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A Threshold–Compensation Hypothesis for Driver Over-the-Top: Subtyping, Screening, and a Research Agenda

Chen Liyuan

The Hong Kong Polytechnic University, Hong Kong, China

Keywords: Golf; Over-the-Top; Kinematic sequence; Scapular stability; Compensation threshold; Lead-leg braking; Constraints-led approach

Abstract: Over-the-Top (OTT) in the driver swing is conventionally treated as a club-head path error, yet a specific subgroup—relatively stable with irons or at reduced speed but with recurrent OTT at full driver speed—resists path correction. This article presents a falsifiable theoretical hypothesis and research agenda. It proposes that, within this subtype, OTT may not originate as a proximal path error but may instead represent the downstream geometric projection of a sequencing reorganization occurring when, under high task demand, the lead-leg braking threshold and/or the scapular stability threshold is approached or crossed. Defining the bandwidth for stable, non-compensatory sequencing as the lower of the two thresholds (B = min), we distinguish four threshold combinations, derive parametric predictions, and set a subtype-first, then-screen, then-verify-transfer pathway. Framed within a constraints-led perspective—the threshold an organismic constraint, full-speed or distance-pursuit driving a task constraint—OTT emerges from their interaction, offering a testable account of its speed and club specificity. We juxtapose competing explanations (address error, top-of-backswing structure, release timing, an internal shift of attentional focus, and a common upstream driver) and design three pre-registration-oriented studies testing the timing of compensation versus path deviation, the transfer of targeted training, and the predictive validity of subtyping. We do not claim to have proven a single cause; we offer a hypothesis testable by subsequent biomechanical and training-intervention research.

1. Introduction

Over-the-Top (OTT) is one of the most common faults addressed in driver instruction, described geometrically as the club-head departing from the ideal downswing plane (“steep” or “out-to-in”). Teaching therefore targets path correction—address, swing imagery, restraint of transitional upper-arm abduction, visual guidance—and for most golfers this helps. To make the propositions below testable, we operationalize OTT by a single primary indicator: the early-downswing out-of-plane deviation of the club-head relative to a functional swing plane, with the plane out-to-in angle as the primary outcome (club-head path and face-to-path angle as auxiliaries); thresholds and event markers are fixed at pre-registration.

Swing performance depends on the proximal-to-distal, sequential release of segments—the kinematic sequence—which distinguishes amateurs from professionals[1], and downswing biomechanical variables relate to striking performance[2]. Within this view, a subgroup of intermediate-to-advanced golfers shows a split pattern that path accounts struggle to explain: relatively stable with irons and at reduced speed, but recurrent OTT at full driver speed, with path correction effective at low speed yet relapsing at full speed. Their OTT is speed-dependent and club-specific, appearing only as swing speed approaches the individual ceiling—more a threshold effect (appearing or disappearing with the capacity–demand gap) than a stable structural fault.

This challenges the path view because, in striking and throwing skills, segmental timing is largely governed by motion-dependent inter-segment interaction rather than independent joint actions[3], so a proximal disturbance propagates distally and is amplified at the chain's end. (The golf sequence is broadly, though not uniquely, proximal-to-distal[1,3]; we invoke the principle only in the general sense that a proximal disturbance propagates.) The terminal "steep, out-to-in" geometry is thus a reading at the chain's end; if the disturbance is proximal, correcting the terminal geometry works at low speed and relapses at full speed, because it addresses the projection, not the upstream conditions producing it.

We propose that, for this subgroup, OTT may be the downstream expression of a sequencing problem whose proximal cause is a compensatory reorganization of movement coordination once a chain link crosses its individual compensation threshold; the path deviation is the outcome, not the origin. The paper (i) reframes such OTT as a screenable, quantifiable threshold–sequencing problem, (ii) defines a stable-sequencing bandwidth via the lead-leg braking and scapular stability thresholds for subtyping, and (iii) sets a subtype-first pathway with a falsifiable agenda. Scope is delimited by three conditions: (a) OTT unstable or absent with irons or reduced speed; (b) OTT rising markedly under full speed or distance-pursuit intent; (c) top-of-backswing structure, grip, and address acceptable (§2.1). One main kill-switch is stated for scrutiny: if scapular compensation cannot be shown to precede path deviation in time, or if targeted training cannot transfer to the real full-speed driver swing, the hypothesis must be downgraded to a subtype-observation hypothesis (conditions in §5). This article is a conceptual hypothesis and research agenda, not an empirical validation study.

2. The compensation–sequencing-error model

2.1. Boundary conditions

The framework does not apply to all OTT; three subtypes lie outside it (Table 1). (1) Top-of-backswing structural OTT: insufficient thoracic rotation or shallow scapular retraction at the top, stable even at low speed; treated by backswing correction. (2) Grip–release-timing OTT: early release or premature wrist-hinge extension, originating in hand control and equally evident with short irons. (3) Address/aim-error OTT: Kim et al. showed a change of one ball radius (2.14 cm) in medio-lateral ball position produces a chain effect on ground reaction force (GRF), segment angles, and center of mass (COM), a left position bringing a more open shoulder angle and greater left-foot loading[4]; resolved by address correction. Moreover, not every weight pattern is a fault: a cluster analysis of 62 professional-to-low-handicap golfers found two stable transfer strategies, "front-foot" and "reverse," co-occurring across skill levels and not errors[5]—so address–transfer reading must separate individual strategy from genuine deviation.

The framework's scope is thus: OTT unstable or absent with irons or reduced speed; rising markedly under full-speed or distance-pursuit intent; top-of-backswing structure, grip, and address acceptable. It must be distinguished from early extension (premature pelvic thrust)—a pelvis–spine sagittal-plane phenomenon at a different level from the upper-chain, transverse-plane reorganization here, though the two may co-occur under high load. The mechanistic argument and conclusions are by default confined to adult, right-handed, male golfers; other populations require separate verification.

Table 1 Exclusion and discrimination of OTT subtypes

Subtype	Discriminating cues	Direction of treatment
Address error	Medio-lateral ball-position shift causes chain effects on GRF/COM/shoulder angle; also visible with short irons	Address and aim correction
Structural (backswing)	Insufficient top thoracic rotation or shallow scapular retraction; OTT stable even at low speed	Backswing structural correction
Release timing	Early release or premature wrist-hinge extension; equally evident with short irons	Hand-control / release training
Threshold–compensation (this hypothesis)	Stable with irons and at reduced speed, high-frequency at full-speed driver; rises with speed / pursuit / pressure	Subtype → screen → threshold training → transfer verification

2.2. Three core propositions

Proposition A (downstream nature): within scope, OTT is the downstream result of compensation, not its proximal cause. When scapular stability approaches the individual compensation threshold, the movement system adopts a non-optimal coordination strategy to meet the striking goal (described behaviorally, with no direct neural claim). A candidate mechanism: an under-working scapular depression–retraction chain lets elevator muscles participate more, the shoulder girdle rises and protracts relative to the thorax, the rotation axis shifts, and the arms more readily take a steep, outside path (Figure 1). This has an anatomical basis—the scapula is both a stable base for glenohumeral motion and a link in the proximal-to-distal chain, its stability depending on dynamic muscular control[8]—and aligns in direction with EMG evidence of a scapular-muscle activation sequence[6] and with scapular dyskinesis in overhead sport[7]. Combined with inter-segment interaction[3], reduced proximal shoulder-girdle stability alters the boundary conditions for the distal arm–club segment. Still, “scapular compensation drives OTT” remains a candidate awaiting temporal verification (§5.1); indeed, the scapula→path link is the weakest evidential step, which Study 1 targets first. A stronger corollary follows: transitional scapular elevation should scale monotonically with intent (speed), linking Propositions B and C.

Proposition B (temporal precedence): compensation occurs earlier than the visible path deviation, the informative window being the transition (P4–early P5), where a stability failure leaves downstream nodes without a stable reference. This is a hypothesis; verification is in §5.1.

Proposition C (threshold–task-constraint trigger): the lower the threshold and the stronger the task constraint, the more readily compensation is triggered. “Intent” splits into three separately operationalizable task constraints—swing-speed demand (physical), distance-pursuit instruction (intentional), and pressure context (psychological)—which should not be conflated. Compensation rises as the gap between node threshold and demanded work narrows; hence the driver versus an iron, pursuit versus routine, and competition versus practice each predict a higher OTT rate, testable separately.

“Compensation threshold” is not “breakdown speed”: the latter merely says technique degrades at some speed; the former is node-specific, predicting which compensation appears (hence which subtype) and that raising a specific node’s threshold selectively changes that subtype’s appearance—identifiable subtype and selective-intervention predictions distinguish it from a generic breakdown speed.

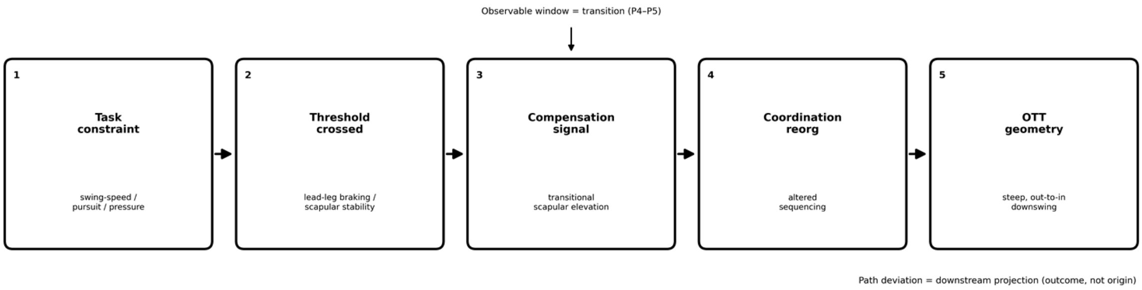

Figure 1 Hypothesized threshold–compensation chain (within the hypothesis's scope)

2.3. Theoretical positioning within the constraints-led approach

The model sits within the constraints-led framework, in which coordination emerges from the interaction of organism, environment, and task constraints rather than a fixed recipe[14]. The compensation threshold is an organismic constraint, full-speed or distance-pursuit driving a task constraint, and OTT the product of their interaction—offering a testable account of its speed- and club-specificity: stable sequencing holds while the task constraint is below the organismic threshold, and two equivalent removal routes follow (raise the threshold by training, or lower demanded speed), consistent with OTT disappearing in slow swings. The model does not conflict with the movement-variability view against a single template[12]; it goes further by naming a measurable organismic constraint and a directional prediction. It also predicts task-constraint scaling: within a golfer, OTT rate should rise monotonically with required swing speed, the inflection set by the individual threshold—corroborating Proposition C at the group level.

3. Dual-threshold bandwidth model and subtyping

3.1. Formalizing the dual-threshold bandwidth

A three-layer model of golf lower-limb dynamics (reported elsewhere) frames lead-leg support–braking as an intermediary node linking GRF expression, momentum redirection, and speed release; with the scapular compensation threshold this gives a dual-threshold structure in which stable sequencing requires both thresholds satisfied at once. Let T_{lead} and T_{scap} be the work ceilings the lead-leg braking and scapular stability bear without compensation, and $D(v)$ the transmission demand at target speed v (increasing in v; v^* the critical speed, B the bandwidth, argmin the node at the minimum—defining symbols only). Stable sequencing holds iff $D(v) \le T_{lead}$ and $D(v) \le T_{scap}$; equivalently for $v \le v^*$, with v^* set by the lower threshold, so bandwidth $B = \min(T_{lead}, T_{scap})$. Proxies: $T_{lead} \approx$ the maximum screening-task load before lead-leg braking loses control; $T_{scap} \approx$ the maximum load/torque before scapular control fails; $D(v) \approx$ demand scaled from speed and the club mass–lever relation—their construct validity requiring prior verification.
Predictions follow: (i) OTT onset speed rises with $\min(T_{lead}, T_{scap})$; (ii) the node crossed first (argmin) sets the subtype (lead-leg → Combination 2, scapula → Combination 3); (iii) both low → Combination 4; (iv) raising only the non-binding threshold leaves v^* unchanged, explaining why training the wrong node fails. The min rule is the simplest weakest-link assumption (an L-shaped iso-bandwidth contour; Figure 2) and is falsifiable by an interaction/multiplicative model—if the nodes trade off or synergize, bandwidth is no longer set by the lower one and the training-priority

order changes. Indirect support: a faster, larger forward COP shift in the downswing accompanies higher club-head speed[13], consistent with lead-side loading as a bandwidth variable; the "lower threshold caps the chain" inference rests on inter-segment interaction (a proximal limit limits the distal)[3].

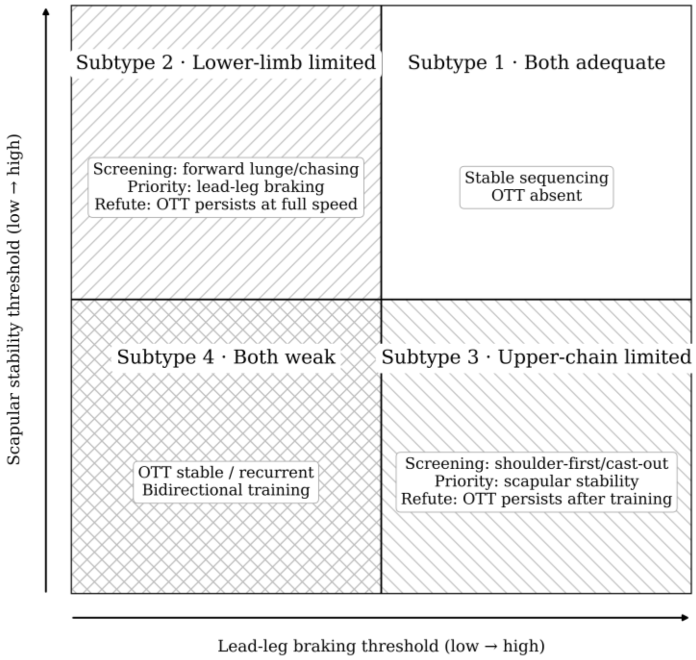

Figure 2 Dual-threshold bandwidth and subtype screening / training matrix

3.2. Four threshold combinations and subtypes

Four combinations follow. Combination 1 (both adequate): stable sequencing, no OTT. Combination 2 (lower-limb limited): inadequate lead-leg braking forces the upper limb to take over deceleration, OTT appearing with forward lunge or "chasing." Combination 3 (upper-chain limited): full lower-limb output jams at the upper level, OTT typically "shoulder-first, arm cast-out." Combination 4 (both weak): OTT stable and recurrent, resisting single-direction training. This matters for training: for a golfer whose lead leg is adequate but scapula limited, adding lower-limb strength does not resolve OTT and may aggravate upper-chain overload. Combination 3 warrants priority sampling among trained intermediate-to-advanced golfers; we make no prior claim about its distribution, which §5.3 addresses.

3.3. Evidence and boundaries

Two lines give indirect support. McHugh et al. (33 males) found impact X-factor, peak pelvis velocity, peak lead-foot GRF, and peak trunk/arm-velocity timing jointly explain a substantial proportion of driver ball-speed variance[9] (the exact figure to be verified verbatim before submission), while X-factor quantification varies by method and validity[10]—so these variables need careful operationalization. Separately, a recent systematic review has suggested an association between swing ground mechanics (GRF, COP) and club-head speed and skill level[11], consistent with, though not establishing, lead-leg braking as a bandwidth variable. Both are correlational, establishing covariation but not causal direction toward OTT. Finally, "stable sequencing" is an ideal: low-handicap golfers show lower outcome variability and relative stability at key positions, yet with individual variability patterns[12]; the framework makes only directional predictions, and if functional variability lets some golfers stay efficient while departing from stable sequencing, Proposition A weakens accordingly.

4. The screening–training–verification pathway

4.1. Screening task family

Shoulder compensation is hard to observe directly in the roughly one-second swing, where multiple compensations are often already engaged. We introduce structurally adjacent, variable-clean, tiered screening tasks sharing four principles: a half-kneeling posture to limit lower-limb involvement, a diagonal force direction, gradable load, and a visible key signal (uncontrolled terminal elevation of the left scapula). Ordered by equipment availability: a pneumatic-resistance-trainer task, cable diagonal pull-down, band diagonal pull-down, medicine-ball diagonal wall throw, and a bodyweight quick check; the first three give a baseline and longitudinal tracking, the fourth extends toward intent, the fifth monitors on-site state. Values are not interchangeable across tasks—only within-task longitudinal comparison is interpretable—and these tasks provide subtyping clues, not a diagnostic gold standard. The half-kneeling posture removes the lower-limb contribution as a task constraint, so residual loss of control implicates the upper chain; the screening threshold is thus task-specific and calibrated per person[5]. An illustrative observation (N = 1, not evidence): an advanced golfer with recurrent full-speed OTT and failed path correction showed stable, visible loss of control in left-scapular terminal elevation once the half-kneeling diagonal pull-down load crossed a grade—illustrating the framework's clinical origin only. One key assumption remains unverified: whether these tasks predict OTT in the real swing—this task-to-swing validity is itself a research question, so readings are auxiliary clues, not swing-level conclusions.

4.2. Training design and the limits of transfer

Langdown et al. (37 golfers, 8 weeks) found the overhead deep squat improved yet 3D swing kinematics did not change[15], showing general fitness gains do not automatically transfer to swing timing. For threshold–compensation-type OTT, scapular-threshold and lead-leg-braking training are reasonable but unverified upstream candidates; transfer is complete only when transitional timing, path, and dispersion improve together. If only screening indices improve while swing indices do not, transfer is incomplete—the main refutation condition of Study 2—and this can be tested as a dose–response: threshold gains should correlate with swing-level improvement.

4.3. The coach's standard sequence

The coach's sequence: (1) exclude address, structural, and release-type OTT[4]; (2) initiate the threshold–compensation pathway only in golfers stable with irons and at reduced speed but high-frequency at full-speed driver; (3) check peak lead-foot GRF, peak pelvis velocity, and peak trunk–arm-velocity timing[9]; (4) observe whether the shoulder girdle jumps out early in transition; (5) after training, verify at the full-speed driver swing.

5. Executable research design

Targeted mechanistic argument requires filling three evidence gaps, corresponding to three studies (summarized in Table 2) sharing a pre-registration orientation (primary outcomes, thresholds, and support/refutation conditions set before data collection).

Table 2 Summary of the three study designs

Study	Sample	Primary outcome	Support pattern	Refutation
Study 1 (timing)	n=36 right-handed adult males	Onset-time difference: scapular elevation vs path deviation	Scapula precedes path; magnitude correlates	No time difference, or scapula later than path
Study 2 (RCT)	n=72 (three arms)	Full-speed driver OTT rate	Arm A > Arm B; retention A > C	Only screening layer improves, or A≈B
Study 3 (subtype response)	n=80 (4×2)	Driver OTT rate (GLMM)	Matched ≫ mismatched improvement	All subtypes respond identically

5.1. Study 1 (timing)

Tests Proposition B: transitional left-scapular vertical displacement onset precedes club-head path-deviation onset. A cross-sectional single-center design enrolls 36 right-handed adult male golfers, 15 full-speed driver swings each. Measurement is tiered: a minimum viable configuration—3D motion capture (≥250 Hz), dual force plates (≥1000 Hz), launch radar—and an enhanced one adding surface EMG (upper/lower trapezius, serratus anterior, rhomboids, to test the elevator-muscle link), a bone-pin-validated acromion marker cluster, and high-speed video. Primary analysis: paired Wilcoxon signed-rank on the two event times, pre-set criterion median difference ≥ 20 ms (pilot-calibrated). Sample size: for $d \approx 0.5$, two-sided $\alpha = .05$, power 0.80, a paired t needs ≈ 34; the Wilcoxon (asymptotic relative efficiency ≈ 0.955 under normality, i.e., ≈ 5% inflation, ≥ 1 under heavy tails) gives $n = 36$ with margin. $d \approx 0.5$ is a placeholder to be replaced from pilot or literature[16]; intra-rater consistency is ICC(3,1) ≥ 0.75. Support: scapular elevation precedes path deviation, magnitudes correlating. Refutation: no difference, or scapula later. Even scapula-first establishes only temporal precedence, not causation; a common upstream driver remains coexisting, to be excluded with Study 2's intervention specificity. The chief challenge is scapular 3D measurement: skin-motion artifact is substantial and non-invasive accuracy declines with humeral elevation and speed[17], so a bone-pin-validated acromion cluster or scapular locator is used, conclusions bounded by known accuracy and aided by a thorax-relative frame and image cross-validation.

5.2. Study 2 (RCT)

Tests a corollary of Proposition C: combined scapular-stability and lead-leg-braking training improves the screening, kinematic, and outcome layers together. Single-blind, three-arm, stratified RCT; 12-week intervention, 4-week retention. Arm A, combined targeted training; Arm B, routine fitness matched in volume and frequency (separating targeted content from load); Arm C, conventional path correction (upstream body versus downstream technical path). Target $n = 72$; sample size for a group × time interaction ($f \approx 0.25$, $\alpha = .05$, power 0.80): ≈ 24/arm, 72 total (f a placeholder, pilot-updated), +15% for attrition. Single primary outcome: full-speed driver OTT rate (per §1), modeled by a binomial GLMM; path deviation, transitional timing, and screening threshold are secondary. Primary contrast (intention-to-treat): Arm A versus B after retention; secondary tests via Holm correction. Dose, exercises, progression, and adherence per Table 3. Support: Arm A improves across all three layers beyond Arm B, and beyond Arm C at retention. Refutation: Arm A improves only at the screening layer (replicating[15]) or A ≈ B. Secondary:

when Combination 3 holds, test whether scapular-threshold training's marginal benefit exceeds continued lower-limb gain.

Table 3 Candidate training-intervention protocol (Study 2; details pending pre-registration)

Element	**Scapular-stability-threshold module**	**Lead-leg-braking-threshold module**
Representative exercises	Half-kneeling diagonal pull-down; lower-trapezius & serratus activation	Lead-leg eccentric braking; landing absorption; single-leg stability
Frequency	3 × / week	3 × / week
Duration	20–30 min	20–30 min
Sets × reps	3–4 × 6–10	3–4 × 6–8
Progression	Advance one grade after two consecutive on-target sessions	Increase load stepwise after stable completion
Progression failure	Drop one grade after two consecutive off-target sessions	Drop one grade after two consecutive off-target sessions
Stop rule	Stop on compensation loss-of-control or pain	Stop on compensation loss-of-control or pain
Adherence	≥2 sessions/week counts as compliant	≥2 sessions/week counts as compliant
Fidelity check	Certified coach rates exercise quality (0–2) each session; records retained	Certified coach rates exercise quality (0–2) each session; records retained

5.3. Study 3 (subtype response)

Tests subtyping validity: subtypes respond differentially to interventions. A 4 (subtype: address, structural, release, threshold) × 2 (matched vs mismatched) mixed design, 20 per subtype, 80 total (interaction partial $\eta^2 \approx 0.06$, $f \approx 0.25$, $\alpha = .05$, power 0.80). A circularity risk is handled by classifying subtype before enrollment via an outcome-independent screening process, with a misclassification sensitivity analysis (confidence stratification or blinded re-rating). Primary outcome: driver OTT rate (binary); as it is not continuous-normal, a binomial GLMM (logit) is used, the key inference on the subtype × intervention interaction (matched vs mismatched). Support: matched improvement significantly exceeds mismatched within each subtype. Refutation: all subtypes respond identically.

5.4. Measurement, blinding, and pre-registration

Shared conventions: the threshold is approximated by the screening-task load at which loss of control first stably appears, compared within task only; raters are blinded to group and test time; primary outcomes, thresholds, and support/refutation conditions are pre-registered (e.g., OSF) before data collection, with the analysis plan (covariates, missing-data handling, multiplicity correction, blinding) locked; data and code are shared at publication.

Together the three test direction (Study 1), strength (Study 2), and specificity (Study 3): failing direction abandons the causal claim; failing strength leaves only explanatory and screening value; failing specificity confines the framework to a subset within a more general account. They are parallel in time, independent in sample, and jointly closing.

6. Discussion: limitations and competing explanations

Three competing explanations remain to be compared: OTT may be driven chiefly by top-of-backswing structure or release-timing error, or by multiple parallel causal paths. The framework does not claim uniqueness; it offers subtyping and predictions these can falsify.

Several situations resist clean explanation. High-level players with marked OTT but no low threshold may need an intent-side loss-of-control dimension. Female golfers may differ: males and females differ in downswing thorax and pelvis kinematics[18], and as the argument rests on male-sample literature, extrapolation must be cautious. Slow-tempo players with recurrent OTT challenge Proposition C, perhaps via an entrenched second-layer compensation. These are real failure points; sustained support for them should tighten scope.

A motor-control/attentional alternative should be juxtaposed: OTT may reflect an internal shift of attentional focus under pressure rather than a crossed physical threshold; an external focus is known to enhance performance over an internal one[19]. A distinguishing test: if an external cue at full speed markedly removes OTT, the threshold account weakens and the attentional one strengthens—implementable as an additional Study-2 arm.

The common-upstream-driver account is hardest to exclude: high intent may raise several nodes' compensation tendency at once, making scapular elevation and path deviation parallel outcomes of one strategy switch. Separating them needs intervention node-specificity beyond temporal precedence: scapula-only training that selectively improves the path supports the hub hypothesis; improvement always accompanying a global change favors a distributed account. Studies 1 and 2 are designed for this.

In sum, this is a falsifiable threshold–compensation hypothesis, not a proven single-cause model of driver OTT; its scope is the specific subtype stable with irons or reduced speed but recurrent at full-speed or distance-pursuit contexts; address error, backswing structure, release timing, attentional focus, and a common upstream driver may each explain some cases; the subtyping and screening pathway can become a stronger mechanistic claim only after support in the temporal, transfer, and subtype-response studies.

7. Conclusion

The framework stands differently across explanation, screening, and training. It reorganizes a path-framed OTT class into a screenable, quantifiable sequencing problem with reasonable basic-literature support; it offers a subtyping decision tree, screening task family, and dual-threshold assessment for coaches with independent assessment capacity, once other subtypes are excluded; and scapular-stability plus lead-leg-braking training is a reasonable candidate whose transfer awaits randomized controlled verification, so its use should be confined to in-scope golfers and verified at the swing level.

Causally, even temporal precedence (Study 1) is not causation—a common upstream driver may trigger both signals—so the scapular node's hub status needs Study 1 (timing) and Study 2 (specificity) jointly, failing which a distributed account follows. The formalization's empirical meaning depends on prior threshold measurability. As a hypothesis and agenda, the paper's value rests on whether the three studies pass on direction, strength, and specificity.

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