Why the Pro's Hit Further than You!

Answers from

3D Motion Analysis

and

The Kinematic Sequence

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So by now you've heard it over and over again that we prefer to look at the efficiency of the swing rather than style

Today I will show you how the kinematic sequence can point out the differences between
the efficiency of a pro swing and the inefficiency of an amateur swing
And from this I will show you why the pro's hit further than you

The way we measure the kinematic sequence is with the use of 3D motion capture technology
and the way we analyze the sequence is using the science of biomechanics.

Biomechanics

- Biomechanics
  - The study of the physics of human motion
- Kinematics
  - The study of motion without regard to the forces that create the motion
  - Position, Joint Angle, Velocity, Angular Velocity, Acceleration etc.
- Kinetics
  - The study of the forces and torques that create motion
  - Force, Torque, Power, Impulse etc.

First though a definition of biomechanics

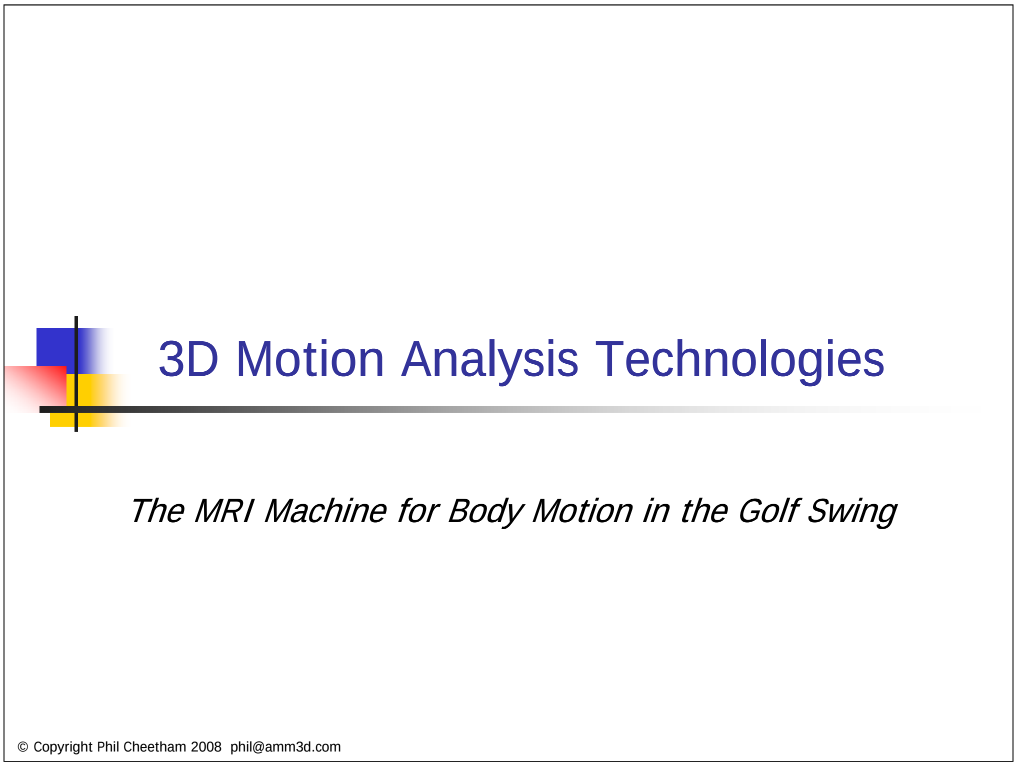
For our purposes biomechanics can be thought of as the study of the physics of human motion; more specifically -

Biomechanics can be broken into two main areas: kinematics and kinetics

Kinematics is the study of motion with out regard to the forces generated

Kinetics is the study of the forces that create motion

I will focus mostly on kinematics



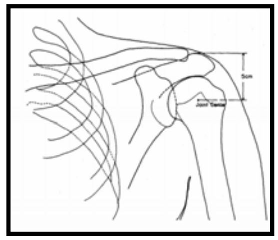
If you think of video swing analysis as an X-Ray machine for golf

3D Motion Analysis can be though of as an MRI for body motion during the golf swing.

It is much more precise and accurate in what it can measure

So lets look at the different technologies that are in use today.

Manual Digitizing from Video



- Multiple Camera Views
- Calibration Frame
- Digitize Body Points in Sequential Images
  - Mouse Crosshair on Joint Centers
- Advantages
  - No need to bother the athlete
  - Only way to get data in a tournament
- Disadvantages
  - Tedious and time consuming
  - Impractical for immediate feedback
  - Low Sample Rate with Standard Video
    - 100mph –> 1/30sec = 60in
  - Digitizing Error
    - Human Error
    - Timing Error

This method can use standard video cameras to capture motion and turn it into 3D data.

Refer to the slide.

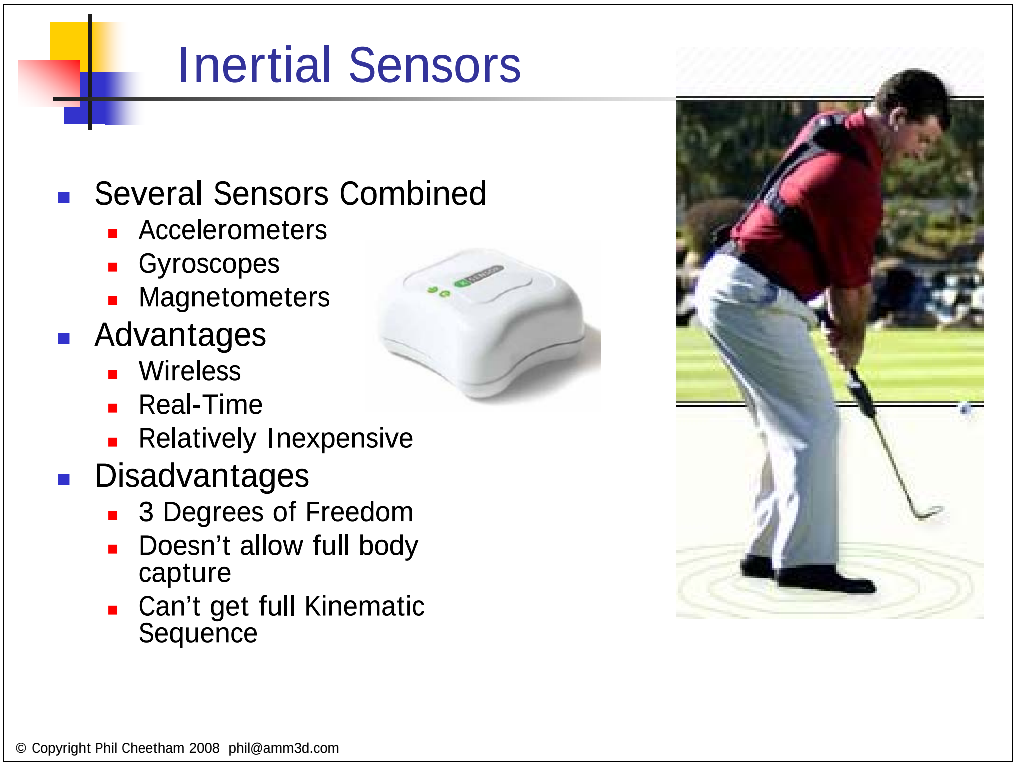
Problematic if not done right:

Slow cameras 30/60Hz (explain impact zone)

100mph = 150ft/sec;

1/30 = 60in; 1/60 = 30in; 1/240 = 7.5in; at club head speed of 100mph

Add that ZenoLink and Chris Welch currently use this method.



Explain Slide

Only 3 Degrees-of-Freedom i.e. only body angles (bend, side bend and rotation)

Does not measure body positions (sway, thrust and lift)

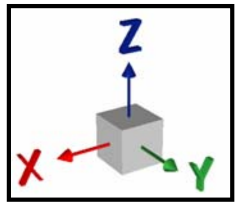
K-Vest (K-Motion Interactive)

BMS/iClub (Motus Corporation)

K-Vest is compatible with TPI 3D

Electromagnetic

- Transmitter and Sensors
  - 4 to 12 Sensor Typical
- Advantages
  - Small Sensors
  - Fast 240 Hz
  - Real-Time
  - 6 Degrees of Freedom
  - Accurate Anatomical Alignment
  - Full Body Capture
- Disadvantages
  - Wired
  - Metal Sensitive (but works on any club)



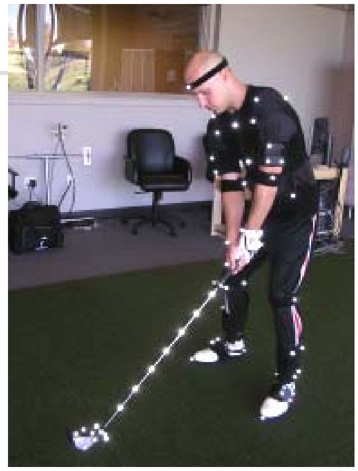
AMM and TPI use this technology and in my opinion it is the best at the moment for quick, easy, accurate and comprehensive data capture

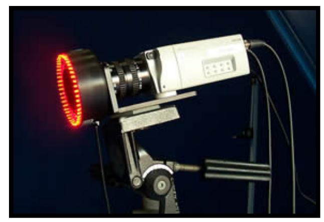
Explain Slide

Can’t put them on the club head so club head parameters are most accurate when club is moving slowly.

Passive Optical

- Reflective Markers
- Video or Infrared Cameras
- Automatic Tracking
  - Markers automatically tracked
  - Lots of cameras (8 – 24 or more)
- Advantages
  - Markers are light
  - No Wires
  - High Sample Rates (500Hz)
  - Can now do real-time display
- Disadvantages
  - Can't be used in Sunlight
  - Maybe time consuming
  - Expensive
  - Complex





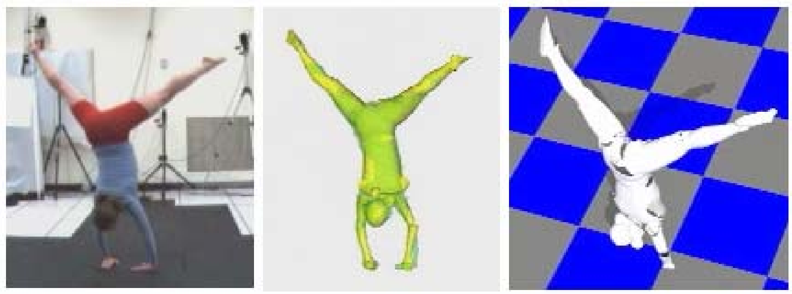
Explain Slide

Can even put markers on the club head

Mention Vicon, Qualysis, Motion Reality (MATT and Motion Golf), STT use this method

Markerless Optical (Future)

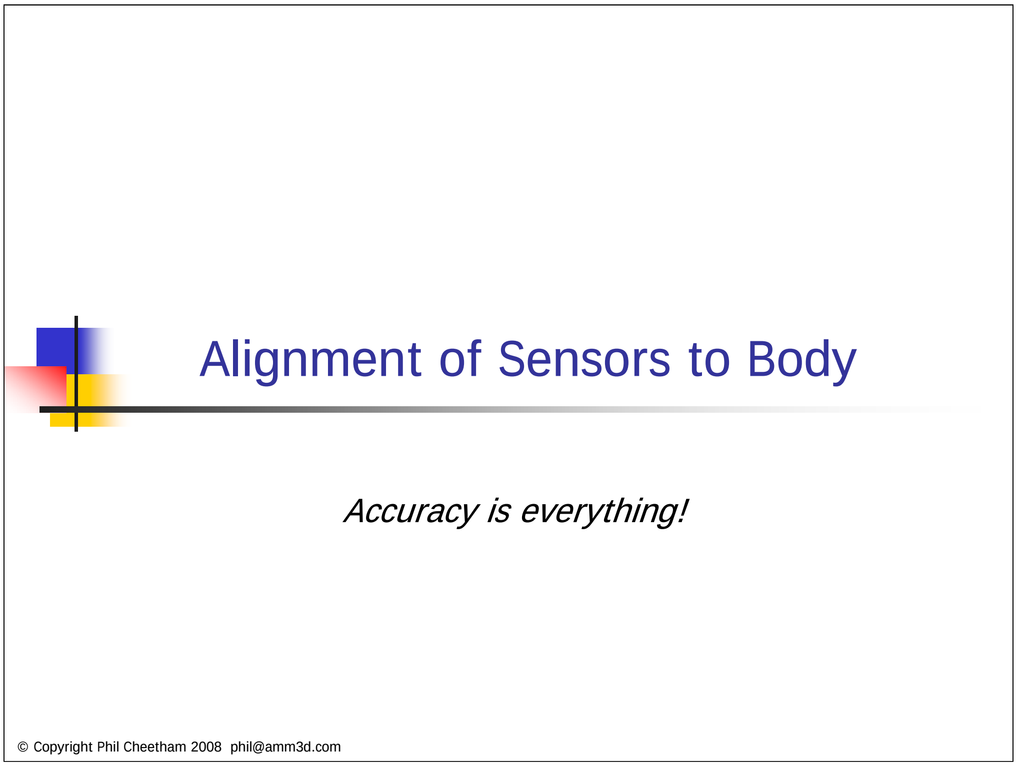
- Exciting Future Technology
- Multiple Cameras and Live Video
- Computer Creates 3D Point Cloud
- Fits 3D Kinematic Model
- Extracts 3D Data



Live Video 3D Reconstruction Kinematic Model

Explain slide

Look out for this in 2–3 years



Lets get back to the present and look at the way the current systems align the sensors to the body. The sensors know where they are but they don't know where the body is so we must align the two somehow.

There are two basic current methods of alignment and they are

Snap Alignment and Anatomical Alignment

Lets discuss these two

Snap Align Method

- Stand Parallel to Target Line
- All Body Angles become Zero
- Advantages
  - Simple and Quick to Do
- Disadvantages
  - Less Accurate
  - Angles not Aligned with True Anatomical Angles
    e.g. Pelvis

Explain slide

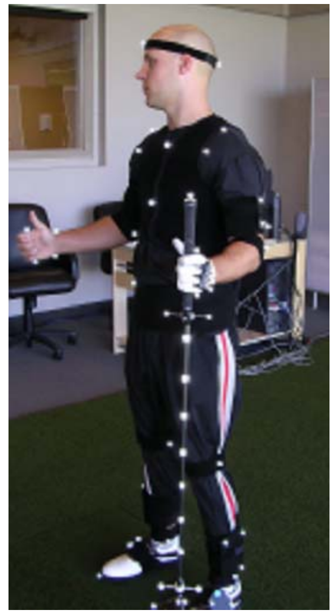
AMM doesn't use this any more (less accurate)

Currently used by K-Vest and BMS

Although the K-Vest will now allow you to input offset angles to correct for this

Anatomical Alignment

- Align Markers Directly to Body
  - Use Digitizing Pen on Body Points
    - Used by AMM 3D-Golf
  - Use Static Markers on Body Points
    - Typically for Optical Systems
- Get “True” Body Angles and Positions
- More accurate but more time consuming

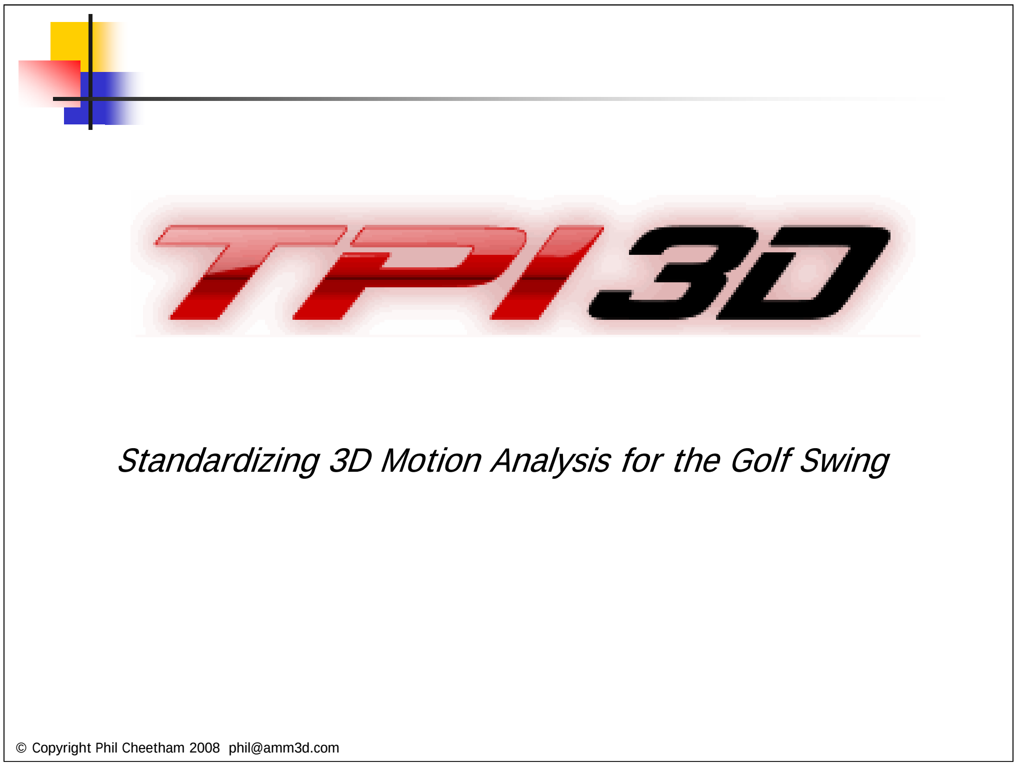


Anatomical Alignment

Allows us to create an accurate anatomical model of the golfer, that is specifically scaled and aligned to that golfer whether 6’3” or 5’ 1”.

Creates a 6DOF local coordinate system with origin at the joint center and axes aligned with the segmental axes.

Allows us to calculate true positions, segment angles and joint angles.



So far we have talked about how to capture the swing but what do we do with it when we have it

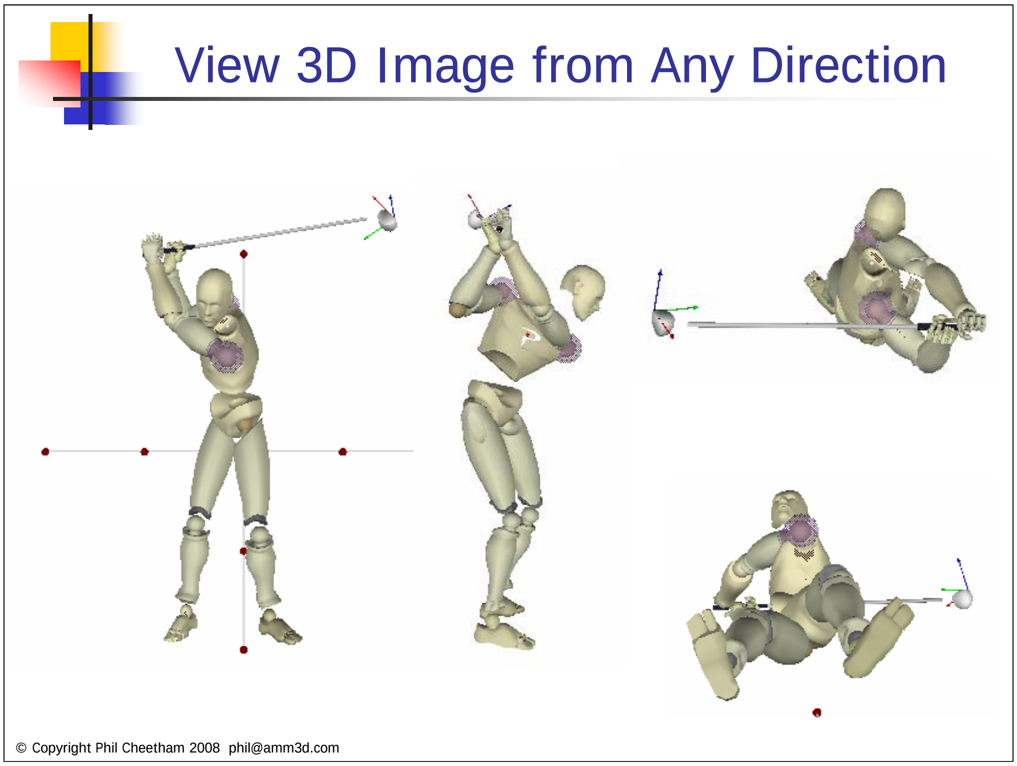
This year AMM and TPI teamed up to bring you TPI 3D.

This puts the my experience combined with, Greg Rose and the TPI Biomechanics Board (9PhDs),

into a golf specific biomechanical analysis software package.

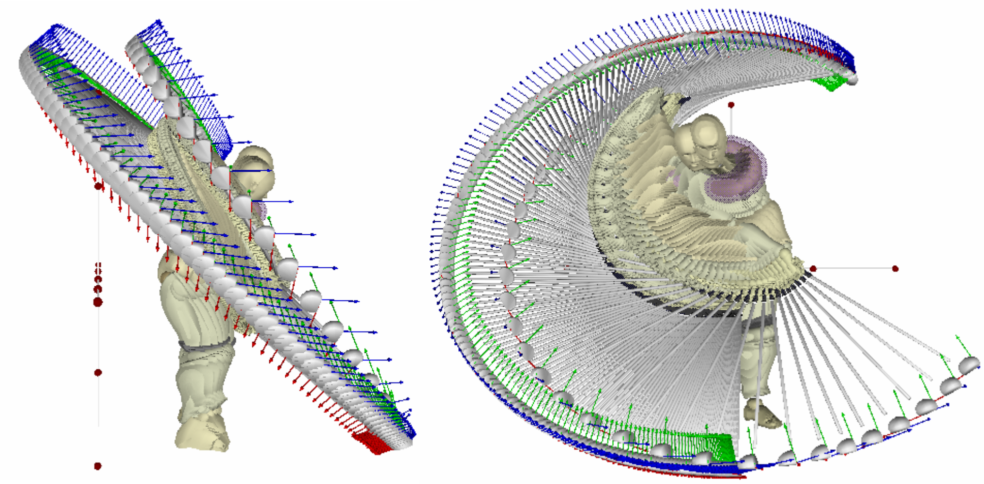
It is compatible currently with K-Vest and AMM 3D-Golf but more hardware platforms will be added in the near future

Our ideas is to standardize golf biomechanics across multiple platforms

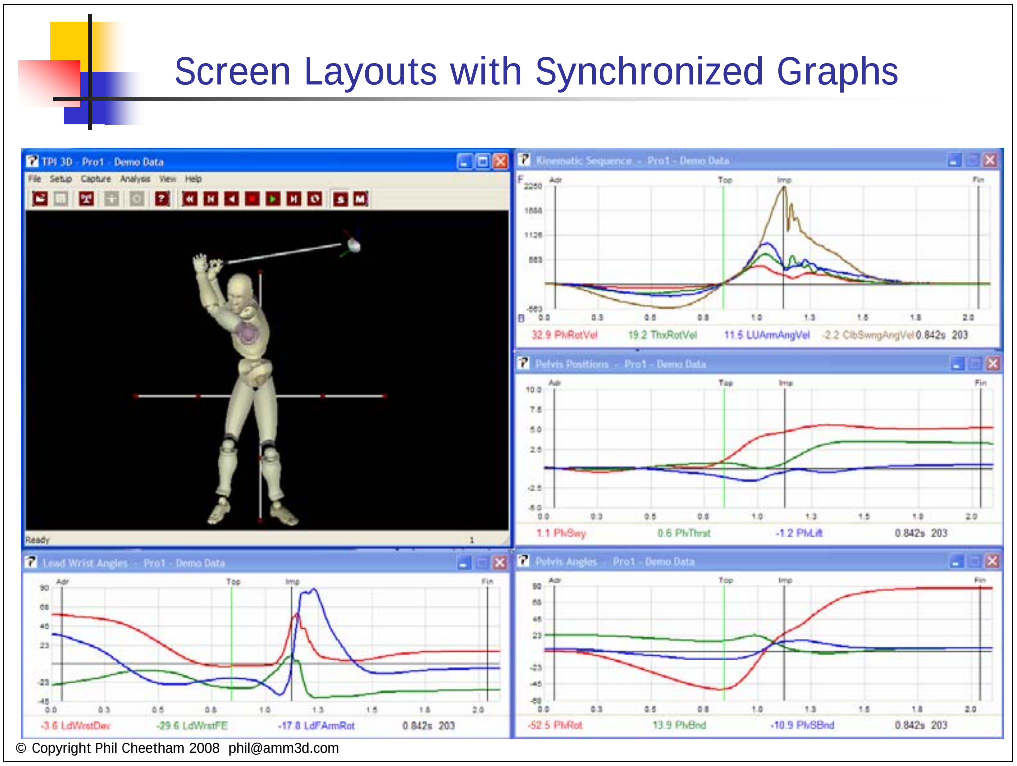


TPI 3D allows you to view the swing from any angle

Multiple Mode for Club Plane View



It allows you to see the patterns of motion; in this case looking at the swing plane



It allows you to save and recall layouts of your favorite graphs synchronized with the 3D animation

Comparison Table and Database

Data Demo | Pro2 | Positions | 97.8 C to 83.4 C

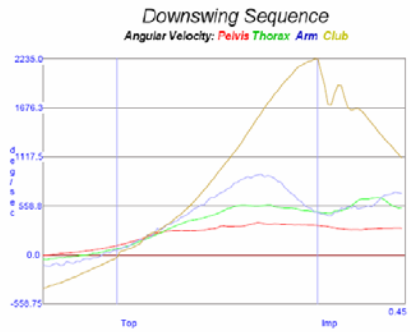
Parameter	Units	Adr	HB	Top	HD	Imp	HF	Fin
Pelvis Rotation (Open-Closed)	deg	2.5 O	17.5 C	55.8 C	30.4 O	41.4 O	50.6 O	113.2 O
Pelvis Bend (Fwd-Back)	deg	23.8 F	21.4 F	17.2 F	14.3 F	10.0 F	10.4 F	14.5 F
Pelvis Side Bend (Trail-Lead)	deg	0.3 L	3.7 L	8.5 L	11.7 T	12.0 T	10.4 T	7.7 T
Thorax Rotation (Open-Closed)	deg	13.3 O	29.8 C	100.0 C	3.5 O	23.5 O	55.6 O	150.6 O
Thorax Bend (Fwd-Back)	deg	36.3 F	35.7 F	6.6 B	34.3 F	24.1 F	2.5 F	36.5 B
Thorax Side Bend (Trail-Lead)	deg	16.0 T	13.5 L	40.8 L	12.6 T	27.0 T	48.2 T	9.7 T
Pelvis Sway (To-Away)	in	0.0	1.6 A	0.8 A	2.4 T	2.5 T	3.4 T	8.4 T
Pelvis Thrust (Fwd-Back)	in	0.0	0.5 B	1.8 F	2.1 F	2.8 F	3.3 F	2.9 F
Pelvis Lift (Up-Down)	in	0.0	0.0	1.8 D	1.1 U	1.5 U	1.3 U	0.2 U
Thorax Sway (To-Away)	in	0.0	1.4 A	1.2 A	0.0	2.0 A	4.5 A	5.8 T
Thorax Thrust (Fwd-Back)	in	0.0	0.1 F	2.4 F	0.5 B	0.9 B	0.6 B	2.5 F
Thorax Lift (Up-Down)	in	0.0	0.8 D	2.3 D	1.7 U	2.2 U	0.9 U	1.3 U
Spine Rotation (Open-Closed)	deg	11.2 O	13.9 C	47.9 C	27.9 C	20.5 C	5.8 C	31.5 O
Spine (Flex-Ext)	deg	12.5 F	14.3 F	23.8 E	20.0 F	14.1 F	7.9 E	51.0 E
Spine Side Bend (Trail-Lead)	deg	16.3 T	9.8 L	32.3 L	1.0 T	15.0 T	37.8 T	2.0 T
Head Rotation (Open-Closed)	deg	3.7 C	13.7 C	19.5 C	4.5 C	0.6 C	3.8 O	77.4 O
Head Bend (Fwd-Back)	deg	46.3 F	42.3 F	33.2 F	49.1 F	52.0 F	49.8 F	8.8 B
Head Side Bend (Trail-Lead)	deg	1.0 L	9.7 L	10.0 L	6.9 T	8.6 T	11.0 T	29.7 T
Head Sway (To-Away)	in	0.1 T	2.8 A	3.7 A	2.1 A	3.1 A	4.6 A	12.3 T
Head Thrust (Fwd-Back)	in	0.0	0.2 B	0.8 F	0.2 B	0.7 B	0.7 B	2.6 B
Head Lift (Up-Down)	in	0.0	0.5 D	0.2 D	0.5 D	0.3 D	0.7 D	8.2 U
Neck Rotation (Open-Closed)	deg	18.1 C	15.7 O	80.7 O	10.8 C	28.5 C	56.0 C	71.3 C
Neck (Flex-Ext)	deg	10.0 E	6.7 E	39.8 E	14.7 E	27.8 E	47.3 E	27.8 E
Neck Side Bend (Trail-Lead)	deg	17.1 T	3.8 L	30.8 L	5.7 T	18.5 T	37.2 T	20.0 L

Rng: PGA-Driver Prj: Full Body 12R TPI 7-14-04

It provides you with a comparison table of hundreds of body motion parameters including segmental angles (fwd bend side bend and rotation) and positions (sway, thrust and lift)

Explain Ranges and Databases.

Comprehensive Biomechanics Report



Sequence Parameters

		Pelvis		Thorax		Arm		Club	
Peak Order	order	1		3		2		4	
Peak Timing Pre-Impact	ms	75	77 to 113	63	54 to 89	71	62 to 81	0	-1 to 5
Peak Speed	d/s	367	415 to 522	570	629 to 764	920	888 to 1036	2233	2108 to 2306
% of Max	%	16	18 to 23	26	28 to 34	41	40 to 46	100	100 to 100
Acceleration	d/s/s	1405	1717 to 2595	2496	2579 to 3856	4873	4190 to 5942	9043	7474 to 9734
Deceleration	d/s/s	420	1223 to 2734	1279	1508 to 3889	6129	5764 to 8356	9537	7821 to 9375

Segmental Interactions

		Pelvis-Thorax		Thorax-Arm		Arm-Club	
Time Between Peaks	ms	13	5 to 43	-8	-18 to 17	71	61 to 79
Angular Speed Gain	d/s	203	184 to 272	350	211 to 321	1313	1160 to 1327
Gain Factor	ratio	1.6	1.4 to 1.6	1.6	1.3 to 1.5	2.4	2.2 to 2.4

Contribution by Joint

		Legs		Core		Shoulder		Wrist	
% Contribution	%	16	18 to 23	9	8 to 12	16	9 to 14	59	53 to 59

The power of the Comprehensive Biomechanics Report.

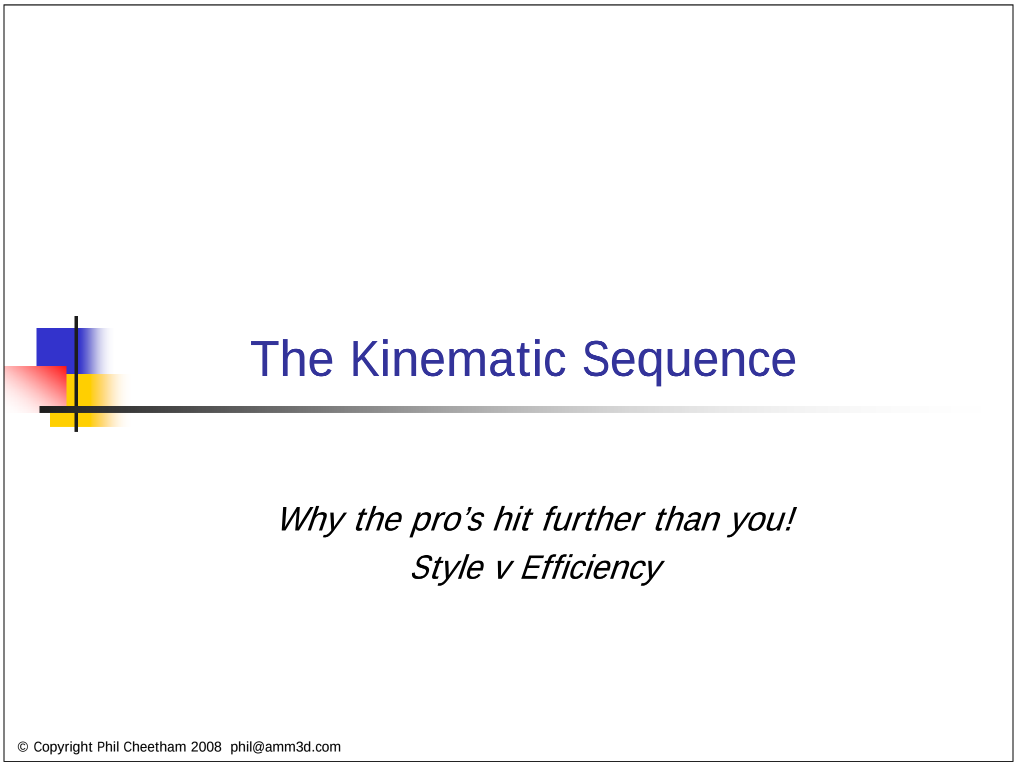
This is a multi-page report that focuses on the kinematic sequence and its key parameters

Here is the page on the Downswing portion of the kinematic sequence

Explain parameters from slide.

It also show the biomechanics of each joint plus pelvis and thorax dynamic stability.

It also compares the golfers values to the ranges of the currently selected database.



Ok lets delve into “style v efficiency”; and why some pro’s hit as far as they do

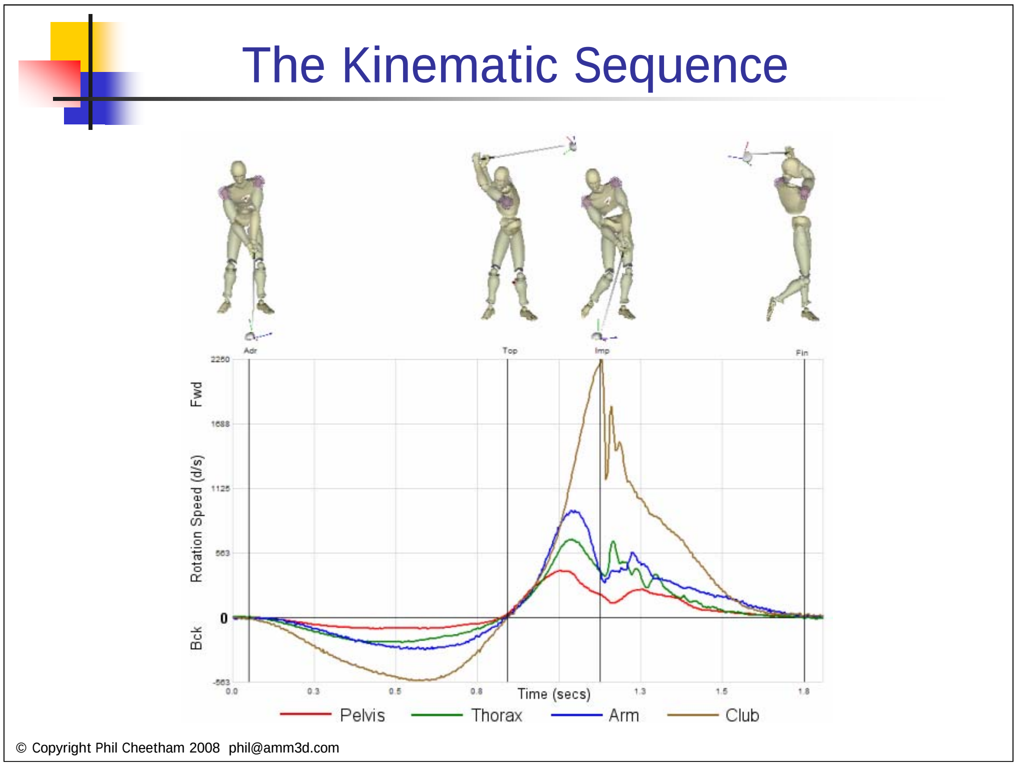
At TPI we don’t believe there is one way to swing a golf club; we believe there is an infinite number of ways to swing a club;

but we do believe there is only **one efficient** way for a specific golfer to swing a club and that is based on what that golfer can physically do.

So first how do we determine if it is efficient or not?

We need to capture their swing on 3D and examine the graph of their kinematic sequence

So lets do that



Explain the kinematic sequence graph (practice this)

Is a way to measure and display the efficiency of energy and speed transfer from the ground up

•**Example kinematic sequence** graph of a current world class **PGA golf professional**

•**Shows** the **rotational speed** of **three body segments** and the **club shaft**

•**Red** is pelvis, **green** is thorax, **blue** is the lead upper arm, **brown** is the club shaft ETC, ETC, ETC

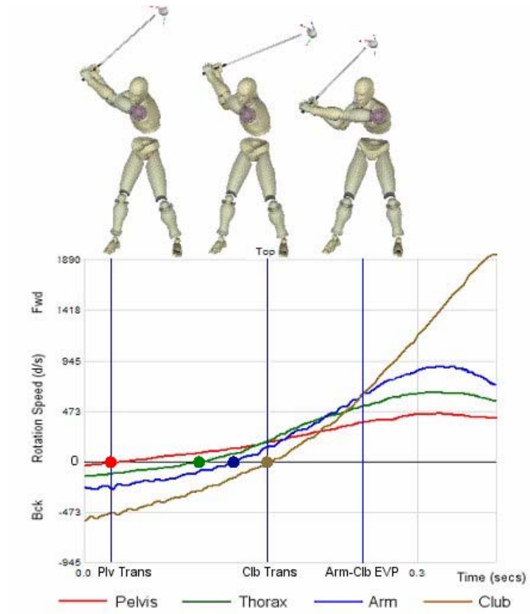
•Two key components – when each curve crosses zero and how each curve then accelerates and decelerates

I will examine two specific phases of the kinematic sequence to understand why the pros can hit it so far and what makes the difference between a so-so swing and a great swing.

The Transition Phase and the Downswing Phase.

Most of our time is usually spend looking at the downswing sequence but let me start first with the transition

The Transition Sequence



Here we see the zoomed in portion of the graph around Top of Backswing or the Transition Phase.

This player has a good transition sequence or order of transition.

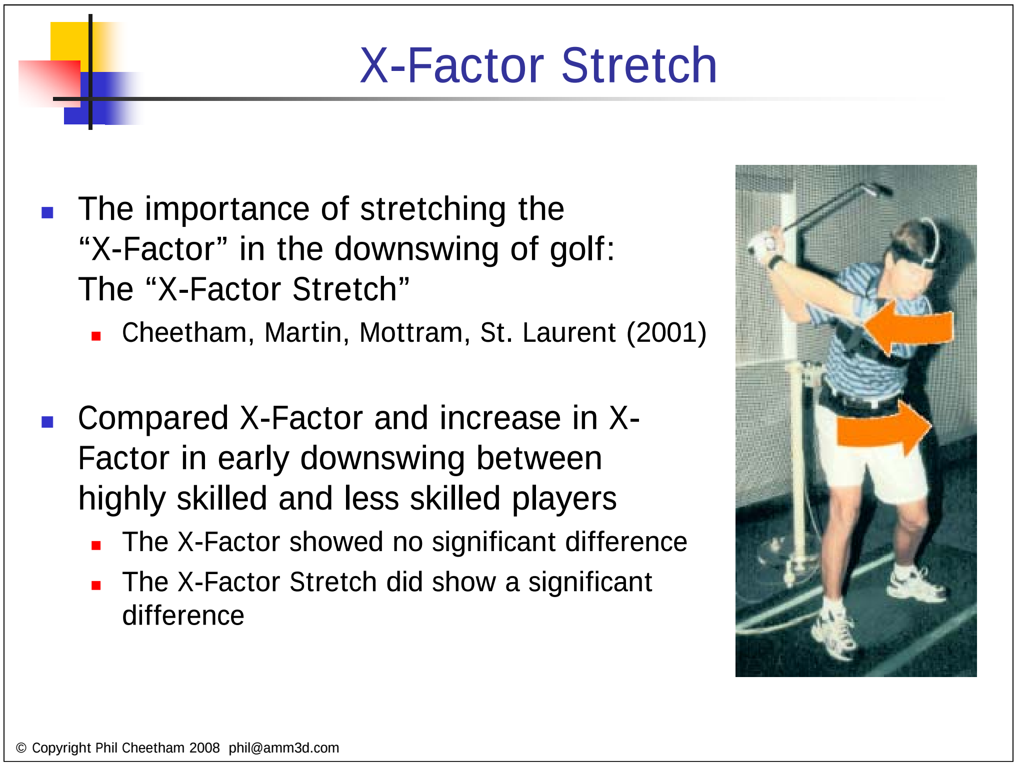
Explain – black line 0, -ve backswing, +ve downswing

Transition order Pelvis, thorax, lead arm, club shaft

This facilitates good joint loading and allows the incorporation of the muscle “stretch shorten cycle” at each joint.

This potentially provides more muscle force at each joint to power the downswing more effectively.

We’ll discuss this in the context of the Pelvis and Thorax transition and the X-Factor Stretch



In 2001 Rob Mottram and I plus other colleagues performed a biomechanics research project called:

(item 1 on slide)

(item 2 on the slide)

We found no sig diff in X-Factor, but did find one in the X-Factor Stretch.

What is the significance of this finding: (next slide)

The Stretch Shorten Cycle

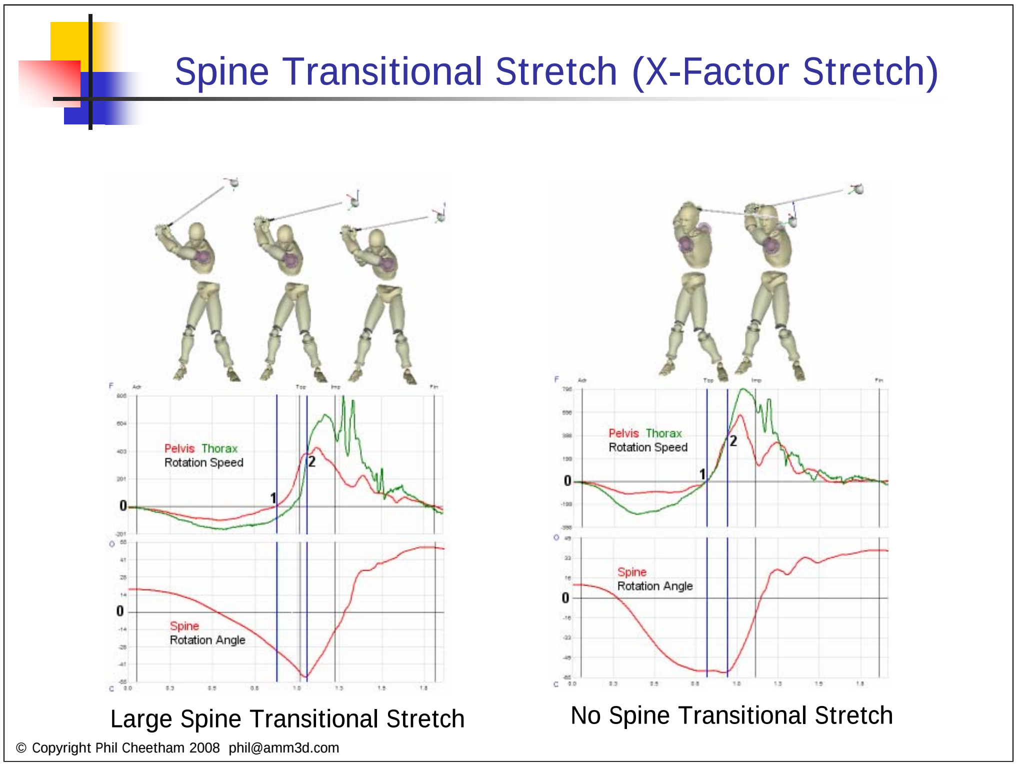
- A rapid eccentric muscle contraction followed by a rapid concentric muscle contraction with minimal pause in between
- Helps increase the force of muscle contraction during downswing
  - Initial Eccentric Contraction – raises initial muscle tension level
  - Stored Elastic Energy – returned during contraction
  - May Stimulate Stretch Reflex

Our research confirmed that an effective X-Factor Stretch (or Spine Transitional Stretch) makes use of the Stretch Shorten Cycle to get the most force production out of the muscle.

Explain from slide

So in the transition phase; if your Pelvis turns before your Thorax you get the benefit of

1. Stored elastic energy from series elastic component
2. Increased muscle force from eccentric contraction
3. Possible increased muscle force from stretch reflex



Here's an example in TPI 3D of a golfer with large transitional stretch and a golfer who has none

Explain the graphs (practice this)

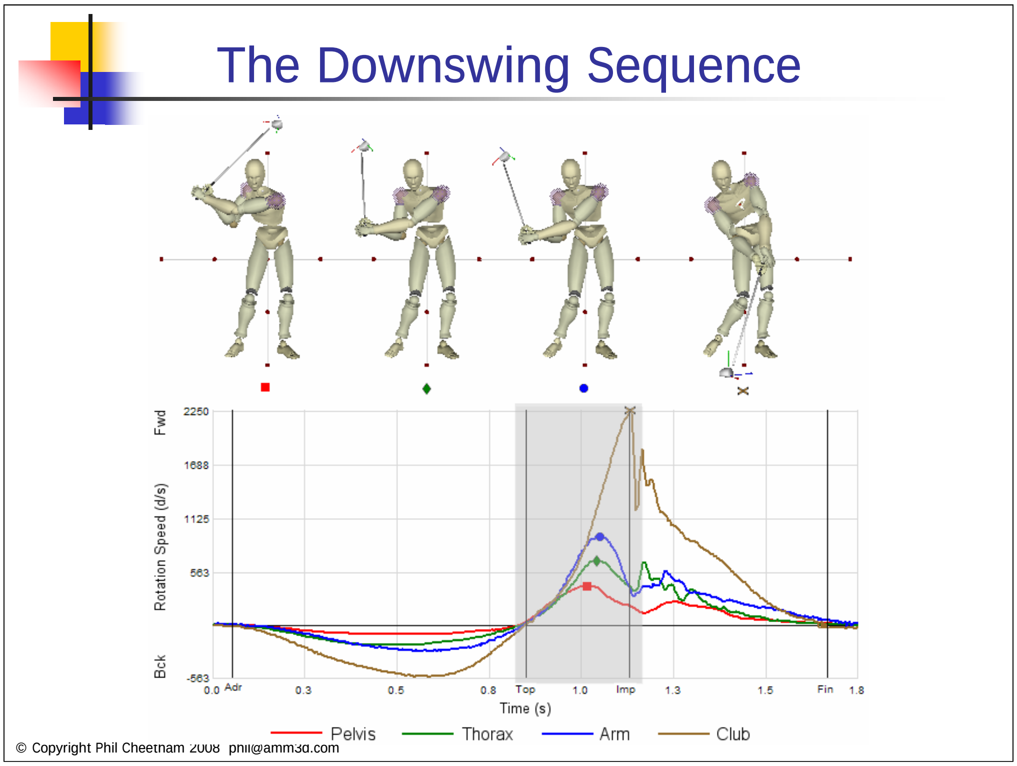
Notice one of these is too large and one is too small

since 2001 we now know that there is more to it than just the size of the stretch; the rate of stretch and recoil (Rob Neal) are very important as is the initial and maximal rates of acceleration which are indications of force development in the muscles (research we are now looking into at TPI and AMM)

Remember that this extra stretch of the muscles should occur at each joint during an efficient golf swing.

PGA Tour	Ipsi Stretch	Contra Stretch	Total Stretch
Spine Link	1.7	3.5	5.2
Shoulder Link	0.8	1.8	2.6
Wrist Link	0.7	3.2	3.9

This stretch occurs also at each joint



- **Explain graph again especially downswing section**

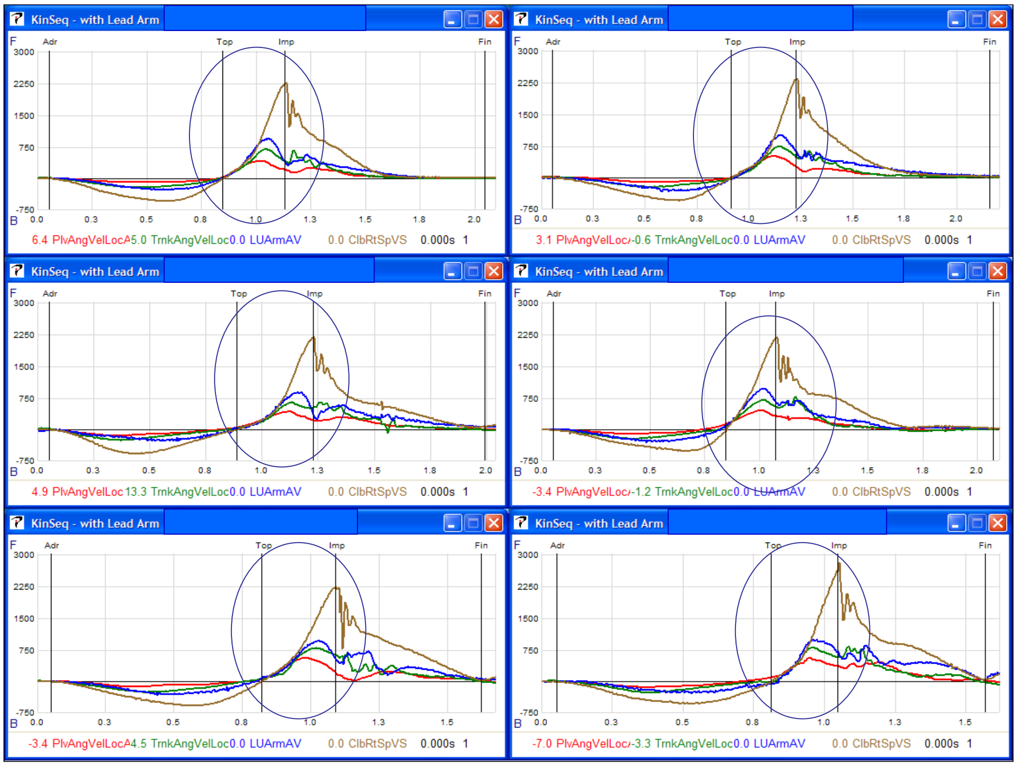
The kinematic sequence of the downswing shows us how efficiently the energy is transferred from one body segment to the next by the muscles in between.

The large muscles of the legs begin by rotating the pelvis (red); so it accelerates; but it then decelerates and transfers energy to the thorax (green) and catapults it to a higher speed; the thorax then in turn decelerates and transfers speed to the arm (blue) which in turn transfers it to the club the brown curve.

Two key issues for efficient energy transfer and build up are

Good acceleration/deceleration, and correct sequencing of the peaks

This signature is typical of what we see in good pro swings.



Just to show how ubiquitous and clear this signature is

here are 6 different graphs of the Kin Seq of recent world class golfers

Point out section of importance in each graph

Cochran and Stobbs (1968)

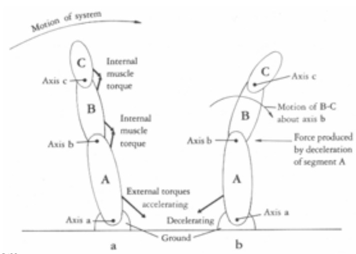
- Disk and Spring Model
  - The question is now: in what order should the springs be released to impart the greatest possible rotation speed to the topmost cylinder.
  - The answer is that they should operate in sequence from the bottom upwards with each successive spring releasing when all or most of the energy of the previous spring has been imparted to the system.

First a quick review of the history of the kinematic sequence:

Review slide

Kreighbaum and Barthels (1985)

- Kinetic Link Principle
  - The kinetic link principle involves a series of linked segments with one end fixed and the other end open, generally getting smaller as they progress.
  - The small distal segment can be made to travel extremely fast by the sequential acceleration and deceleration of the body segments
  - A.k.a. proximal to distal sequencing



Read from Slide

Cheetham & TPI Biomechanics Board (2008)

- Comparison of Kinematic Sequence Parameters between Amateur and Professional Golfer
- World Scientific Congress of Golf
- Science and Golf V

Purpose was to compare timing and magnitude parameters of the Kinematic Sequence between amateur recreational golfers and world class PGA playing professionals

Do major differences really exist?

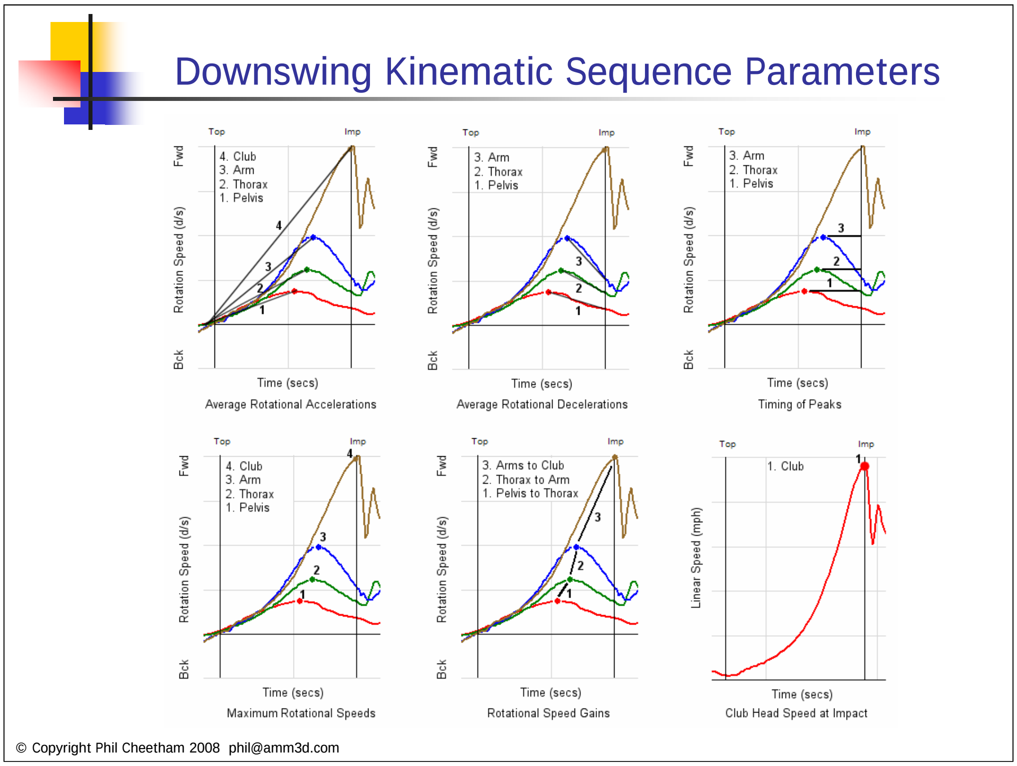
•For years we have **assumed** from **biomechics theory** that **pros and amateurs** are **different**

•Have been using **differences in the curves** to **design training/conditioning programs**

•**But** there has been **no** formal **research** that has documented the differences.

•So at the World Scientific Congress of Golf in Arizona in March we presented to prove our key assumptions:

•So we compared the **key parameters** of the **kinematic sequence** of the downswing between **amateur** recreational players and **world class** PGA playing **professionals**.



Our group consisted of 19 pro and 19 amateur golfers that we had 3D'd at TPI

For our comparison between pros and amateurs we chose 18 Key Kinematic Sequence Parameters that we typically look at and use to analyze the downswing phase (between Transition and Impact)

•Average Rotational Accelerations - Pelvis, Thorax, Arm, Club

•Average Rotational Decelerations - Pelvis, Thorax, Arm

•Maximum Rotational Speed - Pelvis, Thorax, Arm, Club

•Rotational Speed Gain - Pelvis to Thorax, Thorax to Arm, Arm to Club

•Timing of Peak Rotational Speed before Impact - Pelvis, Thorax, Arm

•Linear Club Head Speed at Impact

Parameter	Segment	Units	Pros		Amateurs		T Test
			Mean	SD	Mean	SD	
Average Rotational Acceleration	Pelvis	kd/s²	2.1	0.4	1.5	0.4	0.000*
	Thorax	kd/s²	3.3	0.5	2.3	0.5	0.000*
	Arm	kd/s²	5.1	0.8	3.3	0.9	0.000*
	Club	kd/s²	8.8	1.1	6.0	1.1	0.000*
Average Rotational Deceleration	Pelvis	kd/s²	2.0	0.7	1.6	1.0	0.026
	Thorax	kd/s²	2.6	1.1	1.6	1.1	0.007*
	Arm	kd/s²	7.0	1.2	3.0	1.5	0.000*
Maximum Rotational Speed	Pelvis	d/s	477	53	395	68	0.000*
	Thorax	d/s	727	61	583	84	0.000*
	Arm	d/s	980	68	763	95	0.000*
	Club	d/s	2254	68	1790	111	0.000*
Rotational Speed Gain	Pelvis to Thorax	d/s	250	42	188	72	0.003*
	Thorax to Arm	d/s	253	59	185	76	0.005*
	Arm to Club	d/s	1274	65	1027	147	0.000*
Time of Peak Rotational Speed Before Impact	Pelvis	ms	87	19	78	38	0.124
	Thorax	ms	68	14	59	29	0.147
	Arm	ms	65	8	64	23	0.821
Linear Speed at Impact	Club Head	mph	109	3	88	5	0.000*

We hypothesized that

•The key magnitude parameters will be significantly higher in the pros than the amateurs

•The key timing parameters will be significantly different between the pros and amateurs

We compared group means using a student's t-test with a level of significance of 0.02. We chose this value to balance between type I and type II statistical errors.

Summarizing the **magnitude** variables first:

•**Red** numbers are **significantly different** bet. the pros and amateurs

•As hypothesized, average rotational accelerations and decelerations (except pelvis); maximum rotational speeds; and rotational speed gains sig diff. the pros having greater values.

•Contrary to our hypothesis, means of **pelvis average rotational deceleration**, **not sig**. diff. but pros had larger mean pelvis deceleration.

•The linear club head speed mean value for the pros was significantly larger than that for the amateurs.

•Look at some of the values and read some examples

•Accels increase for each segment

•Max speeds increase for each segment

•So that's okay; so far so good; our study so far proves that we are on the right track.

•What about timing variables

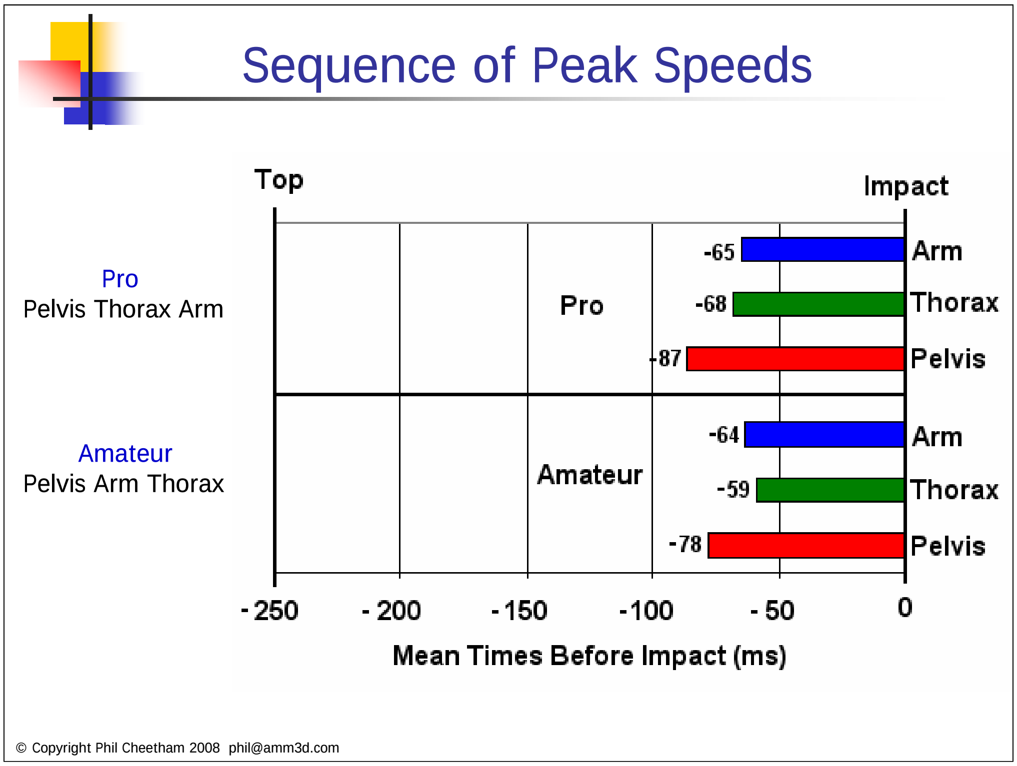
Parameter	Segment	Units	Pros		Amateurs		T Test
			Mean	SD	Mean	SD	
Average Rotational Acceleration	**Pelvis**	**kd/s²**	**2.1**	0.4	**1.5**	0.4	**0.000***
	Thorax	**kd/s²**	**3.3**	0.5	**2.3**	0.5	**0.000***
	Arm	**kd/s²**	**5.1**	0.8	**3.3**	0.9	**0.000***
	Club	**kd/s²**	**8.8**	1.1	**6.0**	1.1	**0.000***
Average Rotational Deceleration	**Pelvis**	**kd/s²**	**2.0**	0.7	**1.6**	1.0	**0.026**
	Thorax	**kd/s²**	**2.6**	1.1	**1.6**	1.1	**0.007***
	Arm	**kd/s²**	**7.0**	1.2	**3.0**	1.5	**0.000***
Maximum Rotational Speed	**Pelvis**	**d/s**	**477**	53	**395**	68	**0.000***
	Thorax	**d/s**	**727**	61	**583**	84	**0.000***
	Arm	**d/s**	**980**	68	**763**	95	**0.000***
	Club	**d/s**	**2254**	68	**1790**	111	**0.000***
Rotational Speed Gain	**Pelvis to Thorax**	**d/s**	**250**	42	**188**	72	**0.003***
	Thorax to Arm	**d/s**	**253**	59	**185**	76	**0.005***
	Arm to Club	**d/s**	**1274**	65	**1027**	147	**0.000***
Time of Peak Rotational Speed Before Impact	**Pelvis**	**ms**	**87**	**19**	**78**	**38**	**0.124**
	Thorax	**ms**	**68**	**14**	**59**	**29**	**0.147**
	Arm	**ms**	**65**	**8**	**64**	**23**	**0.821**
Linear Speed at Impact	**Club Head**	**mph**	**109**	3	**88**	5	**0.000***

•Surprisingly and contrary to our hypothesis – **no sig. diff**. **in** the **means** for the **timing variables**,

•However look at the **size of the standard deviations**. The **large** values for the **amateurs** - they are very **inconsistent** in their **timing**.

•The **pros timing** values are **tight** around their mean, they have more **similar timing profiles** to each other.

•So we can conclude that **consistent timing of the sequence peaks** is very **important** in a fast swing.

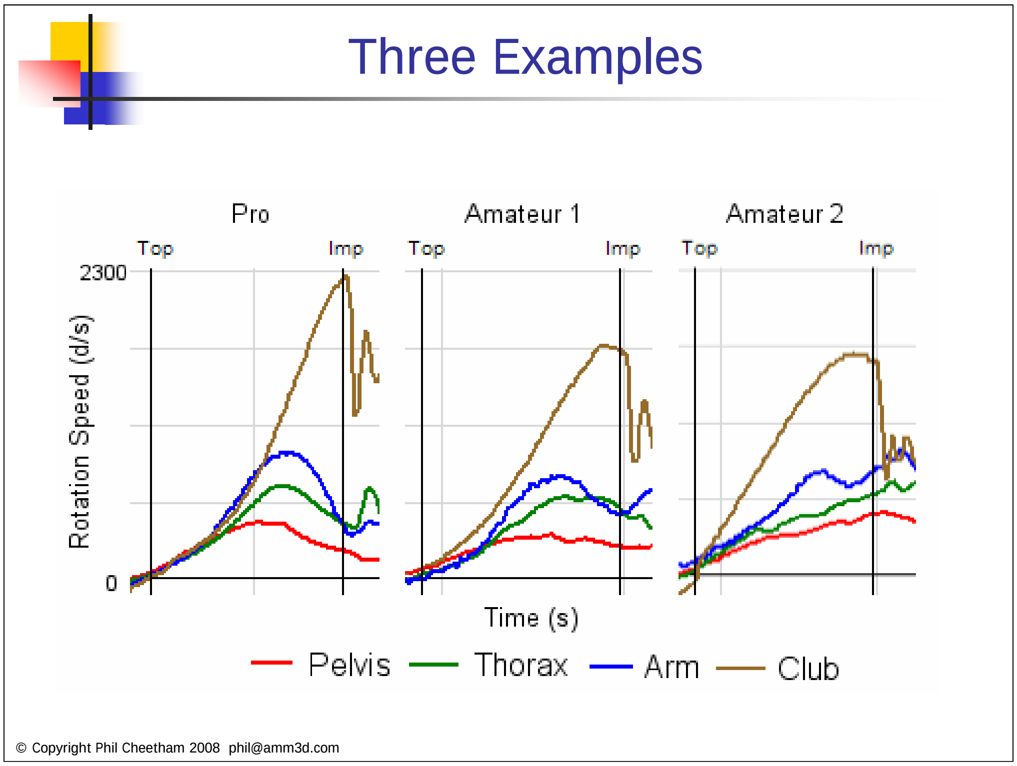


•**Notice also that there is a trend that supports the "Proximal to distal sequencing theory"**

•Pelvis, thorax, arm and club; the **data** of the **pros support this** theory.

•Higher number peaks first before impact
Pros **Pelvis, Thorax, Arm ----** Amateurs **Pelvis, Arm, Thorax**
This suggests that **amateurs** tend to **use their arms** earlier in the downswing

FYI - Pro34a Downswing average = 266ms



•The use of **3D motion analysis** provides the ability to **look at dynamics** that the **naked-eye can not see**. A **good instructor can see postural aspects** of the swing at stationary points such as **address** and **top** of backswing, but 3D analysis allows the instructor to critically review timing, speed and acceleration variations in all parts of the swing that would otherwise not be seen, such as the .25 seconds of the downswing.

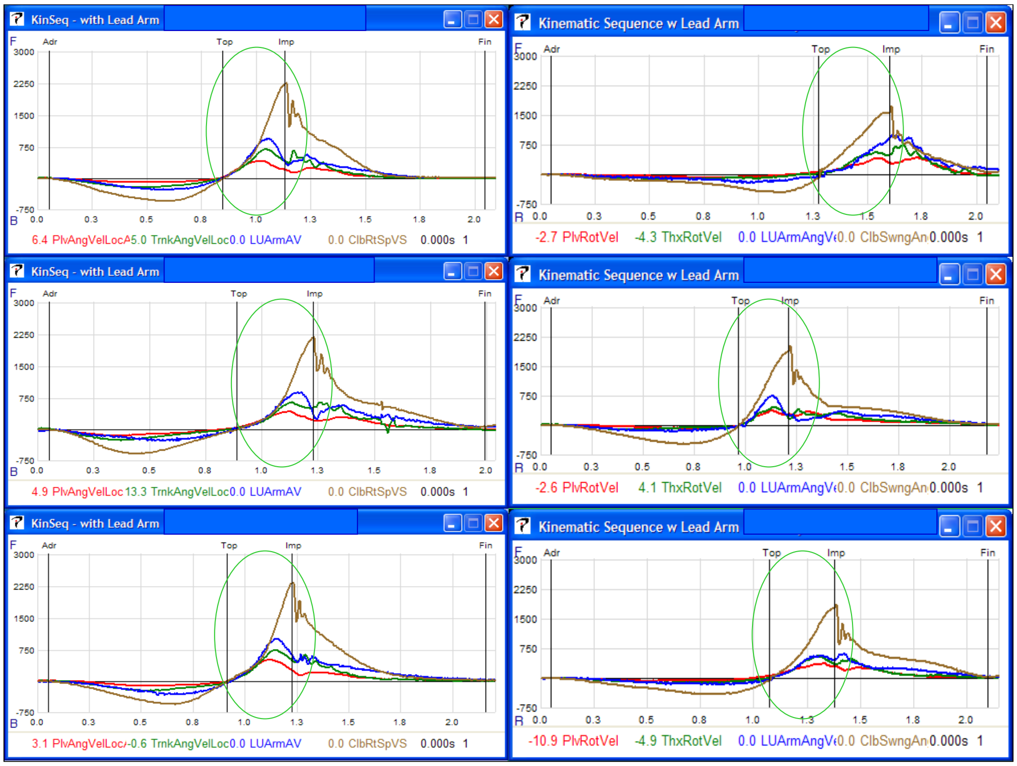
•The **Pro** shows smooth accelerations and decelerations, each curve peaking higher and later than the previous one, with the club peaking at impact.

•The **Amateur 1** shows poorer accelerations and decelerations, lower speeds and the arm peaks before the thorax.

•The **Amateur 2** shows no overall decelerations of the pelvis and thorax before impact.

•**Both amateurs cast** the club; it races ahead of the body segments, peaks too soon and decelerates slightly before impact.

•**Pro does not cast** the club; the arm and the club track each other very closely until the club races ahead at the wrist release point later in the downswing.



•Generally speaking the results show that the **amateurs** tend to have **poorer coordination, weaker accelerations and decelerations, and consequently - inefficient energy transfer** from segment to segment than the pros.

3 Pros (Highly Skilled) and 3 Amateurs (Less Skilled)

Extra Links in the Kinematic Sequence

- Theoretically every extra link in the sequence can add speed to the club
- Unfortunately control becomes more difficult with the added degrees of freedom
- Two examples of elbow as an extra link

I'd like to finish off by showing you some preliminary research that we are doing on extending the kinematic sequence to more segments.

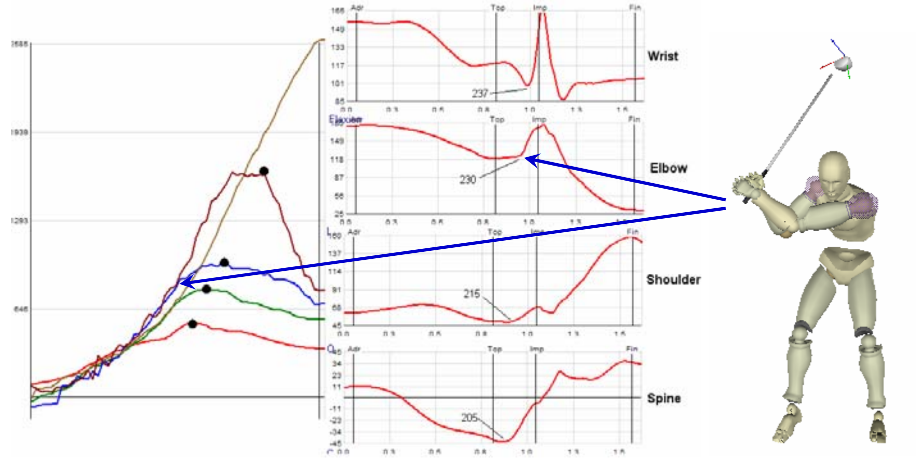
Read Slide

A high percentage of golfers bend their lead elbow at the top of backswing

Is this good or is this bad – Well that depends on how they control that bend during the downswing

Lets look at two examples:

An Effective Extra Link in the Sequence

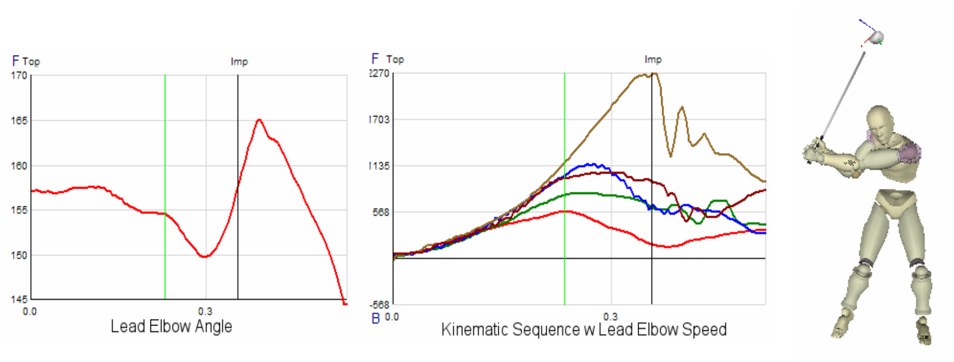


- Bending lead elbow at beginning of downswing, maintaining an elbow set and then rapidly releasing it causes rapid increase in speed.

This golfer has a club head speed of over 130mph and has one of the longest driving distance averages on tour.

Notice the build up and sequencing of the peak segmental speed; and the sequencing of the joint release actions

An Ineffective Extra Link in the Sequence



- Bending lead elbow at wrong time during downswing causes forearm speed to decrease below that of the upper arm

Notice to the right of the green line in the Lead Elbow angle graph; this golfer allows the arm to bend more before extending it.

Forearm actually peaks our slower than the upper arm as you can see in the kinematic sequence graph.

In the Angle Graph - Down means more bend of elbow

Pro’s hit further because they have:

- At Transition
  - An Effective Amount and Rate of Extra Stretch
  - An Efficient Joint Loading Sequence
    - Pelvis, Thorax, Arm, Club
- During Downswing
  - Higher Body Segment Accelerations
  - Higher Body Segment Decelerations
  - Higher Body Segment Peak Rotational Speeds
  - Higher Speed Gains Across Each Joint
  - An Efficient Sequence of Segment Peak Speeds
    - Pelvis, Thorax, Arm, Club
  - Efficient Timing of Peak Speeds
  - Possibly the Ability to Effectively Add Extra Links into the Sequence

A More Efficient Kinematic Sequence!