead arm is to the thorax; it is measured in degrees.

Total Shoulder Angle Table

At Thorax Transition

Shoulder angle at the instant that the thorax turns from backswing to downswing.

At Arm Transition

Shoulder angle at the instant the lead upper arm turns from backswing to downswing.

At Min Angle

The minimum value of the shoulder angle near top of backswing; this is when the shoulder joint is in maximum stretch.

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Page 7 cont.:

Transitional Shoulder Stretch						
	Angle (deg)		Time (ms)		Rate (d/s)	
Contra-Directional	0	0 to 2	8	0 to 40	16	6 to 53
Ipsi-Directional	0	0 to 3	63	24 to 111	6	6 to 37
Total Stretch	0	0 to 5	71	33 to 141	7	7 to 42

Transitional Timings (ms)				
	Thorax		Lead Arm	
To Club Transition	13	4 to 58	4	-6 to 30
To Impact	296	259 to 333	288	244 to 308

Transitional Shoulder Stretch Table

This table expands the Transitional Shoulder Stretch into several portions; Contra-Directional Stretch, Ipsi-directional Stretch and the Total Stretch. It also reports these as the angle of stretch, time of stretch and rate of stretch.

Contra-Directional

This is the shoulder stretch period when the thorax is moving forward in the downswing but the lead upper arm is still moving backwards in the backswing. The angle of stretch; period of stretch and rate of stretch are given.

Ipsi-Directional

This is the shoulder stretch period when both the thorax and the lead upper arm are in the downswing but the thorax is still moving faster than the lead upper arm. The angle of stretch; period of stretch and rate of stretch are given.

Total Stretch

This is the extra stretch of the shoulder between the thorax and lead upper arm transitions. It is the sum of Contra and Ipsi. The angle of stretch; period of stretch and rate of stretch are given. For a comprehensive discussion of these principles and a little bit about backswing also, see the "Spine Rotation from the Kinematic Sequence Graph" discussion section; the principles are the same for the shoulder joint as the spine.

Transitional Timings Table

Transitional Accelerations (d/s/s)				
	Thorax		Lead Arm	
Acceleration	1628	1026 to 2340	2694	1893 to 3958

To Club Transition

Time from thorax or lead upper arm turn around to when the club turns around; measured in milliseconds. Note that club turn around is also the definition of top of backswing.

To Impact

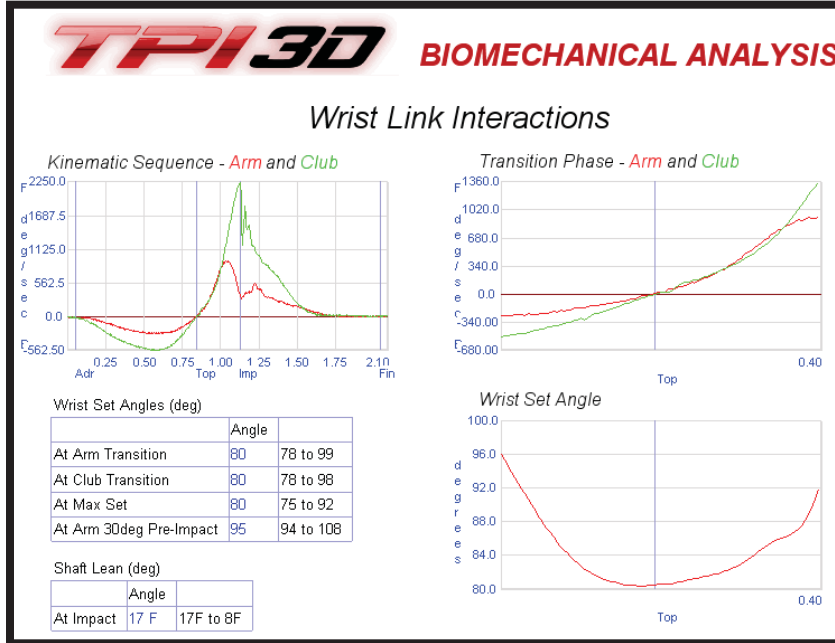
Time from thorax or lead upper arm turn around to impact; measured in milliseconds.

Transitional Accelerations Table

The average acceleration of thorax and lead upper arm during its transition from backswing to downswing, (measured 25ms either side of transition). This measurement gives an idea of the torque that is applied to each segment during transition; measured in degrees per second per second.

TPI-3D COMPREHENSIVE BIOMECHANICS REPORT REVIEW

Pages 8 & 9:



Wrist Link Interactions

These two pages break out the lead arm and club kinematic sequence graphs and also show the wrist set angle curves.

Kinematic Sequence – Arm and Club Graph

The rotation speed of the arm and club segments for the whole swing.

Transition Phase – Arm and Club Graph

The rotation speed of the arm and club segments

zoomed in around the top of backswing area.

Wrist Set Angle Graph

The graph of the angle between the lead forearm and club shaft; measured in degrees.

Wrist Set Angles Table

These are the angles from the wrist set graph at specific points in the transition and downswing.

At Arm Transition

The wrist set angle at upper arm transition

At Club Transition

The wrist set angle at club transition (top of backswing)

At Max Set

The maximum set of the wrist between top and impact. Note that this may seem backwards since it should be the minimum value of this angle. This is because of the definition of wrist set; maximum wrist set is when the wrist is “cocked” the most hence the angle between forearm and shaft will be smallest.

At Arm 30deg Pre-Impact

The wrist set angle when the lead arm is 30 degrees before vertical before impact. The idea here is to give a reading to see if severe casting is occurring. If this number is high above the pro ranges then casting has probably occurred.

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Pages 8 & 9 cont.:

Shaft Lean (deg)	
Angle	
At Impact	17 F 17F to 8F

Transitional Wrist Set Stretch						
	Angle (deg)		Time (ms)		Rate (d/s)	
Contra-Directional	0	0 to 1	4	1 to 28	-7	-5 to 55
Ipsi-Directional	0	-1 to 7	-21	11 to 155	-7	-8 to 61
Total Stretch	0	0 to 8	-17	17 to 179	-7	-4 to 59

Shaft Lean at Impact Table

This is the angle of the shaft with respect to vertical from a face on view at impact. F means the handle end is forward of the club head end; the club is lagging. B means the handle is behind the club head; the club is scooping.

Transitional Wrist Set Stretch Table

Contra-Directional

This is the wrist stretch period when the arm is moving forward in the downswing but the club shaft is still moving backwards in the backswing. The angle of stretch; period of stretch and rate of stretch are given.

Ipsi-Directional

This is the wrist stretch period when both the arm and club shaft are in the downswing but the lead arm is still moving faster than the shaft. The angle of stretch; period of stretch and rate of stretch are given.

Total Stretch

This is the extra stretch of the wrist between the lead arm and club shaft. It is the sum of Contra and Ipsi. The angle of stretch; period of stretch and rate of stretch are given.

For a comprehensive discussion of these principles and a little bit about backswing also, see the "Spine Rotation from the Kinematic Sequence Graph" discussion section; the principles are the same for the shoulder joint as the spine.

Transitional Timings Table

Transitional Timings (ms)				
	Lead Arm		Club	
To Club Transition	4	-6 to 30	0	0 to 0
To Impact	268	244 to 308	283	233 to 296

Transitional Accelerations (d/s/s)				
	Lead Arm		Club	
Acceleration	2694	1893 to 3958	3540	2724 to 5730

To Club Transition

Time from arm turn around to club turns around; measured in milliseconds. Note that club turn around is also the definition of top of backswing.

To Impact

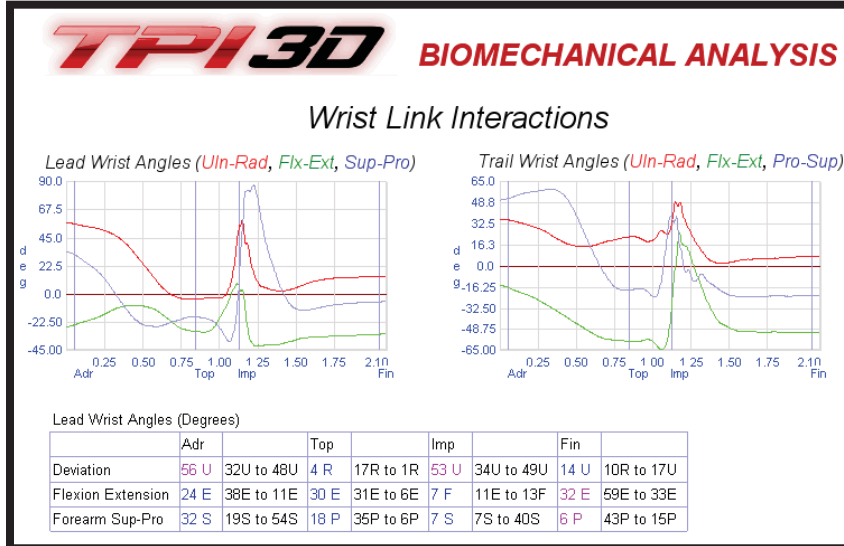
Time from lead arm or club turn around to impact; measured in milliseconds.

Transitional Accelerations Table

The average acceleration of lead arm and club during their transition from backswing to downswing, (measured 25ms either side of transition). This measurement gives an idea of the torque that is applied to each segment during transition; measured in degrees per second per second.

TPI-3D COMPREHENSIVE BIOMECHANICS REPORT REVIEW

Pages 8 & 9:



Lead Wrist Angles Graph

Graph of all three lead wrist angles including ulna-radial deviation, flexion-extension and pronation-supination. The lead wrist is the left wrist for a right hander and right wrist for a left hander.

Trail Wrist Angles Graph

Graph of all three trail wrist angles including ulna-radial deviation, flexion-extension and pronation-supination.

The trail wrist is the right wrist for a right-hander and the left wrist for a left-hander.

Lead Wrist Angles Table

The value of each wrist angle at address, top, impact and finish

Deviation

Ulna and Radial deviation of the wrist; U for Ulna and R for radial; also commonly known as cocking and uncocking.

Flexion Extension

F for flexion and E for extension; also commonly known as bowing and cupping.

Forearm Sup-Pro

This is not really a wrist angle but is convenient to this table. S for supination and P for pronation. Supination is palm down and pronation is palm up. This is forearm roll around the long axis of the forearm. Neutral would be arms held as if holding ski polls with thumbs pointing up.

TPI-3D COMPREHENSIVE BIOMECHANICS REPORT REVIEW

Pages 8 & 9 cont.:

Trail Wrist Angles (Degrees)								
	Adr	Top	Imp	Fin				
Deviation	36 U	26U to 38U	23 U	3R to 21U	35 U	23U to 39U	7 U	17R to 6U
Flexion Extension	16 E	9E to 5F	58 E	61E to 46E	27 E	29E to 10E	51 E	60E to 35E
Forearm Sup-Pro	52 P	24P to 53P	18 S	22S to 10P	37 P	17P to 49P	22 S	46S to 21S

Trail Wrist Angles Table

The value of each wrist angle at address, top, impact and finish

Deviation

Ulna and Radial deviation of the wrist; U for Ulna and R for radial; also commonly known as cocking and uncocking.

Flexion Extension

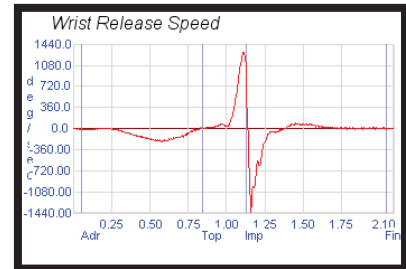
F for flexion and E for extension; also commonly known as bowing and cupping.

Forearm Sup-Pro

This is not really a wrist angle but is convenient to this table. S for supination and P for pronation. Supination is palm down and pronation is palm up. This is forearm roll around the long axis of the forearm. Neutral would be arms held as if holding ski polls with thumbs pointing up.

Wrist Release Speed Graph

Graph of the velocity of the wrist set angle in degrees per second; this gives you an ideas of how fast the wrist set angle releases before impact.



Angular Velocities at Impact Table

These are all angular velocity components in degrees per second measured at the impact point.

Angular Velocities (Deg/Sec)		
	Imp	
Lead Wrist Sup-Pro Vel	2067 S	1171S to 1904S
Lead Wrist Ext-Flex Vel	304 E	258E to 702E
Trail Elbow Extn Vel	325 E	144E to 400E
Club Handle Axial Vel	1606 C	971C to 1599C

Lead Wrist Sup-Pro Vel

How fast the lead wrist is supinating at impact; i.e. rolling from palm down to palm up. A high value here implies that the club face is closing rapidly.

Lead Wrist Ext-Flex Vel

How fast the lead wrist is extending at impact. In a typical pro swing the wrist is slightly flexed (bowed) at impact but is actually in the process of extending.

Trail Elbow Extn Vel

How fast the trail elbow is extending at impact.

Club Handle Axial Vel

How fast the club handle is rotating about a long axis through the shaft. This can also be thought of as club face closing speed. A high speed here may mean it is harder to control the angle of the face at impact, a lower number may mean that there is more margin for error since the club face is closing more slowly at impact.

TPI-3D COMPREHENSIVE BIOMECHANICS REPORT REVIEW

Pages 8 & 9 cont.:

Max Release Speed Table

The maximum opening speed of the wrist set angle just before impact.

Max Release Speed	deg/sec	1308	1045 to 1323
Projected Impact Speed	mph	107	100 to 111

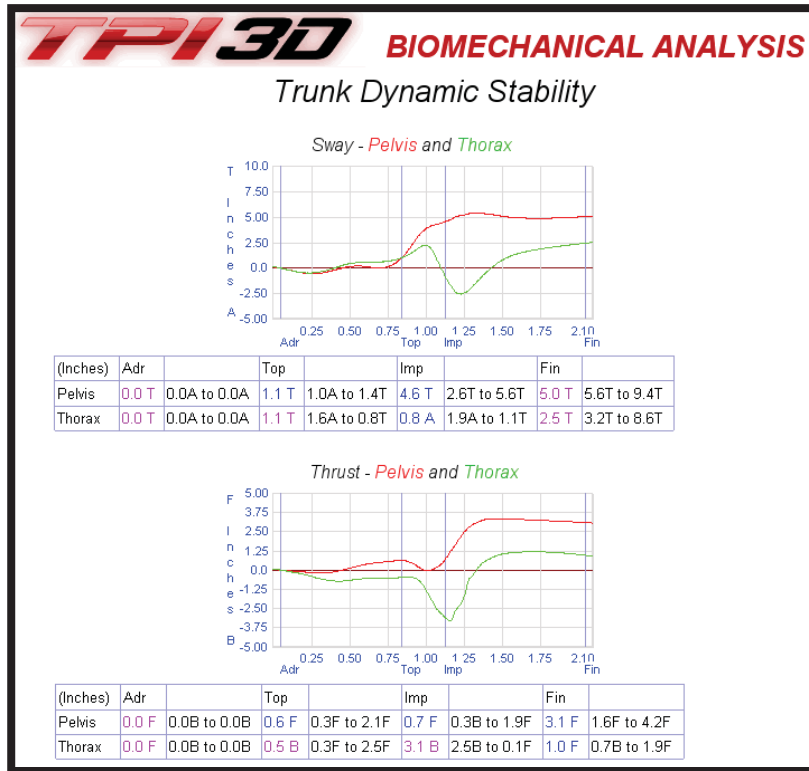
Projected Impact Speed Table

The linear resultant velocity of the club head at impact in miles per hour. Since there is no sensor on the club head itself this speed is calculated by projecting it to the center of the club head; the system however does not know about the bending or twisting of the shaft.

Notes:

TPI-3D COMPREHENSIVE BIOMECHANICS REPORT REVIEW

Pages 10 & 11:



Trunk Dynamic Stability

The trunk is defined as the part of the body that includes the pelvis, abdomen and thoracic areas but excludes the arms, legs, head and neck. So in this report section we are describing the linear and angular motion of the pelvis and thorax, specifically to see if it is excessive, hence the word “stability”. Note that the linear values of sway, thrust and lift are measure for the pelvis with respect to the center point between the two hip joints and for the thorax, a point between the left and right AC joints.

Sway Graph

Sway in our biomechanical definition is side to side linear motion measured in inches. Positive is toward the target and negative is away from the target. Golfers would use the term sway and slide; we just say sway away and sway towards. The red curve is pelvis and the green curve is thorax.

Sway Table

Measurement of the sway of the pelvis and thorax at address, top, impact and finish positions. T is toward the target and A is away from the target. The address position is made zero so the other measurements are with respect to address; measurements are in inches.

Thrust Graph

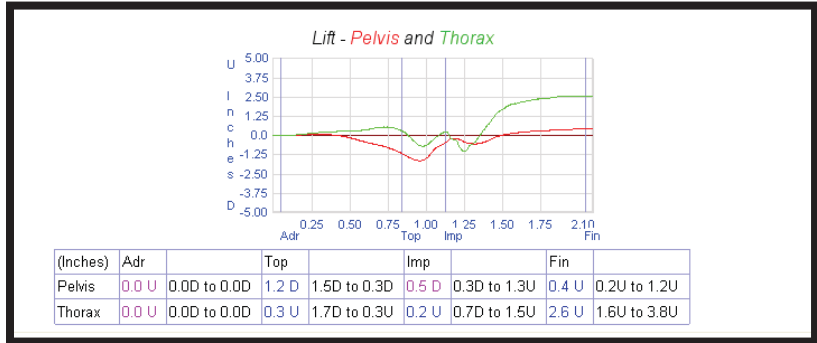
Thrust is measurement forward and backward with respect to the ball; thrust forward (F) would be linear motion towards the ball and if positive; thrust backward (B) would be linear motion away from the ball and is negative. The position at address is considered zero and the other points are measured with respect to address.

Thrust Table

The thrust values at the points of address (zero), top, impact and finish; measured in inches from address.

TPI-3D COMPREHENSIVE BIOMECHANICS REPORT REVIEW

Pages 10 & 11 cont.:



Lift Graph

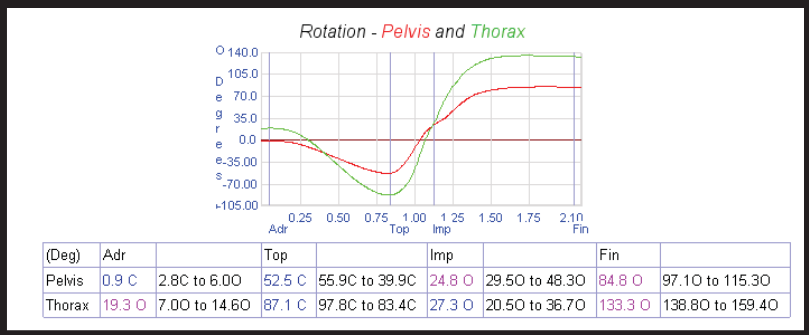
The graph of lift and drop of the pelvis and thorax; instead of calling lift and drop we just call it lift up (U) and down (D). It is measured in inches. Up is positive with respect to address and down is negative with respect to address.

Lift Table

The lift values for the pelvis and thorax at address (zero), top, impact and finish. U is up and D is down. Measured in inches.

Rotation Graph

This is a graph of the rotation angles of the pelvis and thorax through the whole swing; measured in degrees. Rotation is calculated as if one was looking in on the segment, down its local up/down axis where ever the segment is. This angle is not affected by side bend or forward bends and gives the "true" angle of rotation. This is very different than using an overhead view as with video analysis; this method is affected by the bending angles and is an "apparent" angle. The true angle method will tend to give larger angles than the apparent angle method. Backswing past square is negative and called closed (C); forward swing past square is called open (O) and is positive.



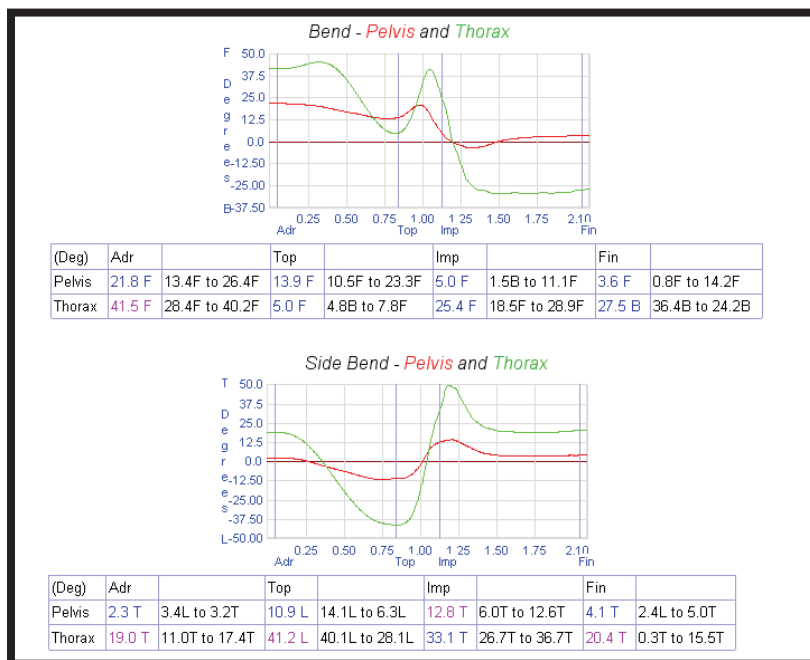
Rotation Table

This table gives the values of pelvis and thorax rotation with respect to the target line at address, top, impact and finish; a square address position would give zero angles. C is closed (away from the target) and O is open, towards the target. These are angles and are measured in degrees.



TPI-3D COMPREHENSIVE BIOMECHANICS REPORT REVIEW

Pages 10 & 11 cont.:



Bend Graph

This is a graph of the forward and backward bend angles of the pelvis (red) and thorax (green) through the whole swing; measured in degrees. Bend is calculated using the angle below or above horizontal of a line passing through the segment from the back to the front; this line follows with the segment and is always measured below or above the horizontal plane. F is bending forward and B is bending back.

Bend Table

This table gives the value of pelvis and thorax forward/backward bend for the address, top, impact and finish positions in the swing, measured with respect to a horizontal plane. F is forward and B is backward. These are angles and are measured in degrees.

Side Bend Graph

This is a graph of the side to side bend angles of the pelvis (red) and thorax (green) through the whole swing; measured in degrees. Side Bend is calculated using the angle below or above horizontal of a line passing through the segment from the left to the right; this line follows with the segment and is always measured below or above the horizontal plane. T is bending to the trailing side (right side low for a right handed golfer) and L is bending to the leading side.

Side Bend Table

This table gives the value of pelvis and thorax side to side bend for the address, top, impact and finish positions in the swing, measured with respect to a horizontal plane. T is bending to the trailing side (right side low for a right handed golfer) and L is bending to the leading side. These are angles and are measured in degrees.

TPI-3D COMPREHENSIVE BIOMECHANICS REPORT REVIEW

Pages 12 & 13:

TPI3D BIOMECHANICAL		<i>Dynamic Range of Motion</i>					
Head Angles (deg)							
Rotation	10 C	22C to 8C	73 O	80O to 97O	83	92 to 116	
Bend	3 B	12B to 1F	48 F	47F to 63F	51	53 to 69	
Side Bend	10 L	17L to 5L	36 T	37T to 51T	46	46 to 65	
Thorax Angles (deg)							
Rotation	87 C	96C to 85C	135 O	139O to 161O	222	229 to 255	
Bend	29 B	44B to 29B	45 F	34F to 44F	75	68 to 84	
Side Bend	41 L	40L to 28L	50 T	43T to 56T	91	75 to 94	
Pelvis Angles (deg)							
Rotation	53 C	57C to 44C	85 O	98O to 116O	138	147 to 168	
Bend	3 B	8B to 3F	22 F	14F to 28F	25	18 to 29	
Side Bend	12 L	14L to 7L	14 T	8T to 14T	26	18 to 26	
Neck Angles (deg)							
Rotation	60 C	70C to 54C	73 O	68O to 79O	133	125 to 147	
Bend	7 E	11E to 1F	14 F	14F to 30F	21	19 to 35	
Side Bend	14 L	22L to 11L	1 T	3T to 16T	16	17 to 36	
Lead Shoulder Angles (deg)							
Elevation	142 B	170B to 136B	11 A	0B to 15A	153	143 to 179	
Horizontal Adduction	42 I	37I to 50I	129 I	133I to 170I	87	87 to 128	
Spine Angles (deg)							
Rotation	41 C	53C to 41C	47 O	29O to 48O	88	75 to 96	
Flexion-Extension	26 F	12F to 27F	9 E	37E to 18E	35	39 to 56	
Side Bend	19 L	22L to 8L	34 T	34T to 49T	54	47 to 66	
Forward Tilt	33 F	28F to 37F	19 F	14F to 21F	14	10 to 18	
Side Tilt	4 F	1B to 4F	32 F	23F to 31F	29	21 to 31	

Dynamic Range of Motion

The first two values are the max values of the parameter in each direction (max and min) and the final value is the total angle traveled (range). For example, pelvis rotation would be; max backswing value, max follow through value and the total rotation that the pelvis made during the swing. The range value will always be (value 1) + (value 2) if the directions are opposite (e.g. pelvis rotation) and (value 1) – (value 2) if the directions are the same (e.g. elbow flexion). This way the last number always represents the maximum excursion of the joint or segment. Note that the max and min values don't necessarily occur at address, top, impact or finish; they can occur anywhere in the swing. These measurements give the reader an idea of how far that joint or segment moved during the swing and could be compared to the actual passive range of motion; physical limitations may show up in this way.

Only the angles that have not been described already will be explained.

Lead Shoulder Elevation

This is a measure of how high the arm is above the shoulder line; measured in degrees. B is arm below the shoulder line and A is arm above the shoulder line.

Spine Angles Table

Rotation

This is the rotation of the thorax with respect to the pelvis as if the pelvis and thorax were brought together to rotate about the same center and a camera on the pelvis looks directly up at the thorax. Note that the motion of the thorax is in relation to the pelvis; the thorax angle discussed earlier is the thorax with respect to the global or world coordinate system.

Flexion-Extension

This is the forward and backward bend of the thorax with respect to the pelvis. Flexion (F) is forward bend of the thorax with respect to the pelvis as is backward bend of the pelvis with respect to the thorax. Extension (E) is backward bend of the thorax with respect to the pelvis as is forward bend of the pelvis with respect to the thorax.

TPI-3D COMPREHENSIVE BIOMECHANICS REPORT REVIEW

Pages 12 & 13 cont.:

Spine Angles Table

Spine Angles (deg)						
Rotation	41 C	53C to 41C	47 O	29O to 48O	88	75 to 96
Flexion-Extension	26 F	12F to 27F	9 E	37E to 18E	35	39 to 56
Side Bend	19 L	22L to 8L	34 T	34T to 49T	54	47 to 66
Forward Tilt	33 F	28F to 37F	19 F	14F to 21F	14	10 to 18
Side Tilt	4 F	1B to 4F	32 F	23F to 31F	29	21 to 31

Side Bend

This is the side to side bend of the thorax with respect to the pelvis. T is bending to the trailing side and L is bending to the leading side.

Forward Tilt

This is the angle of a line drawn from the center of the thorax (between AC joints) to the center of the pelvis (between the hip joints) as looked at from a down the target line view; as if the spine were rigid. This is typically used to see how the golfer is maintaining the primary spine axis. A six-degree-of-freedom system is needed to measure this angle because the positions of the center thorax and center pelvis are needed.



Dynamic Range of Motion

Trail Elbow Angles (deg)						
Flexion-Extension	179 F	163F to 172F	63 F	55F to 72F	115	94 to 113

Trail Wrist Angles (deg)						
Rotation	59 S	40S to 67S	24 P	50P to 25P	83	77 to 106
Flexion-Extension	25 E	13E to 35E	64 F	68F to 54F	89	74 to 96
Deviation	49 U	37U to 50U	2 U	19R to 2U	47	42 to 64

Trail Hip Angles (deg)						
Rotation	33 I	27I to 41I	1 E	32E to 14E	34	48 to 68
Flexion-Extension	47 F	35F to 49F	10 F	8E to 4F	37	37 to 51
Abduction-Adduction	13 D	4D to 12D	20 B	28B to 20B	34	27 to 37

Trail Knee Angles (deg)						
Flexion-Extension	71 F	45F to 64F	27 F	15F to 25F	45	26 to 42

Trail Ankle Angles (deg)						
Flexion	13 D	9D to 15D	45 P	44P to 30P	58	42 to 57
Supination-Pronation	20 S	12S to 24S	9 S	3P to 6S	11	11 to 22

Lead Elbow Angles (deg)						
Flexion-Extension	179 F	166F to 175F	75 F	41F to 68F	104	101 to 130

Lead Wrist Angles (deg)						
Rotation	87 S	71S to 104S	38 P	48P to 25P	125	109 to 140
Flexion-Extension	9 F	4E to 18F	42 E	62E to 40E	50	48 to 69
Deviation	59 U	39U to 54U	4 R	21R to 5R	62	52 to 69

Lead Hip Angles (deg)						
Rotation	17 I	31I to 56I	70 E	56E to 37E	88	79 to 101
Flexion-Extension	38 F	31F to 46F	6 F	3F to 15F	32	22 to 36
Abduction-Adduction	14 D	7D to 15D	28 B	33B to 22B	42	33 to 44

Lead Knee Angles (deg)						
Flexion-Extension	39 F	37F to 50F	3 F	1F to 10F	36	31 to 44

Lead Ankle Angles (deg)						
Flexion	14 D	14D to 22D	3 P	13P to 0P	16	17 to 33
Supination-Pronation	4 S	11S to 24S	9 P	2P to 8S	13	10 to 19

of the center thorax and center pelvis are needed.

Side Tilt

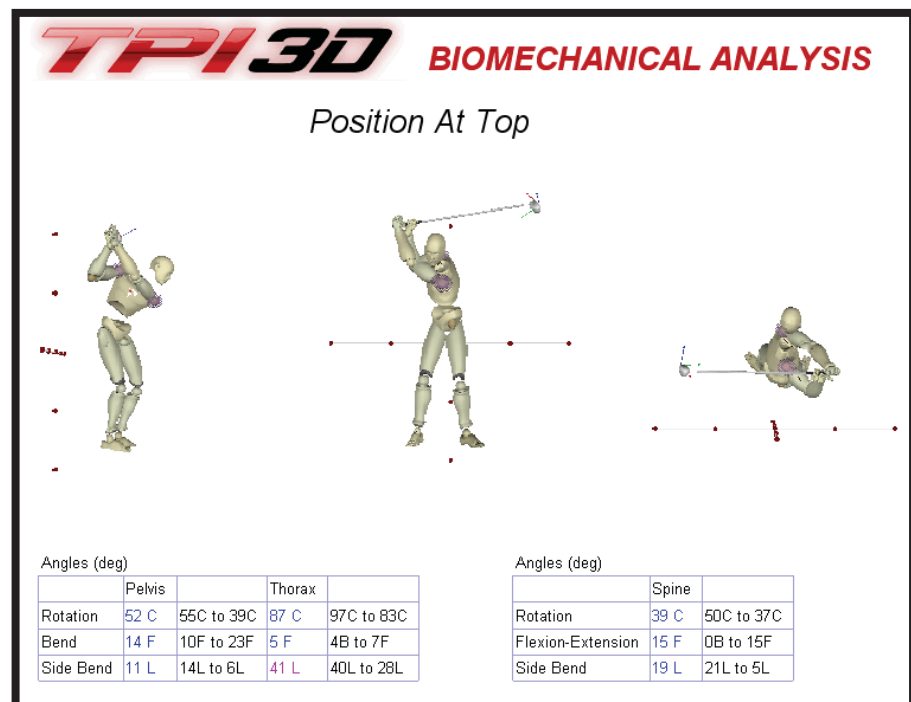
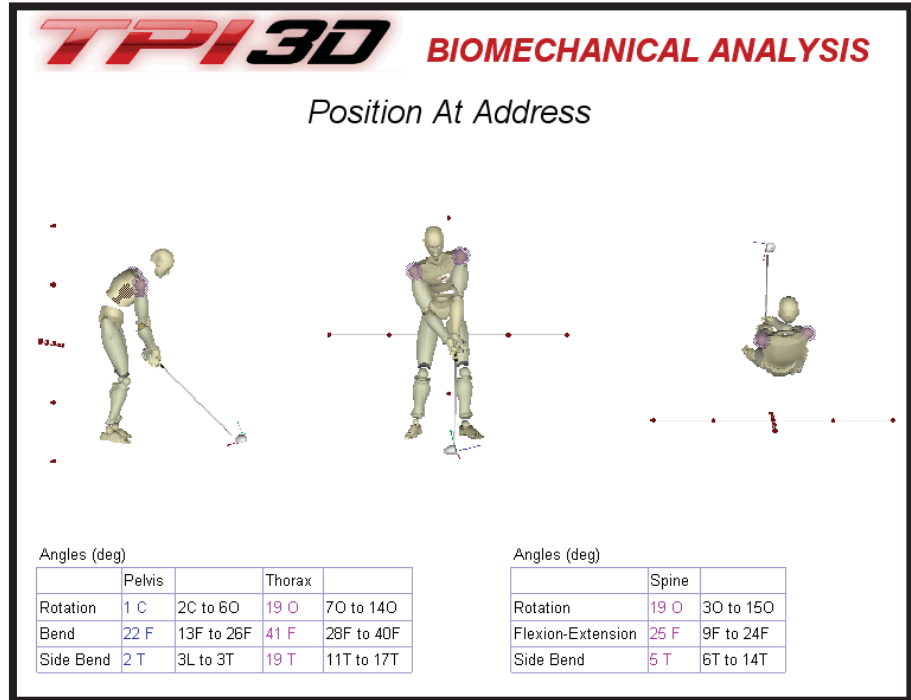
This is the angle of a line drawn from the center of the thorax (between AC joints) to the center of the pelvis (between the hip joints) as looked at from a face on view; as if the spine were rigid. This is typically used to see how the golfer is maintaining the secondary spine axis. A six-degree-of-freedom system is needed to measure this angle because the positions of the center thorax and center pelvis are needed.

TPI-3D COMPREHENSIVE BIOMECHANICS REPORT REVIEW

Pages 14. 15. 16. & 17:

Position at Events of Address, Top, Impact and Finish

Four pages are dedicated to giving information about the body positions at the important points (events) in the swing; one page each for address, top of backswing, impact and finish. Each page has a top view, target line view and face on view of the golfer's image at that event. It also has the pelvis, thorax and spine angles for rotation, bend and side bend; measured in degrees; plus the values of sway, thrust and lift; measured in inches.



TPI-3D COMPREHENSIVE BIOMECHANICS REPORT REVIEW

Pages 14. 15. 16. & 17 cont.:

TPI3D BIOMECHANICAL ANALYSIS

Position At Impact

	Pelvis		Thorax	
Rotation	25 O	29O to 48O	27 O	200 to 36O
Bend	5 F	1B to 11F	25 F	18F to 28F
Side Bend	13 T	6T to 12T	33 T	26T to 36T

	Spine	
Rotation	1 C	19C to 6C
Flexion-Extension	20 F	2F to 19F
Side Bend	24 T	23T to 34T

TPI3D BIOMECHANICAL ANALYSIS

Position At Finish

	Pelvis		Thorax	
Rotation	85 O	97O to 115O	133 O	138O to 159O
Bend	4 F	0B to 14F	27 B	36B to 24B
Side Bend	4 T	2L to 5T	20 T	0L to 15T

	Spine	
Rotation	45 O	28O to 44O
Flexion-Extension	8 B	35B to 17B
Side Bend	31 T	17T to 32T