onform

3D Golf Swing Pose Estimation Model

Model Card

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1. Model Summary

Model Purpose

The OnForm 3D pose estimation model reconstructs a golfer's swing in three dimensions from a single 2D video recorded from **face-on** (camera perpendicular to the target line) or **down-the-line** (camera aligned with the target line). From the reconstructed skeleton, biomechanical metrics are derived that enable an in-depth analysis of the golfer's swing.

Key note: At present, derived metrics are only available when the swing video is captured from the *face-on view*. Support for the down-the-line view will be introduced in an upcoming release.

Inputs

- RGB video of a single full golf swing captured at 120 FPS or higher either:
    - Face-on (FO): camera perpendicular to the target line.
    - Down-the-line (DTL): camera aligned with the target line.

Outputs

- A sequence of 3D joint locations (skeleton) over the duration of the swing
- Derived biomechanical metrics, such as:
    - Torso and pelvis rotations and bends in degrees.
    - Sway, slide, thrust of the torso and pelvis in inches/cm.
    - Swing temp as a ratio of time of upswing to downswing.
    - X-Factor as difference in rotation between a golfer's torso and pelvis.
- Outputs are viewable in the Onform iOS app for now. Support for Android coming soon.

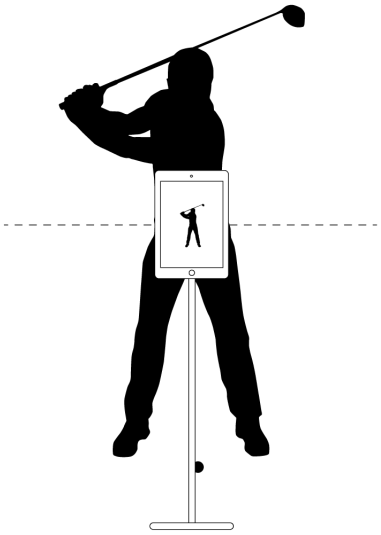
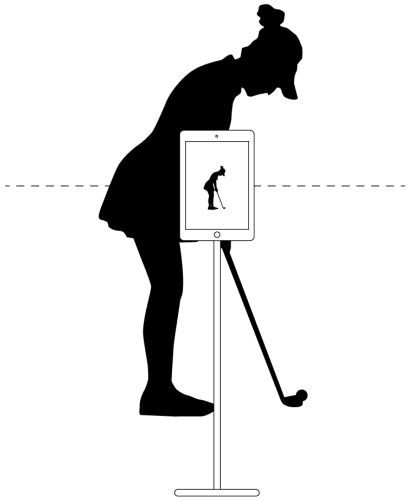
Training Data

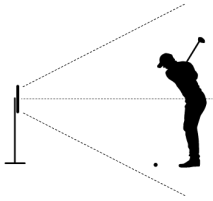
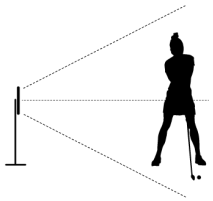
- Model built and tested on data collected from a scientific-grade 3D marker-based motion capture system (OptiTrack).
- Data includes 1200+ swings from 20+ athletes of various skill levels and body types.

2. Model Usage and Limitations

Video Capture Guidelines

Parameter	Recommendation
Camera Angle (Face-on)	Just as it does for 2D video, recording angles matter. We recommend pointing at the centre of the golfer, ideally perpendicular to the target line. Try to keep the camera as level as possible.
Camera Height	Place between waist to chest level of golfer
Distance from Golfer	Golfer's height is at least 50% of the video frame
Lighting	Well-lit, evenly distributed
Clothing	Avoid loose, baggy outfits that obscure joints
View Obstructions	Ensure the full body is visible throughout the swing. If possible, avoid background noise, such as other golfers.

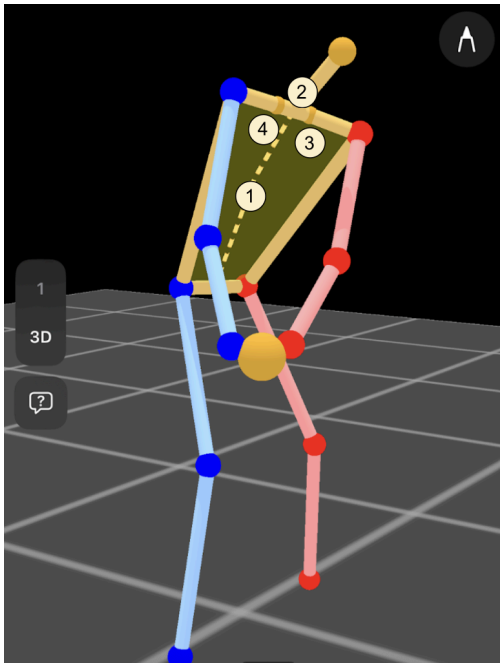
Face-On Camera Angle	**Down-The-Line** Camera Angle
	

Face-On Camera Angle (side view)	**Down-The-Line** Camera Angle (side view)
	

Limitations

- Full swings: While the model is very flexible, it is trained to work best with a full golf swing.
- Multicam setting: The face-on angle will be used for all metrics calculations and supplemented with thrust data from the down the line camera.
- Obstructions: If joints are obstructed or outside the video frame, accuracy may degrade.
- Environment: Model performs best in well-lit environments, with a single human in view.
- Clothing artifacts: Baggy or dark clothing may hinder pose estimation.

3. 3D Skeleton



The 3D skeleton consists of tracked joints representing the head, spine, upper limbs, and lower limbs.

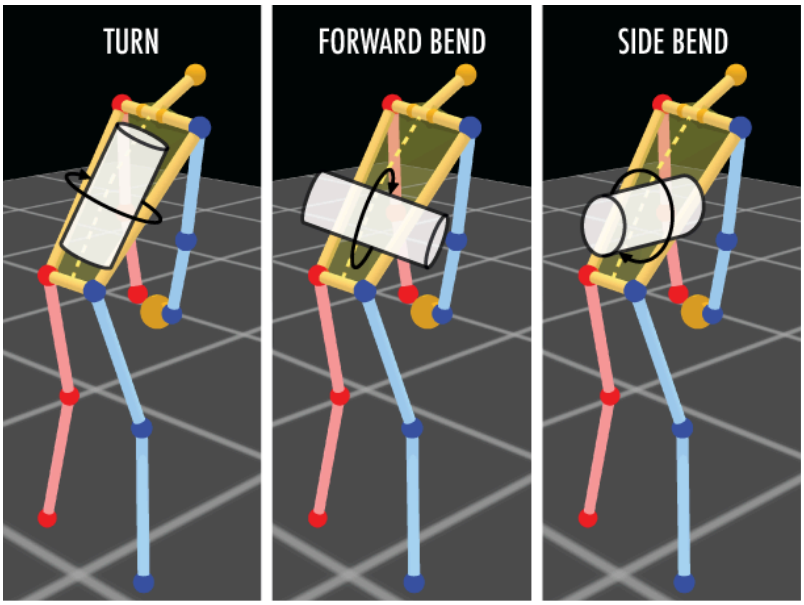
- **Head & Spine:** Head, Neck, Mid Spine, Mid Pelvis, Left & Right of Rib Cage 1
- **Upper Body:** Left & Right Shoulders, Elbows, Wrists
- **Lower Body:** Left & Right Hips, Knees, Ankles

Torso Definition

Consistent with biomechanical literature, the **torso segment** is defined as the rigid body formed by the thorax bounded vertically by the **mid-spine joint** (1), and the **neck joint** (2), and laterally by the center of **rib cage 1** on the left (3) and right (4) sides. This four-point construction captures both the vertical alignment of the spine and the breadth of the upper trunk, providing a biomechanically accurate basis for computing torso orientation and motion.

4. 3D Body Metrics

Torso Orientation Angles



Torso orientation is computed using a **Cardan sequence** in the order **[rotation – side bend – forward bend]**.

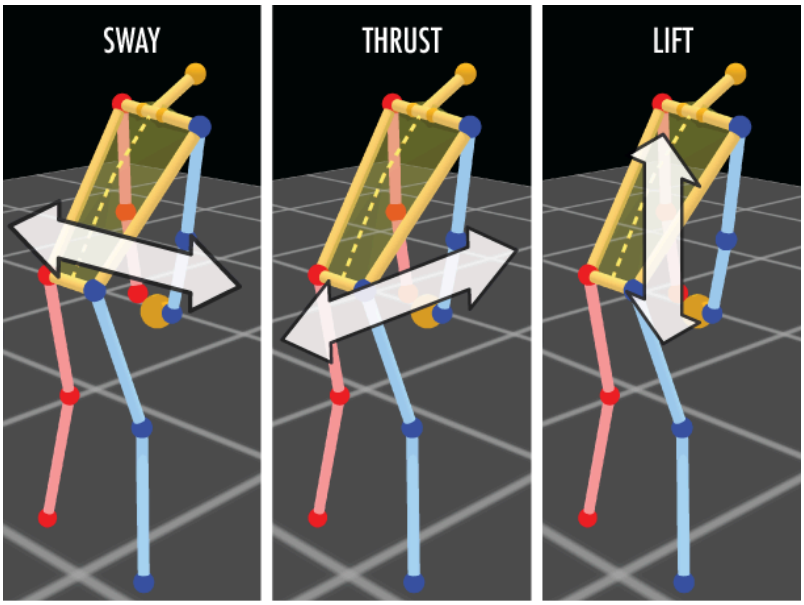
- **Turn:** Angle rotated about the spine axis of the torso, measured relative to the ankle line at address.
- **Forward bend:** Angle about the lateral (left-right) axis of the torso, measured relative to the global vertical reference axis.
- **Side bend:** Angle about the longitudinal (front-back) axis of the torso, measured relative to the global vertical reference axis.

Pelvis Turn

Pelvis turn is computed using the **spine-normal projection method**.

- The **lower spine axis** is defined by the line segment from the mid-pelvis to the mid-spine joint.
- Both the pelvis line (joining left and right hip joints) and the ankle line (joining left and right ankles) are projected onto the plane orthogonal to this axis.
- The angle between these two projected lines within the plane defines the **pelvis turn angle**.

Positional Displacements (sway, thrust, lift)



Displacement metrics are computed as changes in joint position relative to **address** (start of the swing):

- **Pelvis:** displacement of the **mid-pelvis joint**
- **Torso:** displacement of the **mid-spine joint**

Conventions:

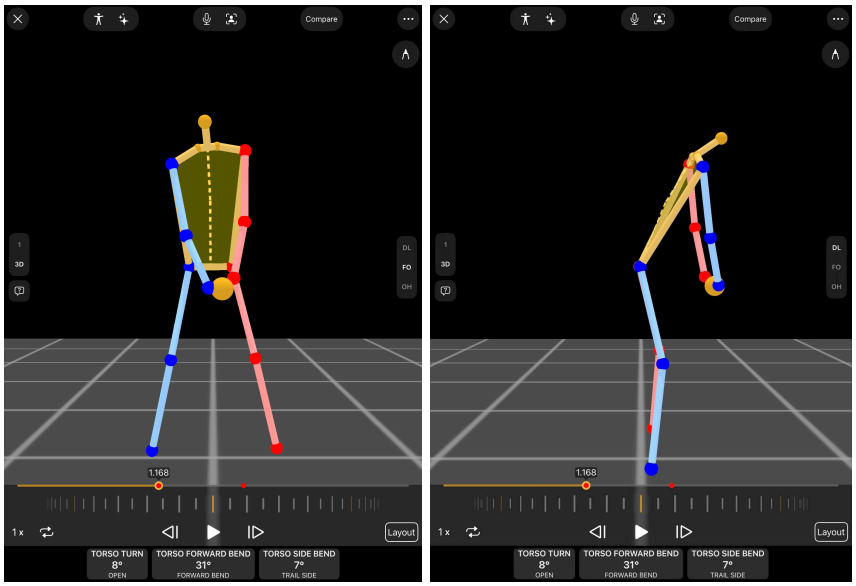
- **Sway:** towards and away from the target line
- **Thrust:** towards and away from the camera (face-on view)
- **Lift:** vertical displacement, up or down relative to the ground

X-Factor and Swing Tempo

- **X-Factor:** Difference in axial rotation between torso and pelvis, representing coil at the top of backswing.
- **Swing Tempo:** Ratio of backswing (upswing) duration to downswing duration.

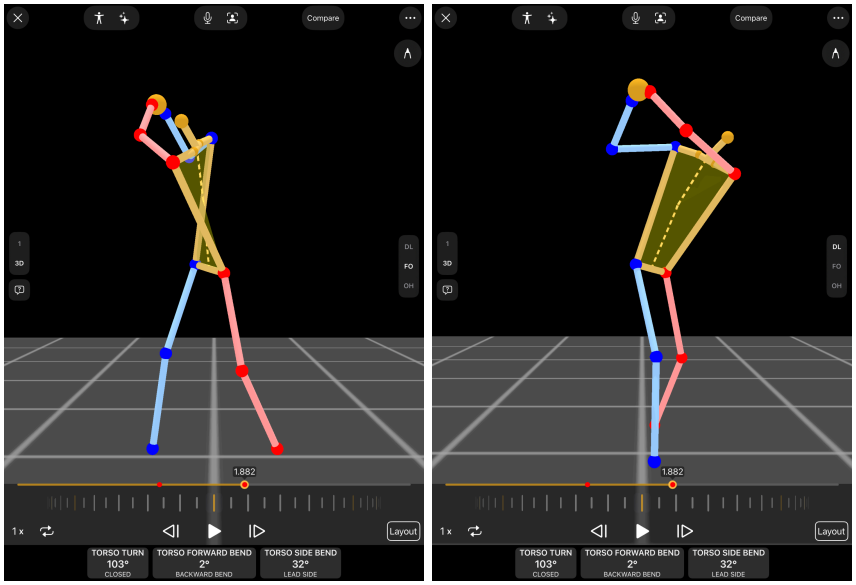
5. Swing Phases and Interpreting Torso Angles

Start of Swing (address):



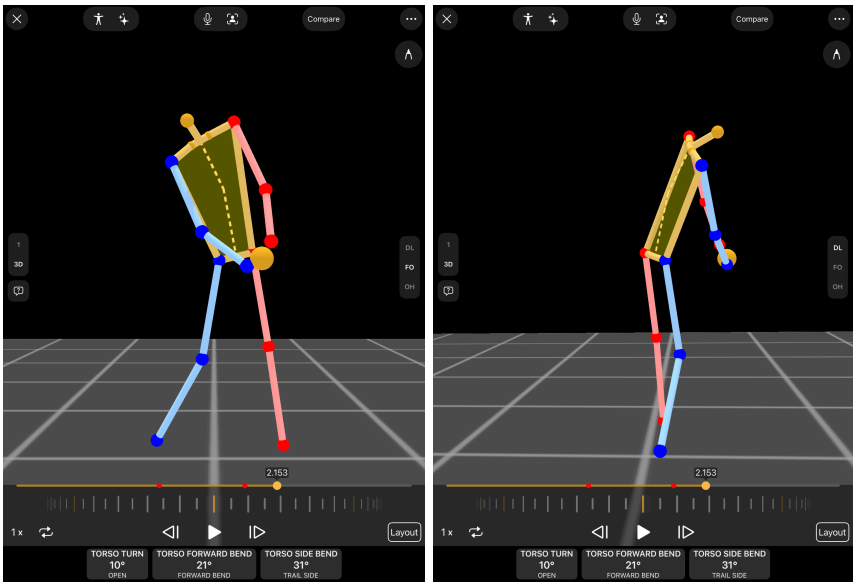
- Defined by the initial coordinated movement of both wrist joints.
- Typical torso values: **forward bend ~30°**, minimal axial turn and side bend.

Top of Backswing:



- Defined as the frame where the **left shoulder–left wrist line** reverses its rotational direction (clockwise → counterclockwise for right-handed golfers).
- Typical torso values: **turn ~100°**, **lead side bend ~30°**, **forward bend ≈ 0°**.
- **Note:** From a down-the-line perspective, the spine appears tilted downward. This tilt results from the combination of axial turn and lead side bend (left shoulder lowered), not from forward flexion of the torso.

Impact Position:



- Not currently marked; will be added once club-head tracking is enabled.
- Typical torso values: all three angles are significant — forward bend, trail side bend (right shoulder lowered), and axial turn open to target.
- **Note:** From a down-the-line view, the shoulder line may appear square to the target similar to the address position. Biomechanically, however, this alignment is achieved through a combination of trail side bend and open torso turn.

6. Model evaluation

We validated our model extensively using our internal motion tracker system and externally against three different systems. Details can be found below.

Internal Validation Results

The OnForm 3D model for face-on swings has been internally benchmarked against the OptiTrack 3D marker based system. The tests were carried out on a set of 190 swings from 3 athletes of different abilities.

Metric	MAE - Top of Backswing	MAE - Impact
Pelvis Turn (°)	3.4°	3.1°
Torso Turn (°)	4.6°	2.5°
Torso Forward Bend (°)	2.7°	1.2°
Torso Side Bend (°)	2.2°	4.1°
Pelvis Sway	0.5 cm	0.6 cm
Pelvis Lift	0.6 cm	0.7 cm
Pelvis Thrust (DTL)	1.0 cm	0.9 cm

Table: Mean Absolute Error (MAE) values for key metrics (torso turn, forward bend, side bend, pelvis turn, sway, thrust, lift). MAE is the mean of the absolute differences between model predictions and ground-truth measurements across the test set. *Note: thrust is derived from the down-the-line model.*

External Validation Results

Important note: When comparing Onform 3D to other systems, it is essential to verify that the **metric definitions and orientation conventions** are equivalent. For example, torso orientation angles depend on the order of the Cardan sequence; mismatched definitions can yield large discrepancies even when both systems are internally consistent.

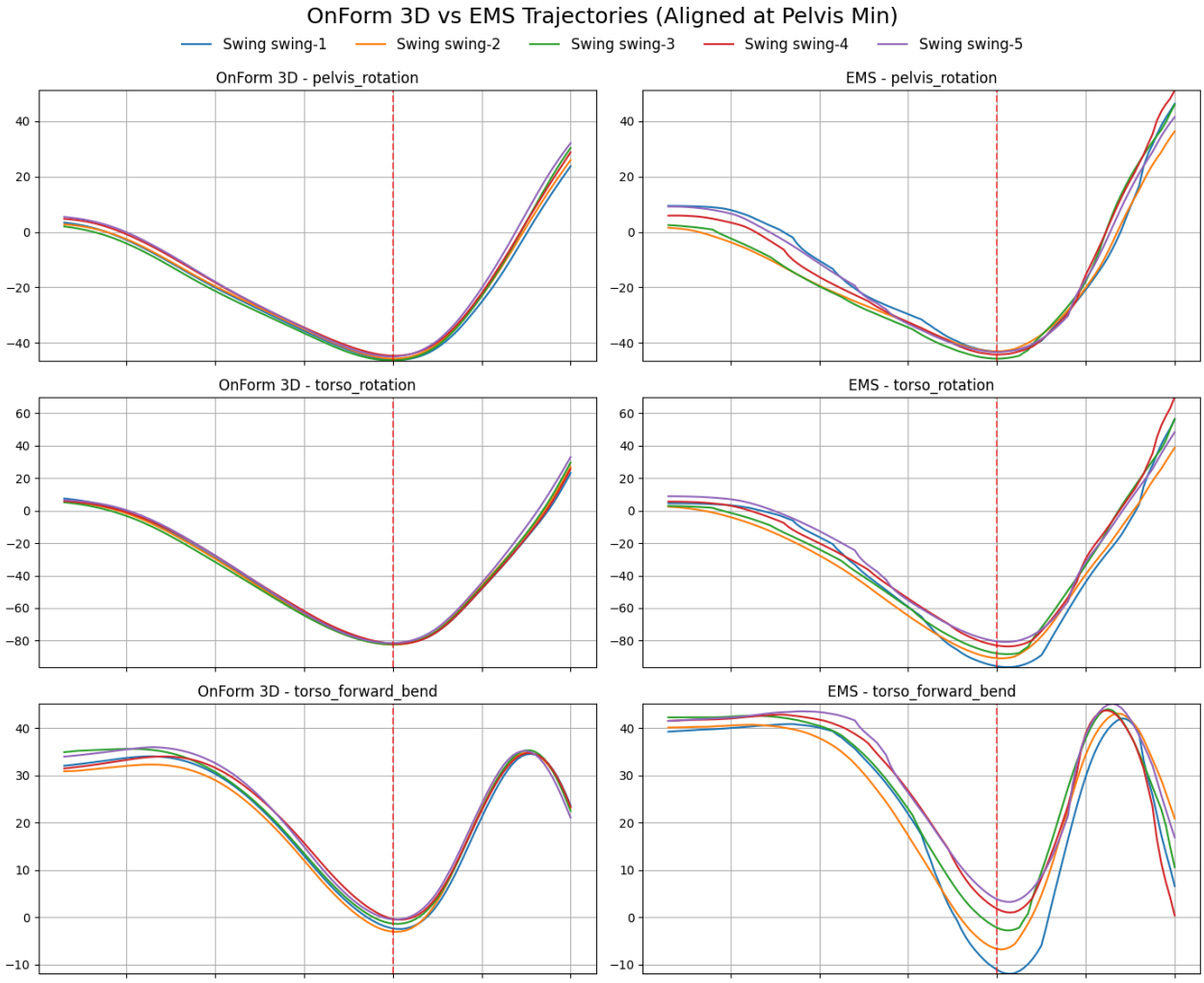
The OnForm 3D model for face-on swings has been benchmarked against a well-regarded **electromagnetic tracking system (Polhemus based),** as well as two external **marker-based motion capture systems (Qualisys and Gears, which uses OptiTrack)**. The tests were carried out on a set of 36 swings from 4 athletes.

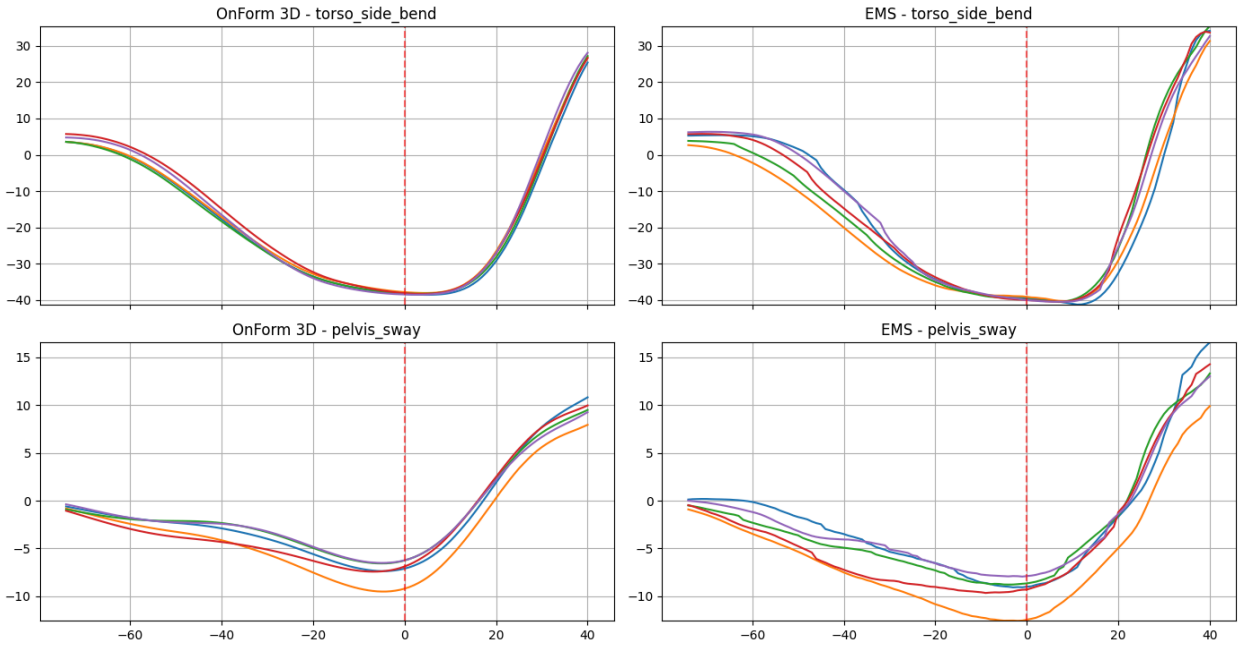
Metric	MAE - Top of Backswing	MAE - Impact
Pelvis Turn (°)	4.9°	4.1°
Torso Turn (°)	4.1°	6.4°
Torso Forward Bend (°)	6.8°	5.4°

Metric	MAE - Top of Backswing	MAE - Impact
Torso Side Bend (°)	2.8°	3.9°
Pelvis Sway	1.4 cm	1.8 cm
Pelvis Lift	0.7 cm	0.8 cm
Pelvis Thrust (DTL)	1.2 cm	1.0 cm

Validating Trajectories

The figure below compares five consistent swings of a pro player against the above mentioned EMS system (Polyhemus based).





Key Observations:

- Electromagnetic traces are noisier due to sensor characteristics.
- Onform 3D outputs exhibit smooth, consistent trajectories.
- The model reproduces not only the values at key positions such as the top of backswing and impact, but also the full trajectory shape throughout the swing.