Kinematics of the Golf Swing

Implications for performance, training and injury

Lecture Note Summary for MSKPlus Course March 2012

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Overview

A. Pelvis, Thorax and Spine Kinematics

Special Topics Covered
–X factor
–X factor stretch
–Lateral crunch
–Proximal to Distal Sequencing

*the majority of data presented here was collected using a 3D magnetic trackers (Polhemus) on scratch or better golfers

B. Variables related to Peak Performance

–Swing characteristics
- x factor
- x factor stretch
- the case against the x-factor stretch

–Golfer characteristics

C. The Swing's Possible Relationship to injury

D. Special Topics

Some Questions about the swing

- Does the spine stay flexed throughout?
- How much lateral bending occurs?
- What moves first during the downswing?
- What structures are put under load?

Swing Jargon: Face ON

Top | Downswing | Impact | Early follow thru

Measuring Kinematics

Cameras

Multiple cameras are used to film the golfer who is fitted with marker sets. These markers are captured and converted to 3D co-ordinates. Math functions are used to find kinematic variables (displacement, joint angles, velocity, acceleration etc). This is often very time intensive and intrusive

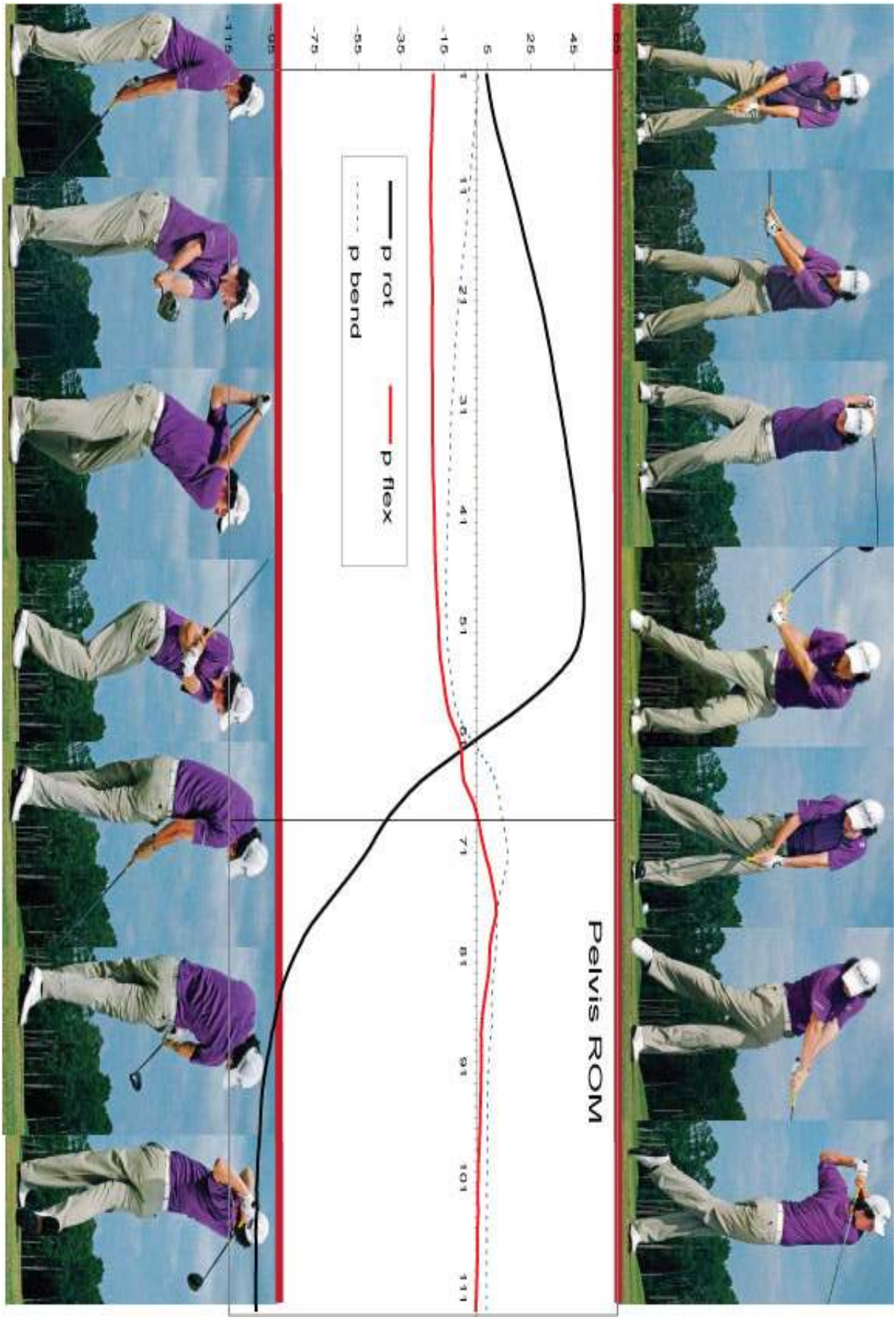
Electromagnetic Trackers

3D trackers are easy to use and are placed on different body parts of the golfer. The trackers give orientation data (angles) and positional data (3D coordinates). As an example, the orientation data is used to give us information about how flexed, rotated or laterally bent the thorax is during the swing. A marker would also be placed on the pelvis giving us information about how the pelvis moves. Finding the difference between the thorax and pelvis would tell us about the general spinal motion during the golf swing. Putting trackers on the arms and club give us further information. An excellent source for this technology is **amm3d.com**. A company run by Phil Cheetham, an expert in sport biomechanics technologies

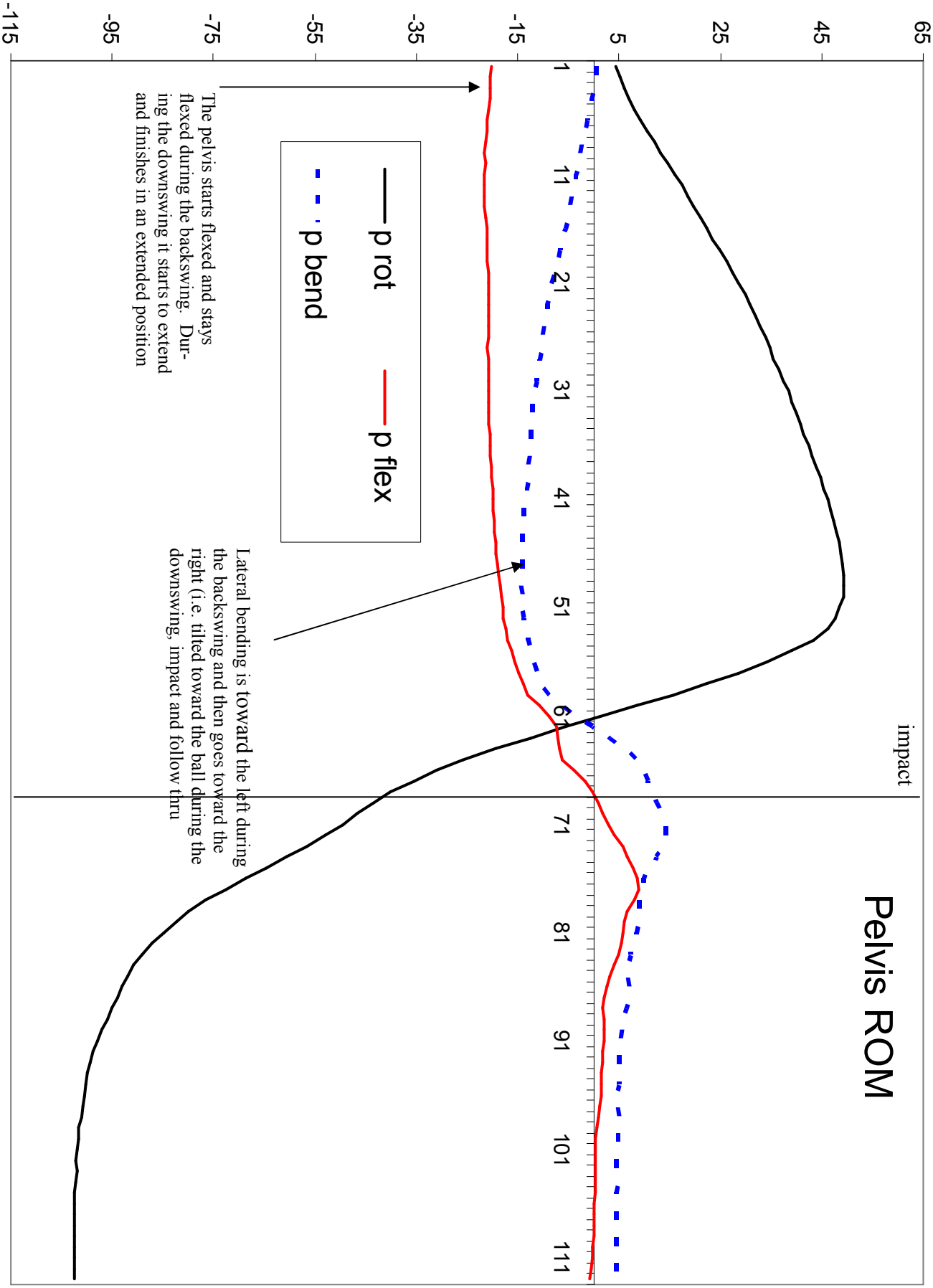
Why should you care?

This is significant because you will get different conclusions based on how you measure the spine. Cameras overestimate thorax rotation during backswing. Different research papers also draw different conclusions about swing kinematics. Many of the differences across papers can be explained by differences in how the spine motion was measured.

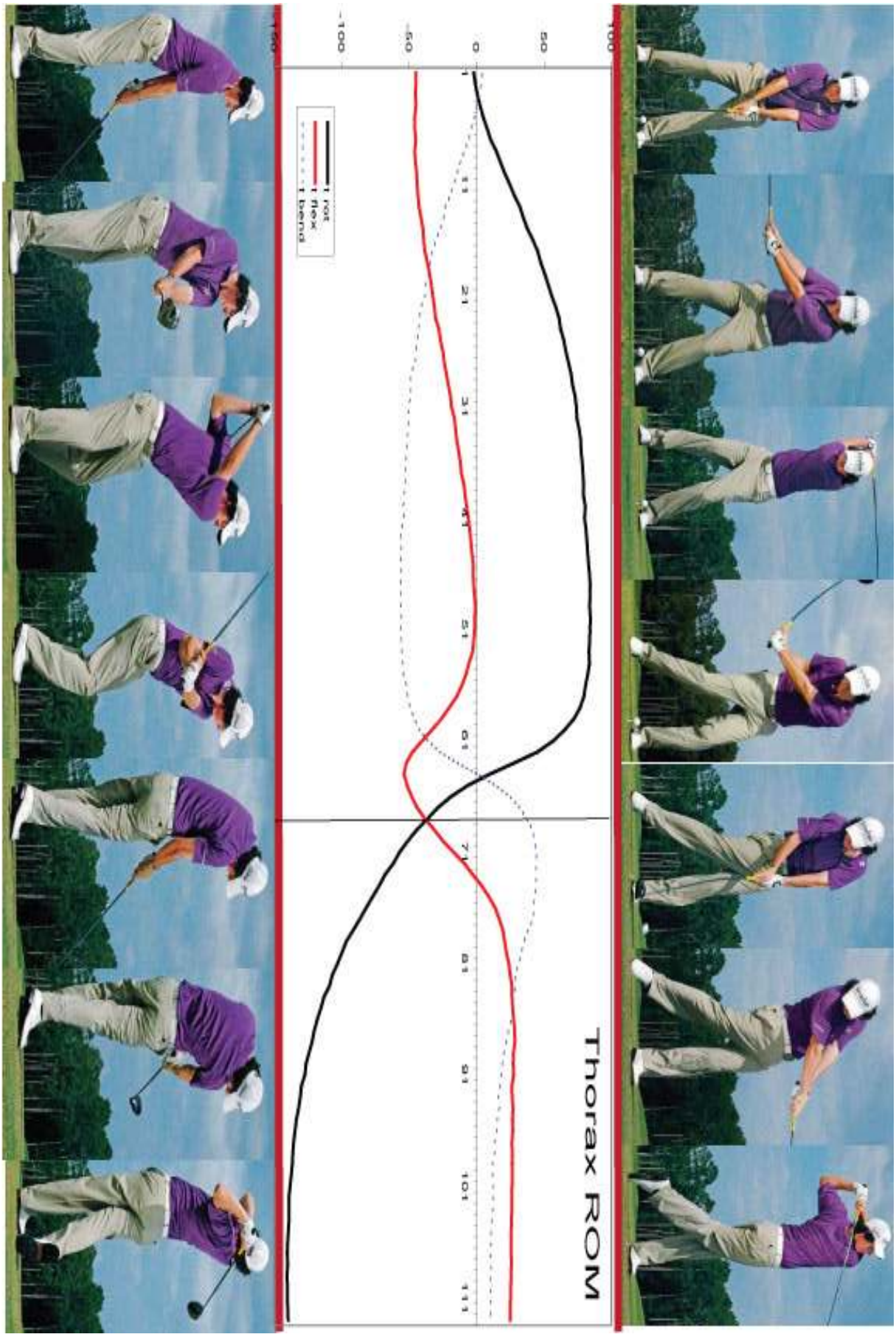
Pelvis Kinematics



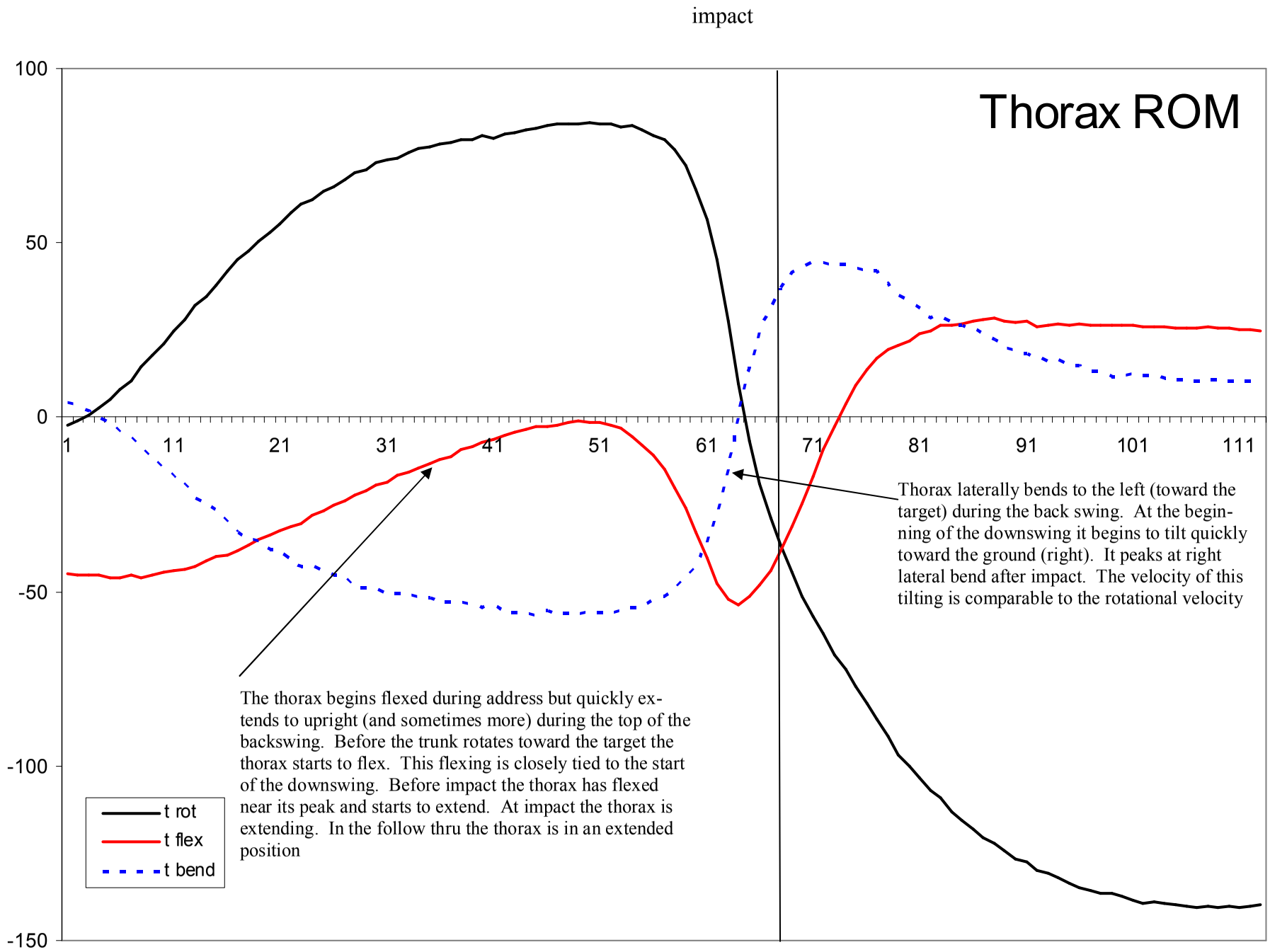
Pelvis Displacement



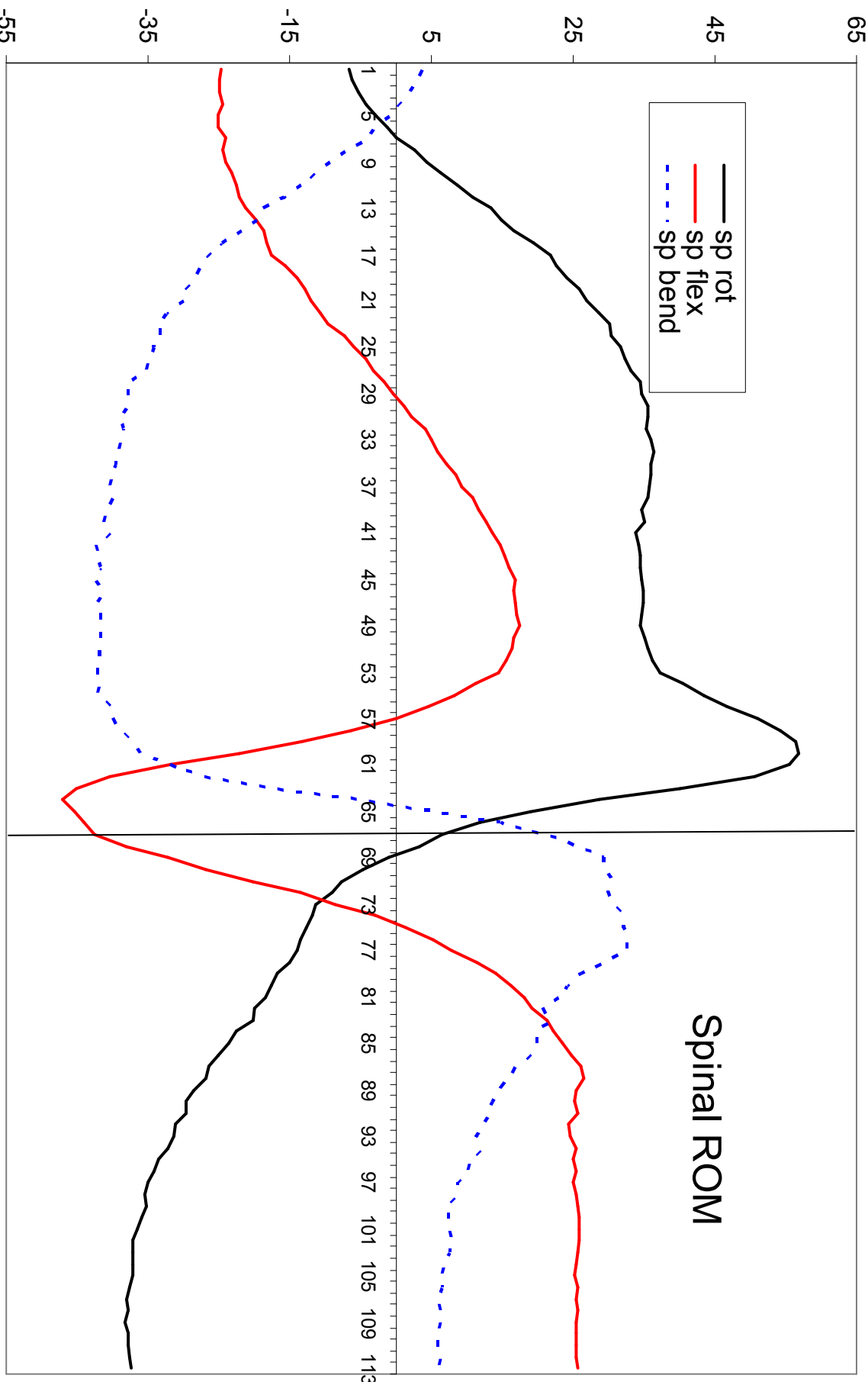
Thorax Displacement



Thorax Displacement

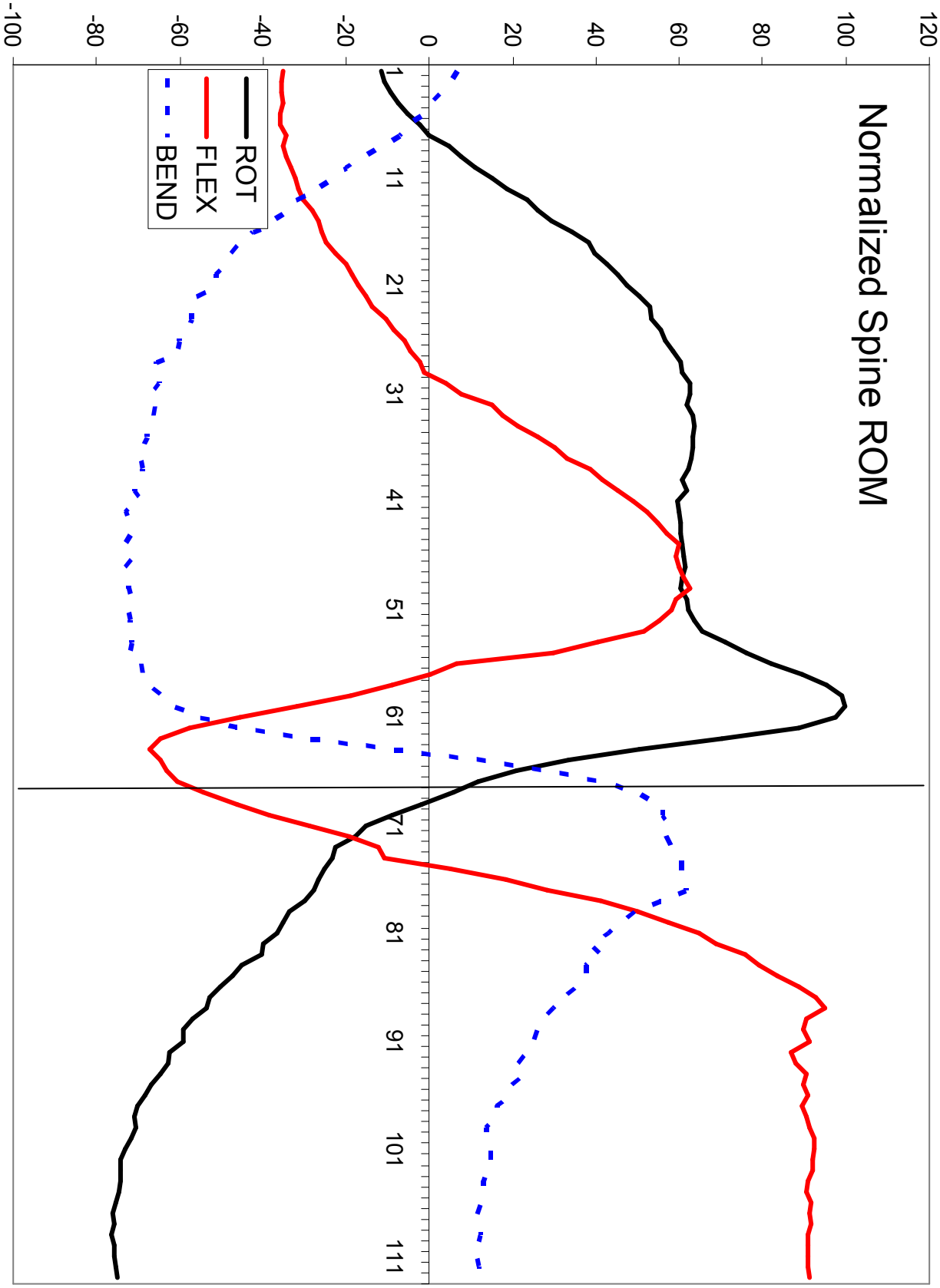


Spine Displacement



Starts to flex greatly during downswing and extends just before impact

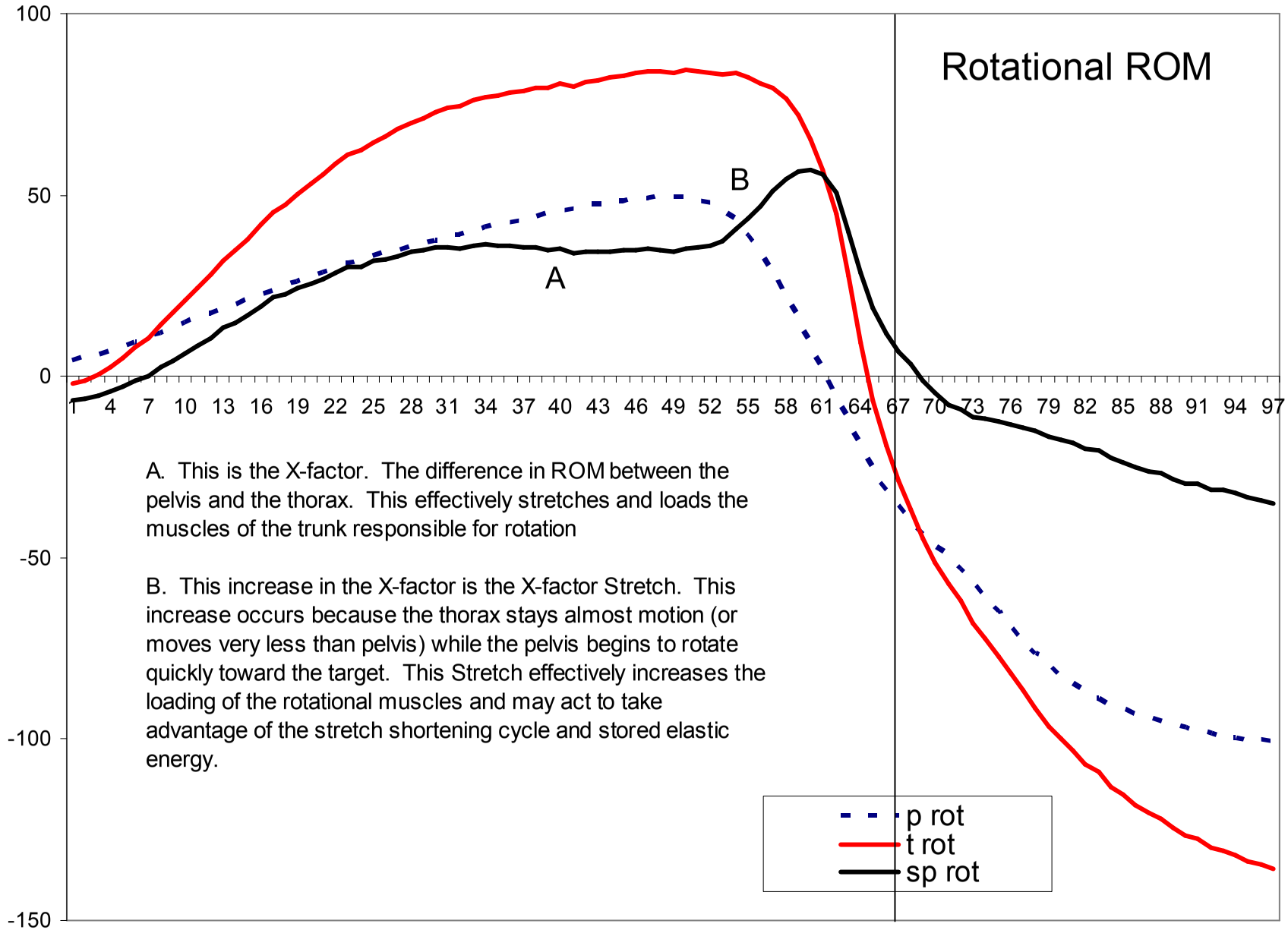
Spine is in relative extension at backswing because pelvis is flexed and thorax has come upright.



Spine ROM is expressed as a % of the maximal ROM found during standard ROM testing. This gives us an idea how close the spine comes to its range limits during the swing. This may have some injury risk significance.

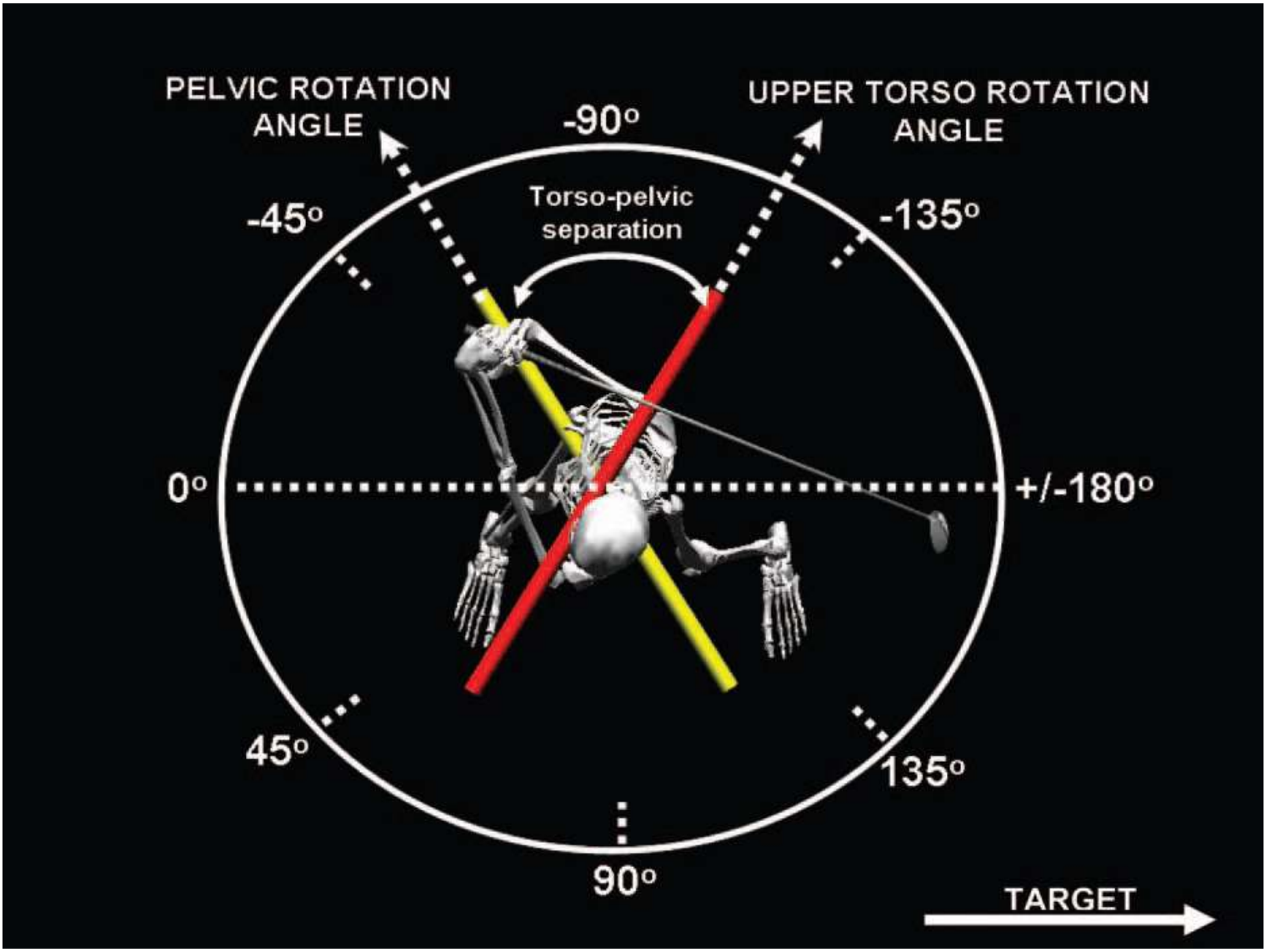
Typically, rotation range of motion during the backswing, right lateral bend during follow thru and spine extension ROM during the follow thru approach or exceed 100% of the maximal available range during upright testing.

Rotation for Thorax, Pelvis and Spine



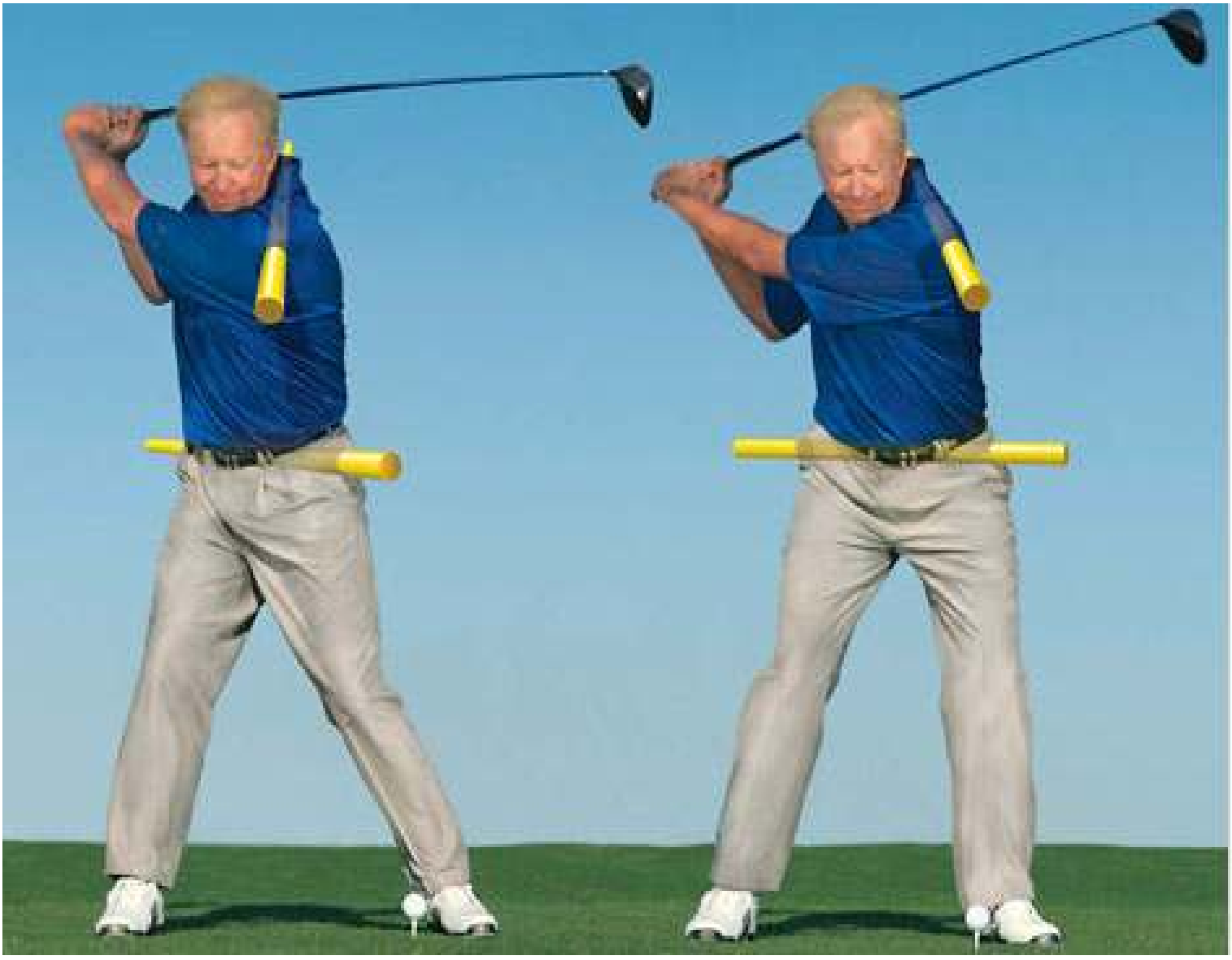
The X-Factor

The difference in rotation (torso-pelvic separation) between the thorax and the pelvis



(Image from Lephart 2007)
Btw: Dr. Scott Lephart and his team are excellent researchers into golf biomechanics, injury and performance. They are based out of Pittsburgh.

The X-Factor Popularizer - Jim McLean



The X occurs when you view the swing from above. It is the difference between the hips and the shoulders.

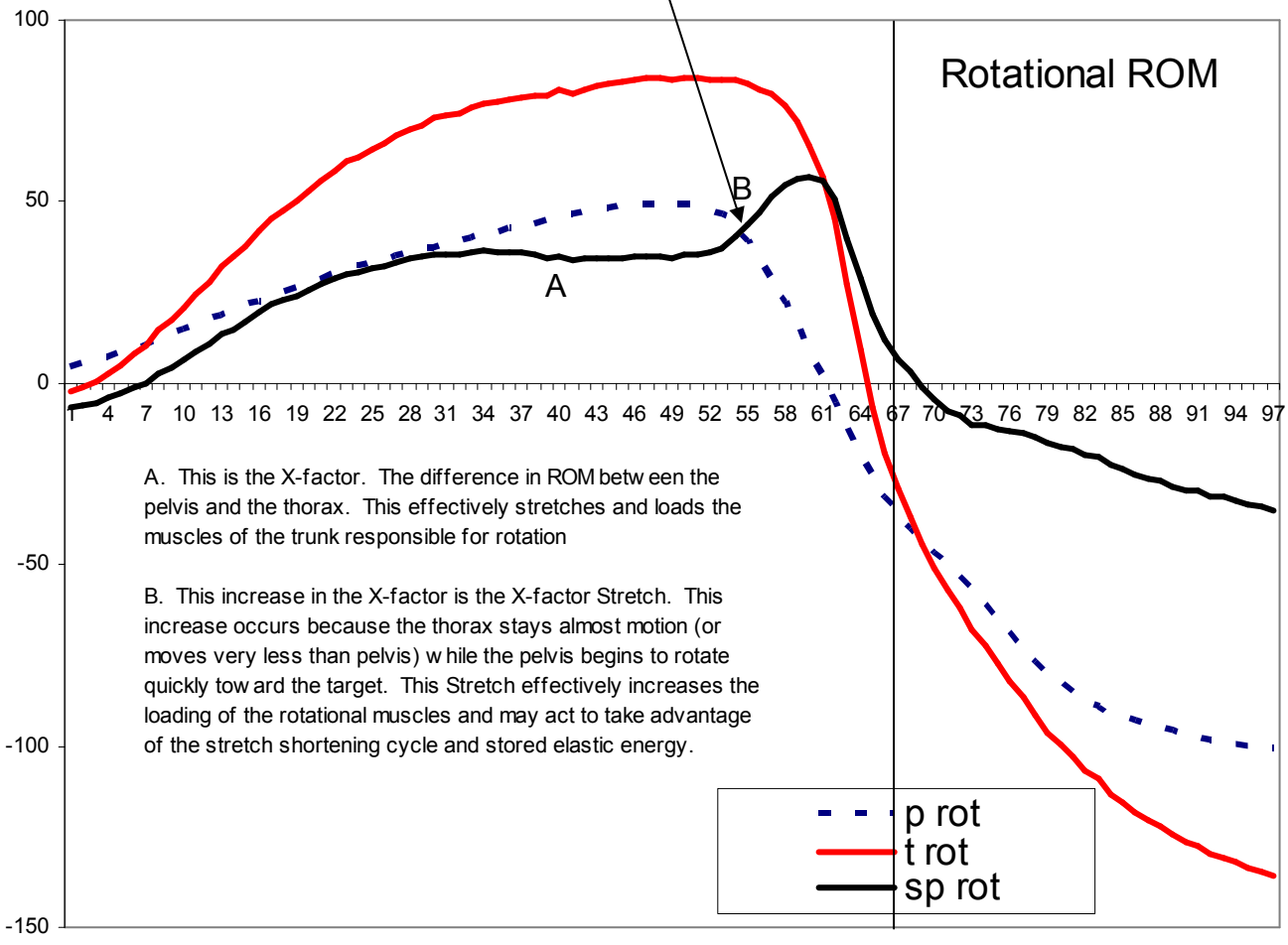
What would happen if you started the downswing with hip rotation that preceded the shoulders?

The X-Factor Stretch

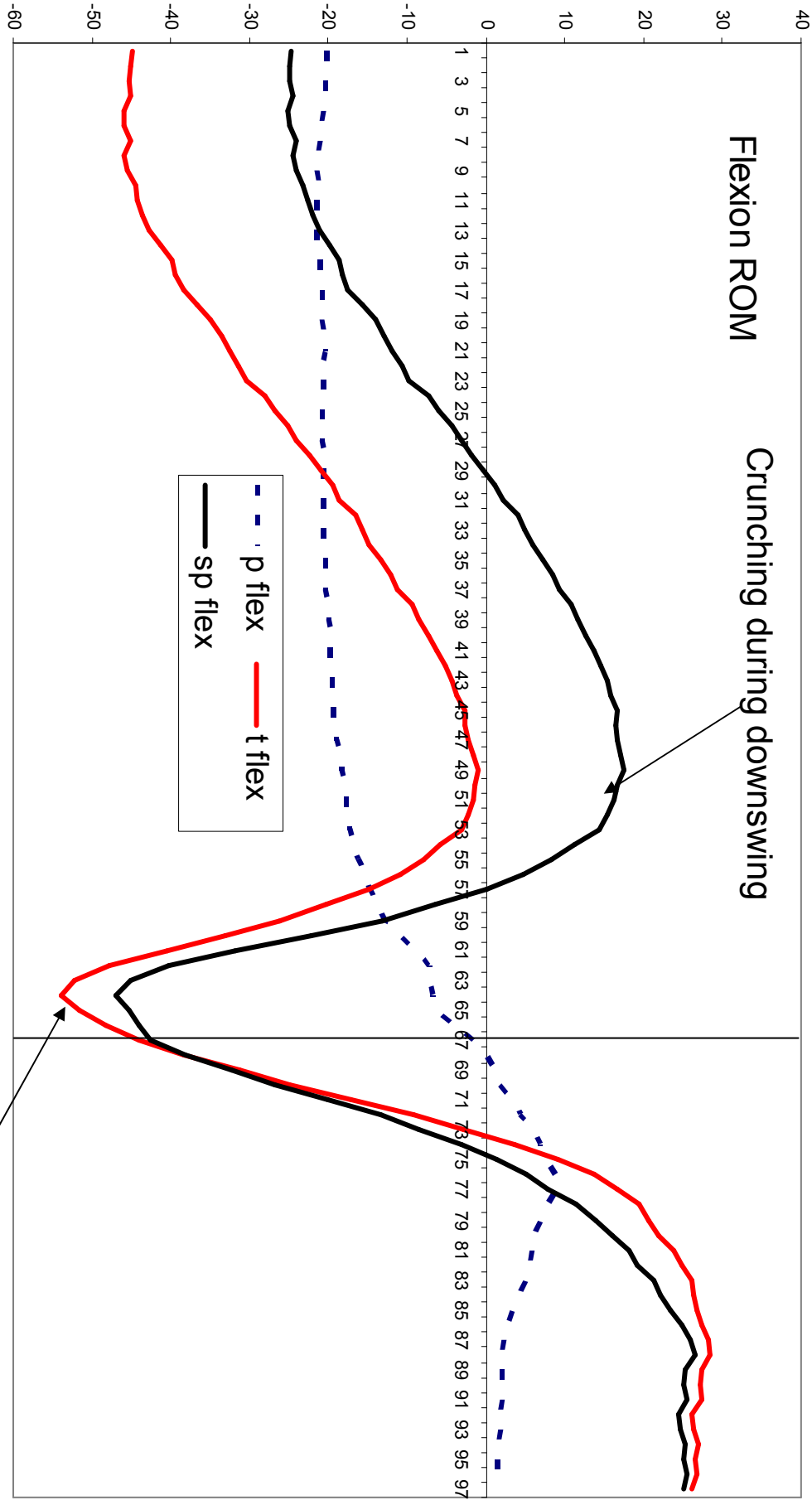
The change in relative position between pelvis and thorax at the start of the down swing.

Can occur when the thorax continues to rotate backwards while the Pelvis starts to go forwards and toward the target.

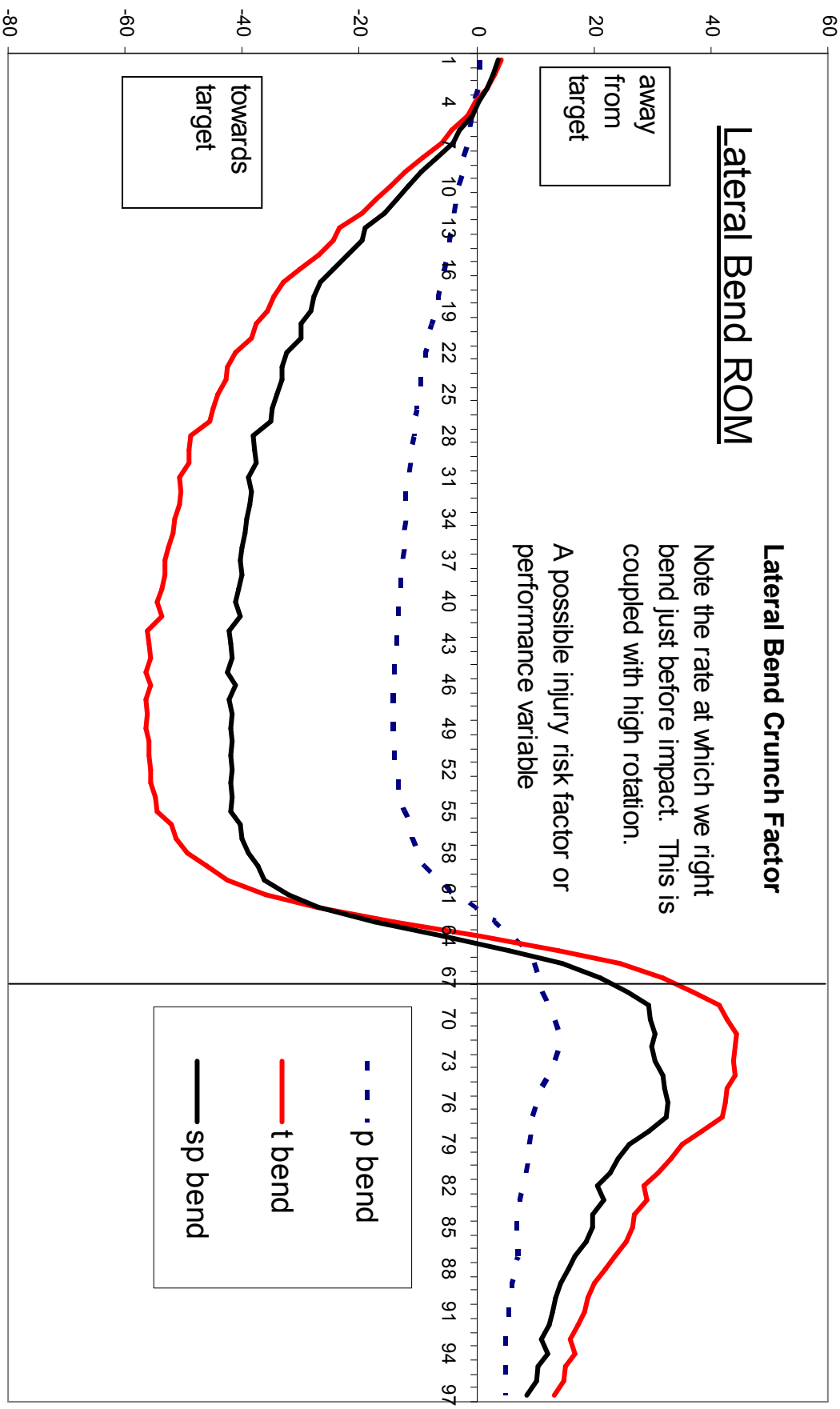
Also seen when the pelvis starts the downswing while the thorax remains stationary.



Flexion for Thorax, Pelvis and Spine



Lateral Bend for Thorax, Pelvis and Spine



Trunk Displacement Summary

Pelvis

- Starts flexed (20 degrees) and extends during downswing toward neutral
- Tilts toward target on backswing (10 degrees) and then tilts toward ball on downswing (10 degrees)
- Rotates away on backswing (45 closed) and then rotates toward target on impact (40 degrees open) continues to rotate open during follow through

Thorax

- Thorax starts flexed but extends to upright during backswing
- Flexes during downswing but just before impact begins to extend
- Tilts (laterally bends) toward target (40 degrees) on backswing
- Tilts toward ground (30 degrees) on impact and continues this on follow through
- Rotates away on backswing (90 degrees)
- At impact is open (30 degrees) but still 10 degrees shy of pelvis

What Swing Kinematics predict Performance?

The next section will investigate the following swing kinematic variables that may be related to either increased club head velocity or be associated with professional golfers/low handicappers.

1. X factor
2. X factor stretch
3. Proximal to distal Sequencing
    - Summation of speed
    - Kinematic sequencing or linking
4. Lateral bend ROM during downswing
5. Extremity Motions

X Factor and Performance

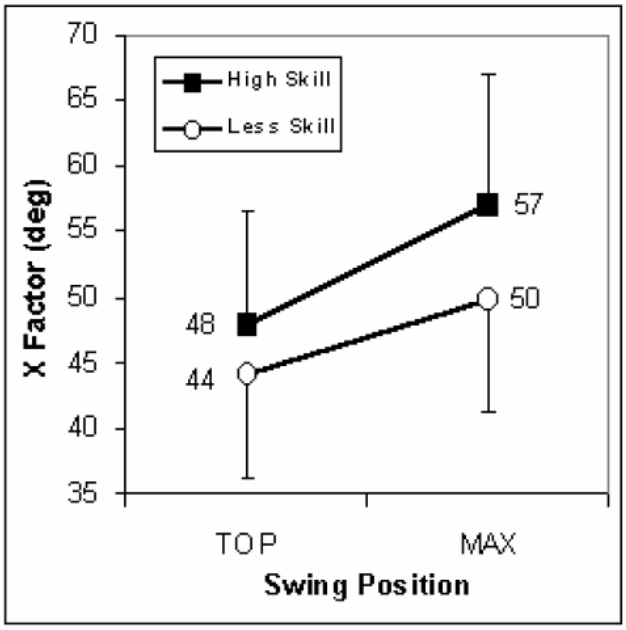
- Some debate about whether this is related to increased club speed
- The most robust study supports the X-factor alone and not the X-factor stretch (Myers 2008, Chu 2010)
- Some (Cheetham 2001) insist it is the X-factor stretch that is important not just the x factor
- All studies agree that it is not the absolute rotation of the hips or pelvis
- A difference between studies is how trunk kinematics were measured. Studies supporting the x-factor stretch measure movement of the spine with electromagnetic trackers on the thorax while the other studies (Myers 2008) measure the thorax rotation via a marker set that is actually placed on the acromion. This would tend to overestimate thorax rotation since some rotation would occur via protraction and retraction of the shoulder blades

Support for the X factor and Performance (Myers 2007)

- Suggested that X factor alone is more important than stretch
- X factor differences between High and Low Velocity (Myers 2007)
  - 59 degrees (High Vel) versus 44 degrees (Low Velocity)
- X factor max between High and Low
  - 61.8 versus 45.6
- Supported by Chu (2010) with massive group (n = 300 ish) but no comparison made between ball velocity groupings
- Measured with VICON camera systems (is this a factor?)

X-factor Stretch Argument

- Some argue more important than x factor alone (Cheetham 2001, Neal 2004)
- Most robust study (Myers 2008, Chu 2010) found no relationship
- McTeigue (1994) found that 70 % of pros begin the downswing with their pelvis suggesting an x-factor stretch. Whether this was statistically related to driving distance or accuracy is unknown.
- Neal (2004) did not find a relationship to performance amongst professionals studied
- Significant differences in measurement of body segments across the different studies
- Logically, the stretch takes advantage of the SSC more than the mere x factor. While the x-factor does create a stretch between rotational muscles of the trunk this is a static hold stretch. Whereas, the stretch that occurs with the x-factor stretch creates an eccentric contraction BEFORE the concentric contraction that initiates and maintains the downswing. The x-factor stretch is akin to a counter-movement jump (squat down quickly and then jump) where the x-factor is akin to squatting down, pausing for a second (an isometric contraction) and then jumping. Cheetham (2001) has shown that Pros do have a greater x-factor stretch than amateurs.



- The relationship to injury is unknown. However, it can be argued that the X-factor stretch may increase tissue loading as the spine will undergo an increased amount of rotation. Considering the debatable advantage of the stretch this is a modification to the golf swing that may be reasonable for those with low back, hip or even lead shoulder injury.

The Case against the X-factor Stretch

Neal (2004) found no relationship between Stretch and driving distance

Pro	Distance	X-Factor	XF Max	X-F Stretch
A Cabrera	300.1	48	72	24
R Pampling	291.9	47	57	10
Steve Allen	291.3	46	73	27
Carlos Franco	289.6	39	55	16
John Senden	287.2	33	57	24
Hunter Mahan	287.1	47	55	8
P-U Johanson	283.8	47	66	19
Brian Gay	281.3	44	54	10
DJ Brigman	280.8	55	72	17
Brad Faxon	266.1	45	64	19
Mean	**285.92**	**45.1**	**62.5**	**17.4**

Our ignorance still trumps all

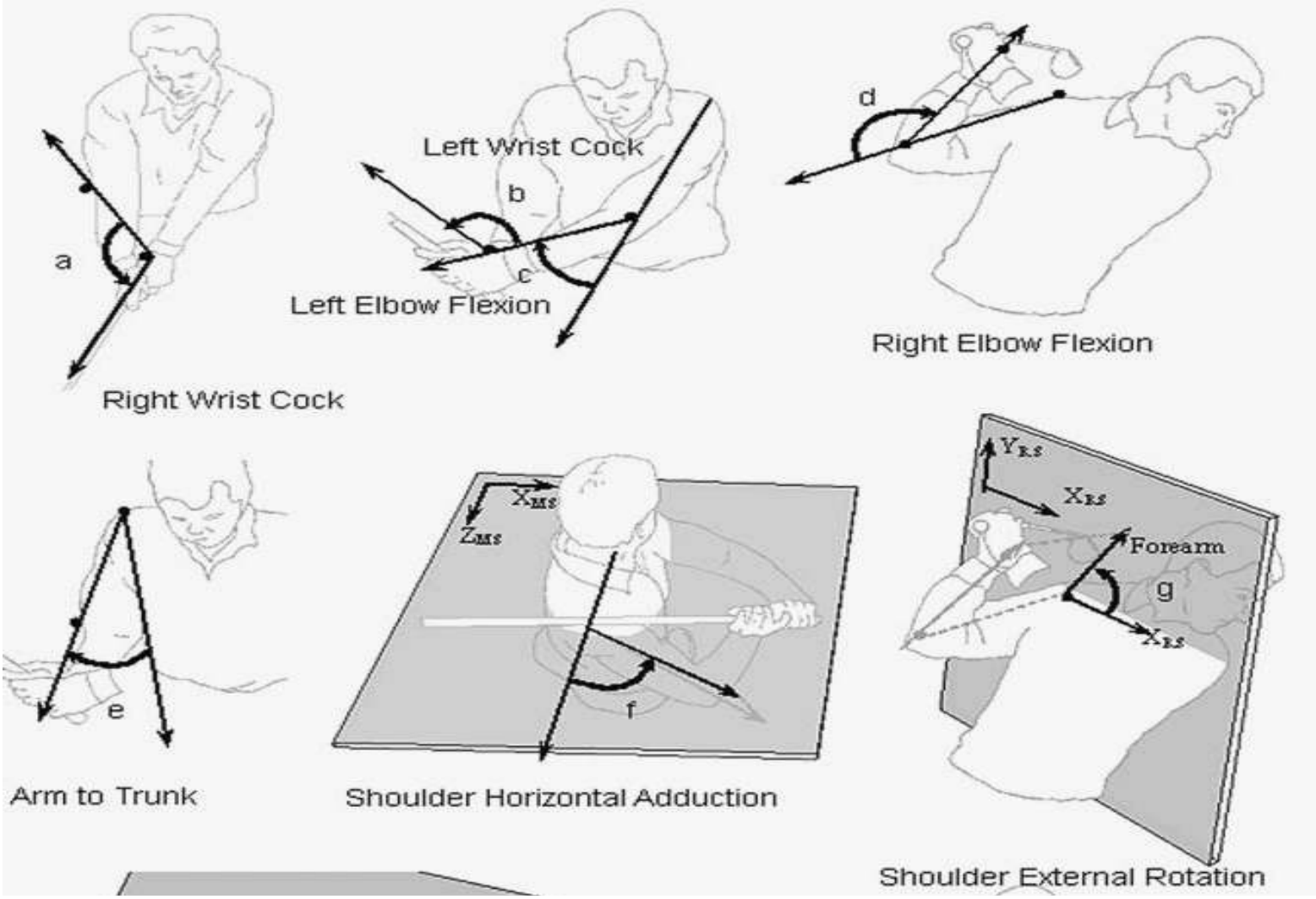
While a debate exists in the co-relational studies that investigate what kinematics predict performance we are still lacking any prospective trials that attempt to modify things like the x-factor stretch and see how these changes relate to performance.

Can acute stretching change the x-factor?

Long term studies have shown changes in the X-factor with training (Lephart 2007).

We have also conducted a short term study to see if an acute bout of stretching would change the x-factor or the x-factor stretch. In more than 15 individuals studied no participant saw changes in these two variables despite changes in their ROM testing. This suggests that structural elements may be trumped by motor control (aka form)

What other kinematic variables predict performance?



Angular differences at the top of the swing between Pros and High Handicappers (HH) exist.

Values in Bold are statistically significant.

Left Horizontal adduction and left wrist cock are ones to watch

	Pro	HH
R Elbow Flex	130	128
L Elbow Flex	58	67
R arm to trunk	43	45
L arm to trunk	90	83
L shoulder HOR Add	**125**	**115**
R Sh ER	**66**	**46**
R Wrist	75	79
Left Wrist	**94**	**103**
Trunk Rotation	**60**	**49**
Trunk Lat Bend	-9	-8

Angular Differences at Impact (Zheng 2008)

	Pro	HH
R Elbow Flex	40	41
L Elbow Flex	**34**	**45**
R arm to trunk	23	24
L arm to trunk	35	37
R Wrist	118	122
Left Wrist	**165**	**156**
Trunk Rotation	**24**	**9**
Trunk Lat Bend	31	28

Does Lateral Bend at impact predict Performance?

- Pros = 31 degrees (impact), 45 degrees follow thru
- High Handicap = somewhat less
- Often associated with increased slide toward target of HH
- McTeigue (1994) and Meister (2010) have made "quantitative qualitative" conclusions

There is a trend and a suggestion in both the literature and qualitative assessment of golf swings that indicates that a greater trunk lateral bend at and after impact is related to proficiency in the golf swing.

Quantitative robust data does not exist

Positional Differences at BackSwing Recap

- X factor
- X factor stretch (inconsistent)
- Greater left arm horizontal adduction
- Greater right arm external rotation
- increased left wrist cock

Pros v Joes Impact Positional Differences

- Left elbow straighter at impact
- Left wrist is less cocked at impact
- Greater X factor (inconsistent finding)
  - –This depends on how it is measured
- Greater Right Lateral bend

Angular Velocity Differences b/w Pros and Joes

	PRO/FAST	HH/SLO
R arm to trunk	248	202
trunk to lateral bend	249	230
left arm to trunk	355	311
left shoulder hor abduction	170	242
trunk rotation	283	314
R shoulder IR	**522**	**326**
L elbow ext	**235**	**166**
left wrist	**1085**	**662**
club shaft	**2413**	**1756**
right wrist	**1183**	**708**
right elbow ext	**854**	**551**
peak pelvis rotation (2)	**401**	**348**
peak thorax rotation (2)	**738.3**	**546**
peak spine rotation (3)	**336**	**239**

Zheng et al (2008) and Myers (2007)

RECAP: Pros v Joes Body Velocity Differences

- Right shoulder internal rotation (Zheng 2008)
- Both elbow extension (Zheng 2008)
- Left wrist uncocking (Chu 2010, Zheng 2008)
- Right wrist uncocking (zheng 2008)

- Torso rotational velocity (Myers 2007)
- Spine rotational velocity (Myers 2007)
- Lateral bend velocity (Chu 2010)
- Pelvis superior shift velocity (Chu 2010)

Proximal to Distal Sequencing (Putnam 1993)

Defined as...

in order to maximize the speed at the distal end of a linked system, the movement should start with the more proximal segments and progress to the more distal segments such that each segment starts its motion at the instant of greatest speed of the preceding segment and reaches a maximum speed greater than that of its predecessor

And related to...

Summation of speed (Bunn 1972)

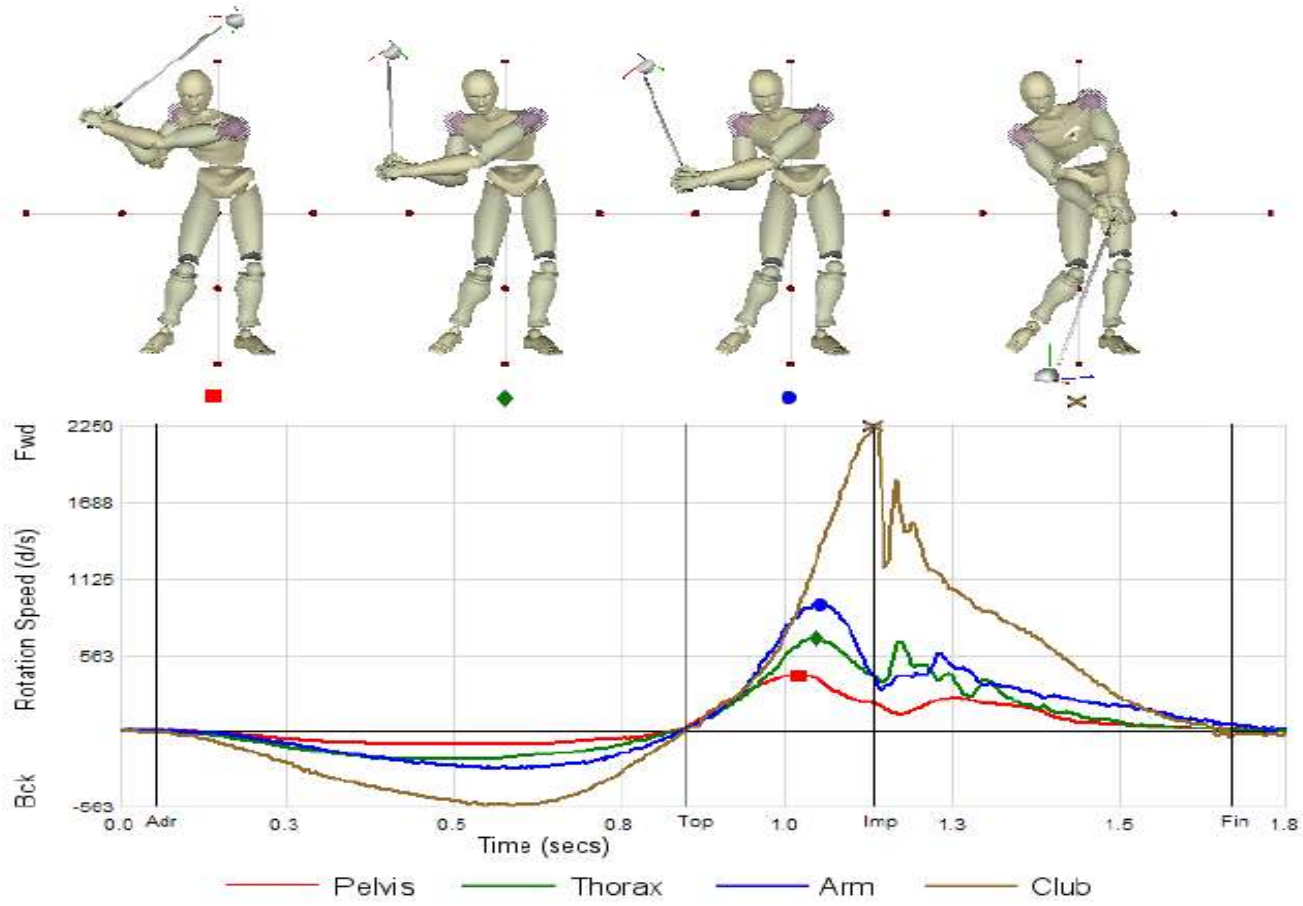
This principal states that each succeeding segment initiates motion at the time of maximum speed of its proximal segment, generating higher distal endpoint speeds than the latter

Relevance

For the golf swing this means we initiate the swing with our pelvis/hips, which followed by our thorax, then shoulders, upper arms, elbows, wrists and finally the club.

Others have extended this principle to suggest that peak velocity of each proximal segment must occur before that of more distal segments. Phil Cheetham (www.amm3d.com) has coined this term.. KINEMATIC SEQUENCING.

PDS (aka Kinematic Sequencing Cheetham)



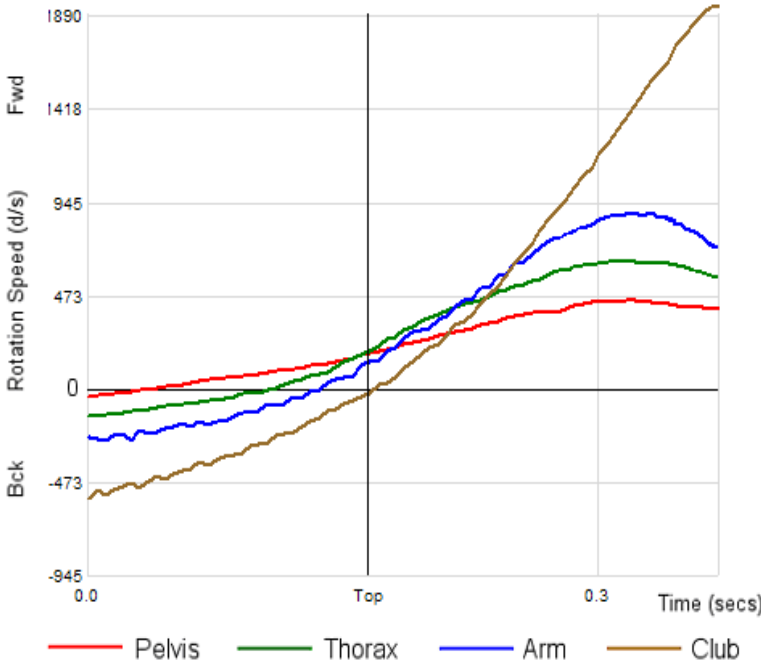
Phil Cheetham writes "During the downswing in golf all body segments must accelerate and decelerate in the correct sequence with precise and specific timing so that the club arrives at impact accurately and with maximal speed. The most efficient sequence of motion for the major segments is: pelvis, thorax (upper body), arms and finally club. This motion must occur sequentially with each peak speed being faster but fractionally later than the previous one. This sequence reflects an efficient transfer of energy across each joint and facilitates an increase in energy from the proximal segment to the distal one. The muscles of each joint produce this increase in energy. On the other hand, if the timing of energy transfer is wrong, energy can be lost and hence speed will be lost; also if one body part has to compensation because another is not acting correctly then injury may result. During the forward swing, the larger, inner segments such as the pelvis and thorax move slower with the speed building as the energy progresses to the smaller distal segments such as the arms and club. Note that the pelvis does not continue accelerating through impact, but decelerates before impact. In order to quantify the differences in the Kinematic Sequence between golfers we compare specific values from the segmental rotational speed curves. For example, we can look at the maximum rotation speeds of each segment; progressive speed gains between segments; sequence of maximum speeds; timing of maximum speeds with respect to impact; average accelerations and decelerations before impact. Using these values we can quickly tell what segment of the body is not performing optimally"

Evidence for PDS Principle and Performance

- Amateurs tend to violate principle (Cheetham)
- 70% of pros rotate hips first (McTeigue 1994)
- 20% of pros rotate hips/thorax together (McTeigue 1994)
- 10% or pros rotate thorax first (McTeigue 1994)

Pro Transition? (source amm3d.com)

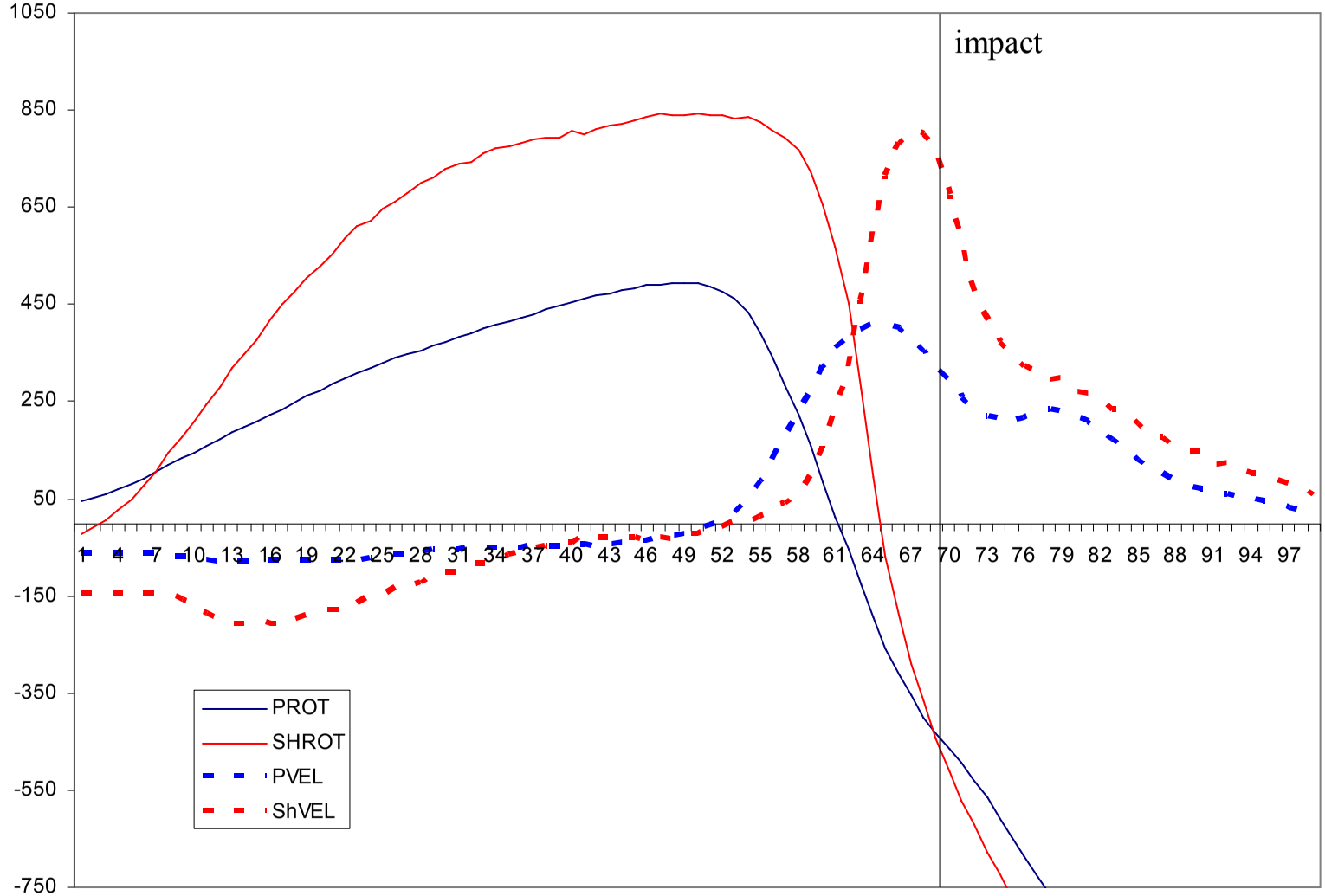
Again, from Phil Cheetham "Any part of the curve below the black horizontal zero line is in the back-swing, any part that is above this line is in the down-swing. Starting from the left of the graph we see that the red (pelvis) line crosses zero first, then the green (thorax) line, then the blue (lead arm) and finally the brown (club). The club crosses exactly at top of back-swing because this, as mentioned, 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 Tran-sition Phase. This transition sequence shown is consid-ered biomechanically correct as far as the order is con-cerned, that is, a good transition order is pelvis, thorax, lead arm, and club.



The amount of time that the red curve is on top of the green curve after it has crossed the zero line gives an indi-cation 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 af-ter crossing zero indicates how much wrist stretch is occurring".

Proximal to Distal sequencing

Compare the pelvis and thorax velocity curves with the curves of their range of motion during thes wing. Notice how the dashed red line starts rising later than the blue and peaks later than the blue. This thorax displacement and velocity. The thorax moving after the pelvis suggests that X-factor stretch is occurring in this golfer



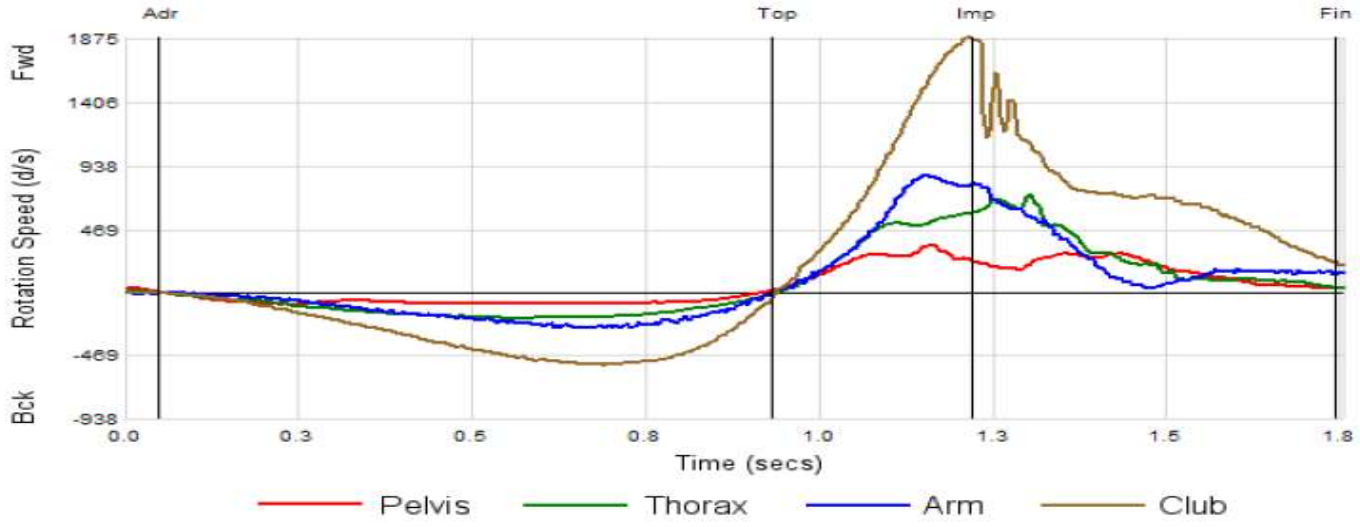
Violation of PDS (Cheetham 2001)

Very little research has investigated Kinematic sequencing or proximal to distal sequencing in the golf swing. One published study (Cheetham 2008) to date has shown that amateurs tend to violate the PDS principle. This can be seen in the table below which shows the timing of peak body segment velocity relative to ball impact. The timing is reported in milliseconds. The greater the number the earlier the peak velocity.

	Pro	Amateur
Pelvis	87	78
Thorax	68	59
Arms	65	64
Club Speed (mph)	109	88

Casting = Egregious Violation of PDS

Casting refers to the starting of the downswing with the arms. It looks like casting during fishing. During casting clubhead velocity is greater than that of other body parts during early parts of the downswing. See the chart below (from Cheetham at www.amm3D.com)



More support for PDS (Zheng 2008)

Zheng et al (2008) measured the timing of peak velocity for different body parts during the golf swing in high and low handicappers. Values are expressed as a percent of the swing (100% being impact). They found:

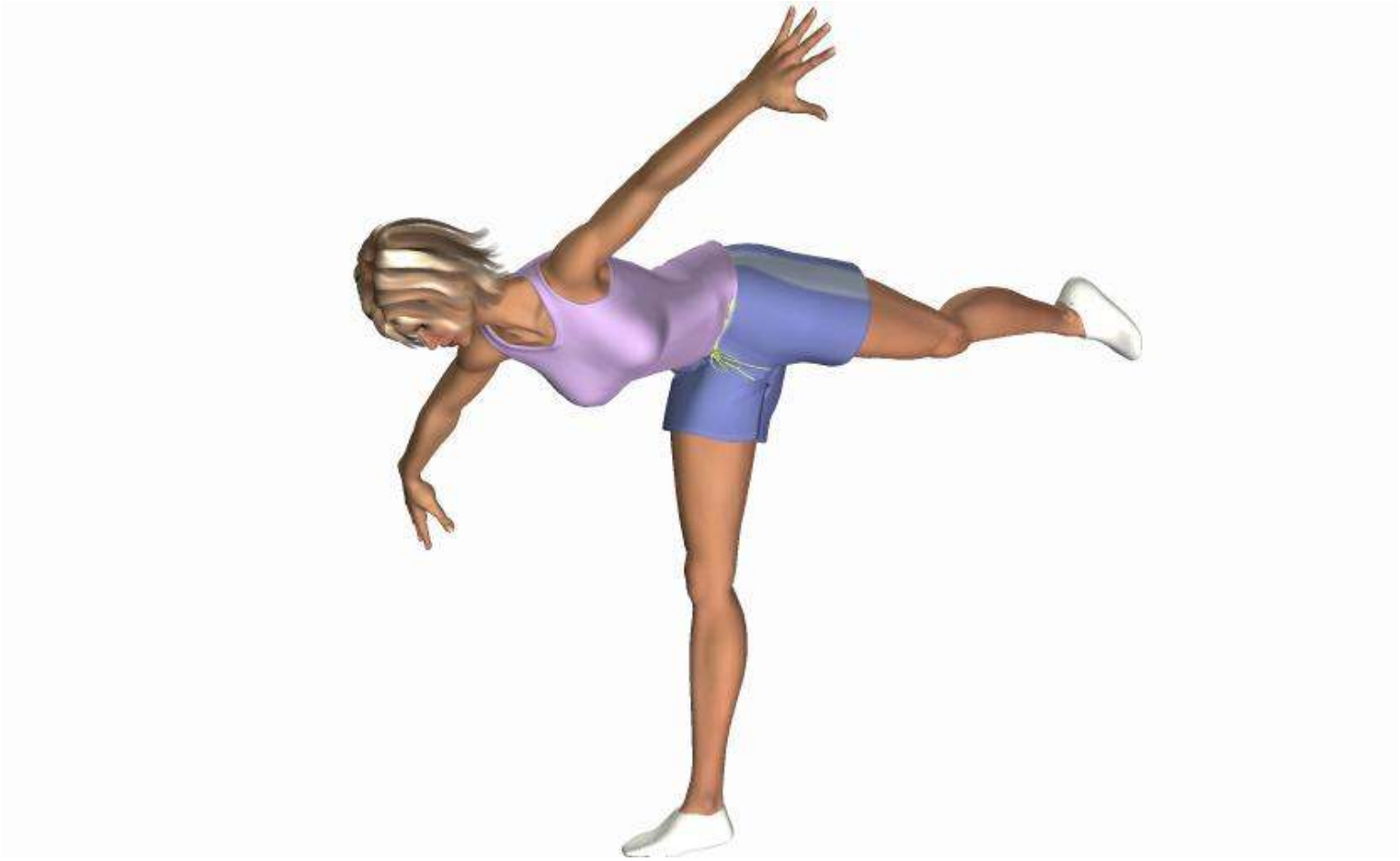
- Left elbow peaks way too early in HH
- Left wrist peaks too early in HH
- Left shoulder abduction peaks too late in HH
- Right elbow peaks too early in HH
- Trend for trunk rotation to peak too late in HH

	PRO	HH
R arm to trunk	**52**	**64**
trunk to lateral bend	59	70
left arm to trunk	**69**	**81**
left shoulder hor abduction	**72**	**91**
trunk rotation	74	87
R shoulder IR	81	80
L elbow ext	83	69
left wrist	**88**	**83**
club shaft	94	91
right wrist	95	93
right elbow ext	**99**	**91**

Did you notice?

Even in the Pro swing there are small violations of the order or peak velocity. Some segments that are more proximal do have velocity peaks that occur later than some segments that are more distal. But an obvious trend exists. Notice how the high handicappers violate the principle to a greater degree.

Physical predictors of Performance



Strength predicts handicap (Sell 2007)

Strength (% BW)	Scratch	>10
R hip abduction	*153.5*	*121.6*
R hip adduction	*132.6*	*109*
R shoulder IR	*59.4*	*48.6*
R shoulder ER	*40.5*	*36*
L hip abduction	*153.9*	*124.6*
L hip adduction	*128*	*110.7*
L shoulder IR	*53.8*	*47.5*
L shoulder ER	40.1	35.1
R torso rotation	*157*	*122.7*
L torso rotation	*154.9*	*125.2*

Flexibility predicts performance (Sell 2007)

ROM	Scratch	>10
R shoulder flexion	177	174
r shoulder ext	*48*	*41*
r shoulder abduction	*181*	*172*
r shoulder IR	60	58
R shoulder ER	*106*	*95*
L shoulder Flexion	*177*	*173*
L shoulder ext	*49*	*42*
L shoulder abduction	185	173
L shoulder IR	65	61
L shoulder ER	99	92

Hip Flexibility weakly predicts performance (Sell 2007)

Balance predicts Handicap (Sell 2007)

The Obvious Fitness Overview of Better Golfers

Stronger More flexible Better balance Better Athletes

Programming Implications

Sound Principles

The data suggests that golfers are athletes. Therefore training golfers like regular athletes is important. This means following the basics of strength and conditioning applies to golfers. We don't need gadgets, we need fundamentals. Get stronger, get faster, get more flexible, get more fit. All variables related to human performance are also related to individuals who are better golfers. BUT, we don't know the limits and we don't know if at an elite level there is a sufficient amount of fitness that leads to no further gains. The law of diminishing returns certainly applies or Camillo Villegas would win all tournaments (Dustin Johnson). We deal with averages and there are always outliers. Examples, will exist where training can negatively effect a complex game such as golf.

Comprehensive Training (limits of functional training)

Functional training is popular, much like instability training had its hey-day 8 years ago. Functional training is basically the use of exercises that are composed of movements that are very similar to the golf swing. I've been a proponent and even wrote a paper advocating and promoting its use. An example of functional training would be a loaded golf like swing against using a cable machine or lift/chop pattern. These are great exercises but the research is not there to support there use exclusively. In fact, there is some research that suggests that some muscles will not approach their maximum when using these exercises even though the person doing the exercise feels they are near their limit (McGill 2009. Isolation exercises (bridging, curl ups, bench press) may still play a role in providing muscles the high intensity stimulus they need to adapt.

Train athleticism (strength to power spectrum)

This relates to the first suggestion. We need to train all aspects of muscular function using a variety of tools. Power is more than peak force. It can be improved with overweight or even underweight training. Adapting approaches from the spectrum of strength and conditioning is important.

Train specificity (movement and velocity)

This is functional training. Now that we understand the movements that occur during the golfswing we can train those movements. This works for both testing an athlete to see where their deficits lie as well as in selecting exercises for training. For example, but your golfer into the ideal backswing position. Do they have fantastic cross body adduction and trunk rotation. If not, train this. Forget about tests that don't relate to the swing. In terms of strength and power, incorporate SwingFans, weighted clubs, cable swings, cable pulls with hip rotations and exercises that dissociate the hips from the thorax into your basic program.

Train capacity (motor and flexibility)

It won't hurt to get better at everything.

Train variety

Avoid habituation. The body is meant to adapt to stresses placed upon it.

Train individuals

McGill, S.M., Karpowicz, A., Fenwick, C. (2009) Exercises for the torso performed in a standing posture: Motion and motor patterns. J. Strength and Conditioning Res. 23(2): 455-464

Kinematic Relationship to Injury

A.Hip and Spine ROM Deficits (Vad et al 2002)

- Deficits in lead hip IR (neutral) and FABERs related to injury
- Deficits in spine extension related to injury
- Both of these ROMs are related to accepting load after impact
- Function as brakes for the swing
- Turning front foot out can ease strain on front hip (Bend Hogan and Bubba Watson)

B. Lateral crunch

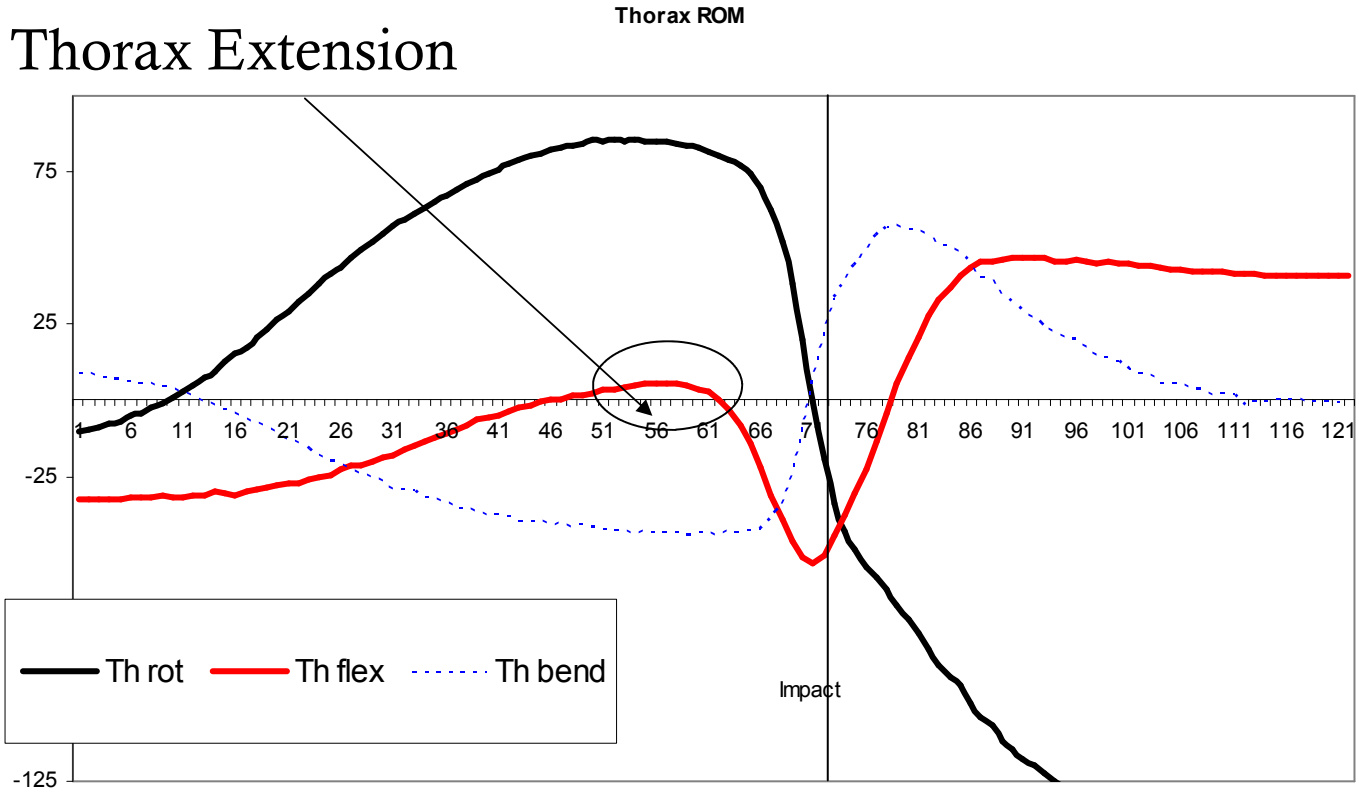
- Product of Rotational Velocity and Lateral Bend Angle
- No statistical relationship found in cross sectional studies performed (Cole and Grimshaw, Lindsay and Horton 2002)
- Research is limited considering cross sectional
- Injury mechanism is logical considering what we know about spine injury mechanics
- Difficult research to do
- Worthwhile considering modifying if you have a chronically injured

C. Spine Extension (Reverse Spine)

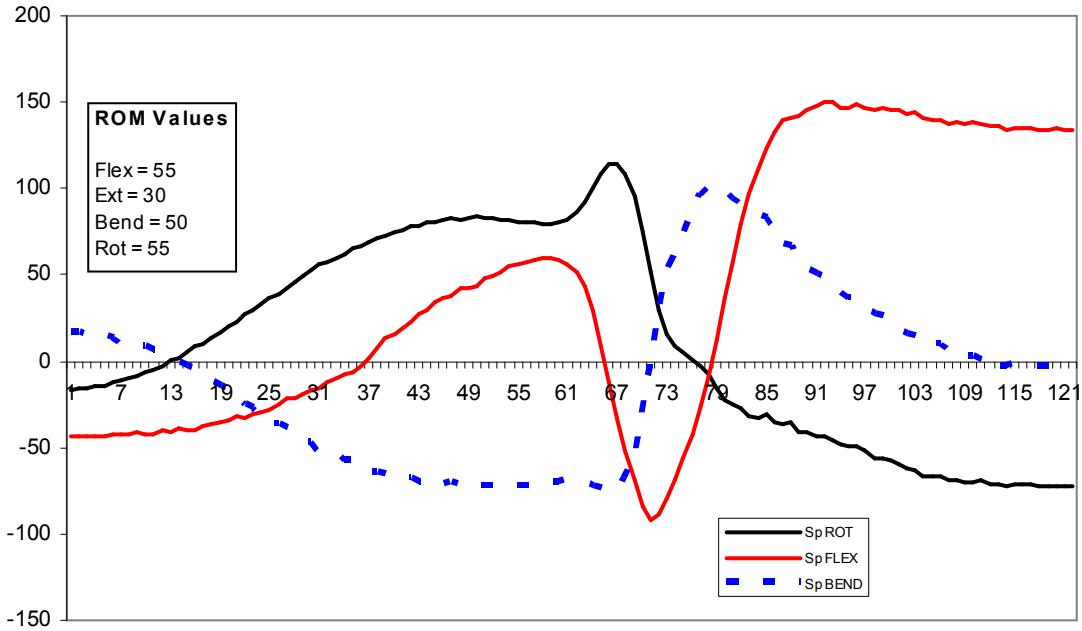
D. Exceeding ROM Capacity

Range of Motion and Injury Risk

Thorax Extension



Exceeding Movement Capacity (End Range Loading)



Values for rotation, lateral bend at impact and extension at follow through all approach or exceed ROM values recorded during upright testing.

BUT…Little research for this mechanism (Lindsay 2002)

Statistical correlations not found in those with back pain and controls

ROM	LBP	No LBP
R Lateral Bend	35.5 (82.1%)	38.2 (79.6%)
Right Rotation	34.8 (108.3)	41.8 (88 %)
Left Rotation	44 (116.4%)	50 (99.6 %)

Contentious Theory about Pro Swings

- Common belief that Pros injury are related to overuse and amateurs to technique
- This may be flawed
- Many elements of a powerful swing can excessively load spine tissue
  - –Lateral bend
  - –High velocity
  - –High rotation
  - –Minimal sway

Injury Solutions: Avoid it or Train it

Disclaimer. This section could obviously be huge. This is just a very brief overview. However, considering the lack of research in the area this amount may actually be fitting. There are a lot suggestions out there but very little evidence.

- Shorten Backswing (unload tissue)
- Feedback drills to unload tissue (mirror)
- Increase capacity of range (create a buffer)
- Increase capacity of tissue
- Is the spine, shoulder or wrist the victim of some other deficit?
    - Address imbalances, weakness, motor control deficits as you would with any other athlete

- be smart in your training. Are you just shagging balls or is your practice thoughtful and directed?

Some Unresolved issues

- The influence of changing variables on both performance and injury
- A definitive link between swing kinematics and injury risk
- Suggestions are based on biological plausibility and the transfer of rationales from other research

Special topics worthy of a full course
Screening our Golfers

I intentionally avoided discussing concepts regarding the screening of golfers for functional limitations that might impact upon their golf swing or injury profile.

I am of the opinion that many of the screening tools used are far removed from the actual swing. In other words they don't actually reflect the demands of the swing itself. Thus, we can identify an assumed limitation in function (e.g during a one leg glute bridge one of the hips drops more than the other) and spend considerable time addressing that fault and assuming that that is the cause of a swing fault or possible an injury risk.

I am of the opinion that breaking the swing down into smaller chunks and using those chunks as assessment tools can help identify areas of weakness that a player might further.

Further, I am of the opinion that general, well rounded physical conditioning program that trains all aspects of physical performance will be beneficial for injury reduction and performance enhancement. A screen that identifies weakness in a physical conditioning program is more beneficial than a screen that might identify irrelevant physical tics that don't have any bearing on golf function. After implementing this then you might want to look for idiosyncracies or functional limitations.