**Cricket Batting Kinematics & Kinetics: Study Reference and Practical Guide**

**Quick Legend — Papers Used in This Document**

* **FD vs Drive kinematic study** (cinematographic, 100 Hz, instrumented bat): “FD/D study”.
* **Skilled vs Less-skilled Off-Drive study** (high-speed cameras).
* **Peploe et al., 2019 / 2018 / 2016:** Range Hitting / Six-hitting (Vicon 250 Hz).
* **McErlain-Naylor et al., 2021:** Male vs Female Power Hitting (n=15/15; Vicon 250 Hz).
* **Intervarsity Pull Shot study:** (Kinovea, n=5).
* **Kourav & R. Kumar:** Female cover-drive (n=5) — strong correlations found.
* **Pulen Das (LNIPE 2023), Praveen Kumar (Uttarakhand U-19), North Maharashtra (Jalgaon):** Indian uni studies (n≈10–12) — mostly 2D Kinovea, mixed results.
* **Cross-sport references:** Baseball, golf, projectile theory from the prior literature you uploaded/mentioned.

**General Measurement Notes (applies to all shots)**

* **Sampling:** For bat/ball/impact studies use ≥250 Hz (Peploe). For whole-body kinematics 100–200 Hz can suffice; phone coaching 120–240 fps acceptable but lower impact timing accuracy.
* **Filtering:** Two-way Butterworth low-pass, cut-off ≈ 15 Hz is standard for marker trajectories (Peploe).
* **Events:** Identify DS (downswing start), STRIDE END, IMP (impact). Measure from −0.6 s → +0.02 s around impact for timing windows.
* **Bat speed:** Compute distal endpoint resultant velocity (m/s) from smoothed 3D positions; peak during downswing is your bat speed metric.
* **Impact location:** Express X (medio-lateral) and Z (longitudinal) offsets from bat sweetspot (Peploe: sweetspot ≈ 17.5 cm from toe along midline — use bat-specific calibration).
* **X-factor:** Pelvis↔thorax transverse separation (degrees) via Cardan sequence (z-y-x).
* **Angles:** Compute joint angles from 3D vectors using the dot-product formula (see formulas section).
* **Head/COM forwardness:** Δx = nose.x − front\_knee.x (normalize by shoulder width or image width). Skilled players have head more forward.
* **MediaPipe IDs (RHB quick mapping):** shoulder L=11, elbow L=13, wrist L=15, hip L=23, knee L=25, heel L=29, toe L=31, nose=0. Swap L↔R for LHB.

**SHOT 1 — FORWARD DEFENSIVE (FD) — Survival stroke**

**Primary sources: FD/D study; Skilled vs Less-skilled.**

**Aim (IM)**

Describe kinematic & kinetic features of FD and compare to front-foot drive.

**Findings (reported numbers)**

Backlift ≈ 0.65 m.  
Front-foot stride ≈ 0.72 m (longer than drive).  
Stride start ≈ 0.64 s pre-impact; downswing ≈ 0.38 s pre-impact.  
Front-foot placement ≈ 0.14 s pre-impact.  
Back-foot drag at impact ≈ 0.05 m forward.  
Bat horiz. velocity (0.02 s pre-impact) ≈ 3.53 ± 3.44 m/s.  
Bat–ball closing speed ≈ 24.2 ± 4.65 m/s.  
Post-impact ball horiz. velocity ≈ 6.85 ± 5.12 m/s.  
Bat angle at impact ≈ 62.6° ± 6.5° (more “open” than drive).  
Grip forces (example at −0.02 s): top ≈ 129 ± 41.6 N, bottom ≈ 52.2 ± 16.9 N.

**Role**

Primary defensive shield — stability, minimal energy transfer, top-hand control. Foundation for drives.

**Achievement**

Quantified timing, grip split and low bat speed mechanics that define FD.

**Readings (what to measure & how)**

* Bat angle at IMP (rotation about global medio-lateral axis).
* Bat distal/wrist speed (peak in downswing).
* Timing: stride start, DS, front-foot placement relative to IMP.
* Grip force split if instrumented (top:bottom).
* Measurement recipe: 100–250 Hz; 2-way Butterworth 15 Hz.

**Thresholds (heuristic)**

* Bat speed (impact): Good < 6 m/s.
* Bat angle: Good ≈ 60°–68°.
* Top:bottom grip ratio: Good ≈ 1.8–2.5 (top dominates).
* Timing: front-foot placement earlier than 0.1–0.2 s pre-impact typical for FD.

**Conclusion / summary**

FD = learn first. Lower backlift, earlier commitment, top-hand dominant. Use for balance, contact, and safe play.

**Ideal / coachable numbers**

bat angle ≈ 62°, backlift ≈ 0.65 m, peak bat speed < 6 m/s.

**Coaching implications**

slow-feed defensive blocks; soft lower hand; single-frame video check of bat angle.

**SHOT 2 — FRONT-FOOT DRIVE (Drive, D) — Scoring ground drive**

**Primary sources: FD/D study; Skilled vs Less-skilled off-drive.**

**Aim (IM)**

Compare Drive vs FD; identify skilled movement markers in front-foot off-drive.

**Findings (reported numbers)**

Backlift ≈ 0.74 m (higher than FD).  
Stride length ≈ 0.68 m (shorter than FD).  
Stride start ≈ 0.58 s pre-impact; downswing ≈ 0.36 s.  
Front-foot placement ≈ 0.06 s pre-impact (later than FD).  
Back-foot drag ≈ 0.10 m.  
Bat horiz. velocity (0.02 s pre-impact) ≈ 11.8 ± 4.61 m/s.  
Bat–ball closing velocity ≈ 32.3 ± 5.06 m/s.  
Post-impact ball velocity ≈ 19.5 ± 2.13 m/s.  
Bat angle at impact ≈ 77.8° ± 7.05° (more vertical).  
Skilled markers: Trigger step used in ~70% of skilled vs ~20% less-skilled; head/COM further forward at contact.

**Role**

Attack variant of FD: later stride, higher backlift → more bat speed while maintaining control for ground placement.

**Achievement**

Showed skilled players rely on anticipatory trigger movement and head/COM positioning rather than purely higher bat speed.

**Readings**

* Head-over-knee Δx (nose.x − front\_knee.x) normalized.
* Trigger detection (binary: present/absent) via small preparatory foot displacement.
* Bat speed & bat angle at IMP.
* Stride length & timing.

**Thresholds (heuristic)**

* Bat speed: Good ≈ 10–15 m/s (distal).
* Bat angle: Good ≈ 75°–82°.
* Trigger use: Good if >50% of quality trials.
* Head-over-knee Δx: Good if +1% to +6% image width ahead of front knee.

**Conclusion / summary**

Drive = attacking FD with timing emphasis. Train triggers, keep head over ball, and develop front-leg bracing.

**Ideal numbers**

backlift ≈ 0.74 m, bat angle ≈ 78°, peak bat speed ≈ 12 m/s.

**Coaching implications**

trigger-step → drive drills; video timing feedback; leg/ core strength for bracing.

**SHOT 3 — COVER DRIVE (off-drive through cover) — DETAILED section (expanded)**

**Primary sources: Kourav & R. Kumar (female, n=5); Pulen Das (LNIPE, n=10); Praveen Kumar (Uttarakhand U-19, n=12); North Maharashtra (Jalgaon, n=12); other small 2D Kinovea studies. (Peploe/Range & FD/D background informs mechanics but cover-drive specifics mainly from the Indian studies above.)**

**Important methodological note (read first)**

most cover-drive papers you supplied use 2D Kinovea, small n (5–12). Some authors reported “no significant relationship” using tabulated r thresholds; I rechecked critical r for df = n−2 and noted that some correlations meet α=0.05 (e.g., Pulen Das: left knee |r|=0.642 and CG |r|=0.729 are significant for n=10). Kourav’s female sample (n=5) produced very large correlations (e.g., r=−0.970) but df=3 → extreme values prone to overfitting. Treat these as directional, coach-useful signals rather than definitive population norms. 3D capture + larger n recommended for confirmatory norms.

**Aim (IM)**

Identify which joint angles, CG and balance associate with better cover-drive performance.

**Paper-by-paper findings (specific numbers & statistical notes)**

**Kourav & R. Kumar — female senior cricketers (n=5)**

* Left knee angle (placement): r = −0.970 (p < .01). Mean left knee at placement = 152.6° ± 8.44°. Interpretation: more flexion (smaller angle) → better judged cover drive.
* Right hip angle (execution): r = +0.897 (p < .05). Mean right hip exec = 170.8° ± 6.98° (rear-hip near full extension = bracing).
* Left elbow angle (execution): r = +0.902 (p < .05). Mean left elbow exec ≈ 106° ± 28.5°.
* Additional high r’s (right ankle, right knee, right elbow, right wrist) ~0.75–0.79 but small n limits inference.
* Interpretation (Kourav): front-knee flexion at placement, rear-hip bracing at impact and extended lead arm correlate strongly with better judged technique in females.

**Pulen Das (LNIPE Guwahati, n=10) — re-evaluation of reported results**

* Reported r values: Left knee r = −0.642, Height of CG r = −0.729, left elbow r = −0.111, right elbow = −0.194, right knee = −0.070, balance = −0.392.
* Statistical note: For n=10 (df=8), two-tailed α=0.05 critical r ≈ 0.632. So |r|=0.642 and 0.729 exceed that threshold → statistically significant. That implies: more front-knee flexion (negative r) and lower CG (negative r) significantly correlate with higher cover-drive score in this sample.
* Reported mean Height of CG ≈ 70.6 cm ± 6.33 cm; mean Left knee placement ≈ 145° (table shows angle 145° mean).
* Interpretation (Pulen Das corrected): front-knee flexion and lower CoG at impact associate with higher judged performance.

**Praveen Kumar — Uttarakhand U-19 (n=12) & North Maharashtra (n=12)**

* These papers reported no significant relationships for the angular variables at the α=0.05 level (they used critical r ≈ 0.576 with df=10 in some reports).
* Example numbers: Uttarakhand left shoulder r = 0.553 (close to but not exceeding critical r), right elbow r = −0.551. Pulen/others show heterogeneous results.
* Measurement context & limitations: 2D sagittal photography, small n, single-frame angle reads, performance grades by judges (subjective). That reduces power and raises error from out-of-plane motion.
* Interpretation: no single joint angle uniformly predicts cover-drive success in these male university samples — likely because performance depends on multivariate coordination, impact timing/location, and ball-to-bat dynamics beyond single angles.

**Synthesis across studies (what is consistent?)**

* Front-knee flexion at placement is the most consistent positive predictor: Kourav (very strong), Pulen Das (significant after recheck). Practical target band emerges around 135°–155° (i.e., moderate flexion).
* Lower Centre of Gravity at contact (CG height) correlates with better performance in Pulen Das (|r|=0.729). Normalize CG to stature for cross-player comparisons (e.g., CG height / standing height). Lower CG → better stability & ability to “get over ball.”
* Lead elbow extension at execution (reach through) correlates positively in Kourav (≈ 100°–110° at contact). Extended lead arm increases effective bat-arm lever for a cleaner path.
* Rear-hip bracing (hip extension) at contact (right hip ≈ 170°) supports trunk rotation & energy transfer.
* Other angles (shoulder, ankle, wrist) showed mixed/insufficient evidence given small samples.

**Why the discrepancies?**

* 2D vs 3D: sagittal 2D misses out-of-plane motion (e.g., bat/arm twist).
* Small n and judge scoring: low statistical power, subjective scoring.
* Single-frame vs continuous: single moment snapshots miss dynamics leading up to impact (downswing kinematics).
* Equipment & ball variability: lab vs field differences change timing/approach patterns.

**Cover Drive — READINGS (what to measure & exactly how)**

**Essential sensors / capture**

* Minimum: sagittal high-speed camera ≥ 120 fps (better 250 Hz for research). Calibration line on ground (2 m stick) for spatial scaling.
* Best: multi-camera 3D (Vicon / Optitrack) ≥ 200–250 Hz to compute joint centers & 3D angles; attach reflective markers at shoulder, elbow, wrist, hip, knee, ankle, bat blade markers for impact detection.

**Primary kinematic variables**

* Front knee angle at placement (degrees): compute between hip→knee and knee→ankle vectors at the placement frame (just before DS). Dot-product formula (see formulas section). Aim to measure mean + SD across 3 trials.
* Height of Centre of Gravity (CG) at impact (cm): compute segmental CG via anthropometric model (Hanavan or similar) — normalize to stature (CG% = CG\_cm / standing\_height\_cm).
* Lead elbow angle at contact (degrees): shoulder→elbow→wrist at IMP. Extended ≈ 100°–110° reported.
* Rear hip angle at execution (degrees): hip joint orientation at IMP (hip near full extension ~170° suggests bracing).
* Bat angle at impact (global medio-lateral axis): for launch/loft control (important if cover drive is struck with slight loft).
* Head-over-knee Δx: nose.x − front\_knee.x normalized by image width or shoulder width (positive = head ahead). Good cover drive shows head slightly forward.
* Impact location on bat (X, Z): if available, to confirm sweetspot strike (central hits produce cleaner cover drives).

**How to compute (recipes)**

* Joint angle (example elbow): u = shoulder − elbow; v = wrist − elbow; θ = arccos( (u·v) / (|u||v|) ) → convert to degrees.
* CG: segmental summation method (use standard segment masses & centers); if using Kinovea use their centroid estimate but prefer calibrated 3D.
* Normalization: report angles ± SD and CG as % of height to compare across players.

**Measurement windows & trials**

* Collect minimum 6–10 trials per player to capture consistency; choose best 3 judged trials and worst 3 to study variability.
* Event frames: choose Placement (foot plant immediate pre-downswing), DS, IMP. For placement angle use frame at stride end (~0.06–0.14 s pre-impact depending on drive/paper).

**Cover Drive — THRESHOLDS (practical coach bands)**

Note: thresholds are heuristic: derived from means in studies + coaching logic. Tune per athlete.

* Front knee angle (placement):  
  Good: 135° – 150° (moderate flexion: stable & mobile).  
  Watch: 151° – 160° (a bit too extended).  
  Warning: >160° (too upright / ineffective weight transfer) or <125° (too crouched — may hamper reach).
* Height of CG (at IMP) (absolute depends on stature):  
  Good: ≤ 68 cm OR CG% ≤ 0.38 of stature (example heuristics; Pulen Das mean 70.6 cm → use normalized values).  
  Watch: 68–74 cm or CG% 0.38–0.42.  
  Warning: >74 cm or CG% >0.42 (too high = unstable).
* Lead elbow angle at IMP:  
  Good: 100° – 110° (extended but not locked).  
  Watch: 90° – 99° (slightly flexed).  
  Warning: <90° (too cramped) or >150° (locked).
* Rear hip angle at IMP (hip extension degree):  
  Good: 165° – 175° (braced).  
  Watch: <165° (insufficient bracing).
* Head-over-knee Δx normalized:  
  Good: +1% to +6% image width (head slightly forward).  
  Warning: head behind front knee or >+10% (overcommit).

**Cover Drive — COACHABLE DRILLS & PROGRESSION**

* Placement focus drill (tape + mirror):  
  Place tape marker where front foot should land. Batter practices stepping to that marker and holds placement for 0.5–1 s while coach checks front-knee angle (target 135°–150°) and CG (player should feel “over” front thigh). Use repeated reps, feedback via phone video (120+ fps).
* Impact-hold drill (slow ball / toss):  
  Feed slow balls; batter executes cover drive and holds impact position for 1–2 s. Coach checks rear hip bracing (~170°), lead elbow reach (~100°–110°), head-over-knee. Over time reduce hold time and increase ball speed.
* Sweetspot & bat path drill:  
  Use soft ball tossed on a short length; attach reflective marker low on bat or use impact sensor to reward central impacts. Combine with target on ground for line.
* Dynamic transfer:  
  Combine placement & hold: small-net throws at game pace; video each trial; compute front knee angle & CG; aim to reduce variance across trials.
* Strength & S&C:  
  Single-leg squat (front leg), Romanian deadlifts for posterior chain, anti-rotation core (band chops) to improve ability to brace rear hip.

**Testing protocol (recommended)**

* Capture: 3D if possible at 200–250 Hz; else sagittal at 240 fps with 2 m calibration.
* Trials: 10 trials; record judged score (3 judges) and impact kinematics. Use best-3 average and intra-trial SD as consistency metric.
* Report: mean front knee placement ± SD, CG% ± SD, lead elbow ± SD, % central impacts.

**Cover Drive — INTERPRETATION GUIDELINES (quick)**

If front knee angle >160° (upright): cue “get lower” / increase front knee flexion; use step-and-hold; check stride length (may be too long).  
If CG high: cue “get over the ball”, ankle dorsiflexion drills, load front leg earlier.  
If lead elbow too bent (<95°): work on reach drills and shoulder mobility; check bat length/inertia.  
If rear hip not braced (<165°): strengthen posterior chain and practice bracing at impact (impact-hold drills).  
If high variability across trials: focus on timing & ball reading drills (anticipation), not just joint angles.

**SHOT 4 — PULL SHOT (horizontal hit to short ball)**

**Primary source: Intervarsity Pull Shot Kinovea (n=5)**

**Aim (IM)**

Analyze linear displacement & kinematics for pull shot.

**Findings (reported)**

* Stride shortening from backlift → impact → follow-through (tightening base).
* Stride% relative to body height falls at impact/follow-through.
* Coordinated knee/hip/shoulder/elbow changes and bat blade orientation; small sample so no robust numeric norms.

**Role**

Tighter base increases stability & reduces timing variability for short deliveries; bat horizontal plane emphasised.

**Readings & thresholds (heuristic)**

* Stride % reduction: expect 10–25% decrease of stride length (backlift→impact) — measure baseline per player.
* Front toe angle (heel→toe) open +10°–30° for off-side pulls.
* Lead knee at impact: typical coach range 120°–140°, but verify per player.

**Coaching implications**

Short-ball feeds emphasizing shortened stride + front toe open; video at 120+ fps to confirm stride tightening and bat horizontal plane.

**SHOT 5 — RANGE HITTING / SIX-HITTING (Power mode)**

**Primary sources: Peploe et al., 2019; Peploe et al. 2018/2016; McErlain-Naylor et al., 2021 (gender comparisons)**

**Aim (IM)**

Identify technique parameters predicting bat speed, post-impact ball speed, and carry distance.

**Key findings (numbers & models)**

* Carry distance: 3.5 – 103.5 m, mean ≈ 52.2 ± 19.6 m.
* Ball launch speed mean ≈ 28.1 ± 4.2 m/s.
* Max distal bat endpoint speed mean ≈ 25.7 ± 1.96 m/s.
* Ball launch speed regression: Impact location X alone ≈ 30% variance; adding bat speed IMP & impact Z increases explained variance to ≈67–69% (SEE ≈ 2.3 m/s).
* Bat speed regression: X-factor DS ≈ 28% explained; adding lead elbow extension & wrist uncocking increased explained variance to ~66–78% (Peploe reports final model explaining 77.7% of bat speed variation; SEE ≈ 0.92 m/s).
* Bat angle at IMP explained ~82.6% of vertical launch angle variance (central impacts).
* Impact offset sensitivity: 2 cm off-centre (medio-lateral) → ≈ 6% reduction in ball speed.

**Role**

Primary drivers: 1) central impact location; 2) high bat speed at impact; 3) vertical launch angle (bat pitch).

**How bat speed is created**

X-factor (pelvis-thorax separation) → lead elbow extension → wrist uncocking (proximal → distal chain).

**Readings & thresholds (practical)**

* Impact location: Good ≤ ±1 cm from sweetspot (Warning >2 cm).
* Bat speed (distal): Good ≥ 25 m/s (elite), 22–25 m/s watch, <20–22 m/s warning.
* X-factor DS: Good ≥ 20° (male means 17.6°, females lower).
* Lead elbow extension (DS→IMP): Good ≥ +20° (males mean ≈ +29.7°).
* Wrist uncocking (DS→IMP): Good ≥ 8–15° relative change (Peploe reports large values min→IMP ~57° but use relative change).
* Launch angle: target ~40° for max carry (theoretical opt ≈ 42°); players often choose ~37° for margin.

**Conclusion / summary**

Train sweetspot accuracy first, then raise bat speed through rotational power (X-factor), elbow extension and wrist whip. Optimize launch angle to ~40° when aiming for maximum carry.

**Coaching implications**

Phase practice: sweetspot drills → rotational power (med-ball/anti-rotation) → arm chain / wrist timing drills.  
Monitor bat moment of inertia and scale bat if inertia mismatches player strength (McErlain-Naylor point).  
Use ball flight model (with drag) for carry prediction — Peploe’s iterative model recommended for research.

**SHOT 6 — GENDER DIFFERENCES IN POWER HITTING**

**Primary source: McErlain-Naylor et al., 2021 (n=15 male, 15 female)**

**Aim (IM)**

Compare power-hitting kinematics between male and female batters controlling for height & mass.

**Key findings (numbers)**

* Max bat speed: males 28.4 ± 2.5 m/s vs females 22.6 ± 2.3 m/s (large effect).
* Ball launch: males 33.5 ± 2.6 m/s vs females 27.3 ± 2.8 m/s.
* Carry distance: males 80.7 ± 10.0 m vs females 57.7 ± 8.8 m.
* X-factor DS: males 17.6° ± 8.3° vs females 12.4° ± 10.1° (p = .030).
* Lead elbow extension DS: males +29.7° vs females −3.0° (p = .008).
* Wrist uncocking: no significant gender difference.

**Role & interpretation**

Males generate higher bat/ball speeds mainly via greater X-factor and lead elbow extension; female batters more often adopt checked/flex elbow strategies. Wrist whip similar across sexes — mechanical emphasis for coaching differs (strength & equipment scaling matter).

**Coaching implications**

Female development: progressive strength & rotational power training; consider bat inertia scaling; technique interventions must be supported by S&C.  
Males: target increased X-factor and elbow extension patterns but monitor shoulder health.

**NUMERIC SUMMARY TABLE (quick reference)**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Metric | FD | Drive | Cover Drive (good target) | Pull | Range / Sixing | Male vs Female (target diff) |
| Backlift (m) | 0.65 | 0.74 | — | — | — | — |
| Stride length (m) | 0.72 | 0.68 | — | shorter at impact | — | — |
| Bat angle at IMP (°) | ~62.6° | ~77.8° | 75°–82° preferred | near horizontal | vertical pitch controls | males slightly more forward |
| Bat pre-impact speed (m/s) | ~3.5 | ~11.8 | — | — | peak distal ≈ 25–27 (elite) | male ≈ 28.4, female ≈ 22.6 |
| Bat–ball closing speed (m/s) | 24.2 | 32.3 | — | — | ball launch mean ≈ 28.1 ±4.2 | male launch ≈ 33.5, female ≈ 27.3 |
| Sweetspot sensitivity | — | — | important | — | ±1–2 cm critical | — |
| X-factor (°) | — | — | — | — | Good ≥ 20° | male mean 17.6°, female 12.4° |
| Lead elbow extension (°) | — | — | lead elbow at IMP ≈ 100°–110° | — | DS→IMP extension good ≥ 20° | male +30°, female −3° on avg |
| Ideal launch angle (°) | N/A | lower for ground drive | N/A | N/A | ~40° optimum (players ~37.5°) | — |

**FORMULAS & AUTOMATION SNIPPETS (practical)**

**Joint angle (shoulder → elbow → wrist)**  
u = S − E ; v = W − E  
θ = arccos( (u·v) / (|u||v|) ) → deg.

**Spine lean (hip → shoulder vs vertical)**  
h = shoulder − hip  
spine\_lean = arccos( (h · ẑ) / |h| ) → degrees (positive = forward).

**Head-over-knee (normalized)**  
Δx = x\_nose − x\_front\_knee  
Δx' = Δx / image\_width (or shoulder\_width).

**Bat distal speed**  
v\_dist(t\_i) = |p(t\_{i+1}) − p(t\_{i−1})| / (2 Δt) after smoothing (2-way Butterworth 15 Hz).

**X-factor (transverse)**  
X = |ψ\_thorax − ψ\_pelvis| where ψ are yaw angles (Cardan z-y-x sequence).

**Ball carry (simple)**  
R = v^2 sin(2θ) / g (no drag). Use iterative solver with drag coefficient for cricket ball (Peploe method) for accurate carry.

**SHIP-ABLE METRIC SPECS (MediaPipe / automation quick) — RHB mapping**

* Front elbow angle (shoulder=11, elbow=13, wrist=15) — Good: 140°–170°; Watch 120°–139°; Warning <120° or >175°.
* Spine lean (shoulder 11 vs hip 23): Good 5°–20° forward.
* Head-over-knee Δx (nose 0 vs front\_knee 25): Good +1%–+6% image width.
* Front foot direction (heel 29 → toe 31): Off-drive Good +10°–+30° open.
* X-factor (pelvis vs thorax, transverse): Good ≥20°.
* Bat distal speed (wrist 15): FD <6 m/s; Drive ~10–15 m/s; Range ≥22–25 m/s (elite 25–27 m/s).

**FINAL SYNTHESIS — short coach-ready takeaways**

* **FD:** teach first — backlift ~0.65 m; bat angle ~62°; low bat speed & top-hand control. (FD/D)
* **Drive:** higher backlift (~0.74 m), later stride, bat angle ~78°, bat speed ~12 m/s; skilled use triggers and head over knee. (FD/D + Skilled vs Less-skilled)
* **Cover Drive:** most consistent predictors across studies are front-knee flexion (~135°–150°) and lower CG at impact; lead elbow extension (~100°–110°) and rear-hip bracing (~165°–175°) support quality execution. Small-sample male studies are mixed (likely method/size limits). (Kourav; Pulen Das; Indian uni studies)
* **Pull:** signature is stride tightening approaching impact and compact base. (Intervarsity pull)
* **Range/Sixing:** sweetspot accuracy ±1 cm + bat speed ≥25 m/s and X-factor ≥ ~20° are central. (Peploe et al.)
* **Gender:** males on average show bigger X-factor and elbow extension → higher bat speeds; wrist uncocking is similar. Training implications: S&C and equipment scaling matter. (McErlain-Naylor et al., 2021)