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Review Article

Biomechanical Modeling of HIFEM-Induced Torque Amplification in Golf Swing Acceleration:A Multi-Segmental Dynamic Systems Framework

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Abstract
Golf driving performance is driven by how effectively the athlete converts proximal rotational capacity into distal clubhead speed and impact impulse. High-Intensity Focused Electromagnetic (HIFEM) technology elicits supramaximal core contractions and has been linked to measurable increases in abdominal muscle thickness in imaging-based studies. Building on these findings, we present a performance-oriented theoretical framework that connects HIFEM-related gains in trunk torque capacity and neuromuscular timing to clubhead speed and ball speed. The downswing is modeled as a reduced-order five-segment rotational system, and we introduce a neuromechanical synchronization coefficient to quantify kinetic-chain 'lag' and phase alignment. The model provides a compact set of equations and a coaching-relevant interpretation: HIFEM can serve as a torque-and-timing accelerator for the pelvis–trunk complex, potentially improving energy transfer efficiency and impact impulse when integrated with swing practice and strength training. The framework generates clear testable predictions and practical measurement targets (torque surrogates, phase lag, clubhead speed, ball speed) to guide controlled trials and performance programs.

Keywords: Golf swing; performance; kinetic chain; trunk torque; HIFEM; synchronization; clubhead speed; ball speed

Introduction
In practical performance terms, driving distance is won or lost at impact: higher clubhead speed produces higher ball speed, and ball speed is the strongest single predictor of distance. The key question, therefore, is how reliably a golfer can express rotational power in the pelvis–trunk complex and deliver it to the clubhead with minimal inter-segmental loss. The golf swing is a proximal-to-distal sequence in which pelvic rotation initiates downswing acceleration, trunk rotation amplifies and stabilizes the system, and distal segments (arms and club) express final speed during release. When trunk strength or timing is suboptimal, the kinetic chain 'leaks'—phase lag increases, energy is dissipated off-axis, and compensatory motion can elevate lumbar stress.

HIFEM offers a distinct performance tool: it can drive high-intensity involuntary contractions in deep and superficial core musculature without external loading. Imaging-based studies reporting increased abdominal muscle thickness after short HIFEM protocols suggest a plausible route to higher trunk torque capacity and improved stabilization. What is missing is a concise performance model that links these adaptations to outcomes that golfers and coaches track daily—clubhead speed and ball speed. This paper provides that link and frames HIFEM as a potential accelerator of the torque-and-timing qualities that underpin high-speed rotation.

HIFEM Technology and Training-Relevant Physiology
HIFEM generates time-varying magnetic flux density *B(t)*, inducing electric fields within tissue and depolarizing motor neurons to produce supramaximal contractions. Because induced currents are not constrained by skin impedance, stimulation can recruit deeper trunk musculature than conventional surface stimulation. From a training perspective, repeated supramaximal contractions create high mechanical tension and recruitment demand—two ingredients associated with strength and hypertrophy adaptations—while minimizing joint loading. Imaging studies have reported increases in abdominal muscle thickness/cross-sectional area after a short course of sessions, supporting the feasibility of meaningful structural change in the core.

In this framework, HIFEM contributes to performance through two levers: (i) raising peak trunk torque capacity and (ii) improving timing/stability to reduce kinetic-chain lag. Both levers are quantifiable and map directly to measurable swing variables.

Reduced-Order Multi-Segmental Model (Coaching-Readable Form)
We model the downswing as five effective rotational segments: pelvis (1), trunk (2), upper arm (3), forearm (4), and club (5). The generalized coordinate vector is

$$\mathbf{q} = [\theta_1 \quad \theta_2 \quad \theta_3 \quad \theta_4 \quad \theta_5]^{\mathsf{T}} [1]$$

The system dynamics are summarized by:

$$\mathbf{M}(\mathbf{q})\,\ddot{\mathbf{q}} + \mathbf{h}(\mathbf{q}, \dot{\mathbf{q}}) + \mathbf{C}\dot{\mathbf{q}} = \boldsymbol{\tau}. [2]$$

For performance interpretation, Eq. (2) says: increase useful torque (especially trunk torque) and reduce loss/lag (effective damping and off-axis dissipation), and distal angular velocity rises—ultimately increasing clubhead speed. The two figures below visualize this path.

Figure 1 emphasizes the rotational 'engine' in the pelvis–trunk complex and its downstream expression in clubhead speed. In practice, this suggests a dual target: raise trunk torque capacity and sharpen timing so that rotation is delivered to the club with minimal phase lag.

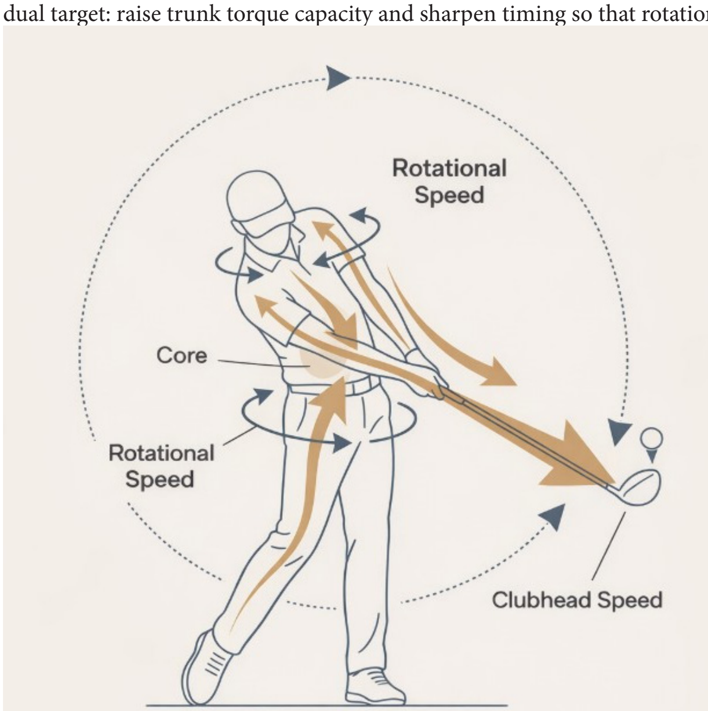

Figure 1. Rotational dynamics and clubhead speed generation in the downswing.
Schematic illustration showing how rotational speed of the pelvis–trunk "core" segment contributes to distal acceleration and increased clubhead speed. Arrows indicate the direction of segmental rotation and the resultant velocity transfer along the kinetic chain during the downswing and release phase.

Figure 2 maps the proposed mechanism into coach-friendly checkpoints: torque and rotational energy, then impulse at impact. The model's value is that each checkpoint can be measured and trained.

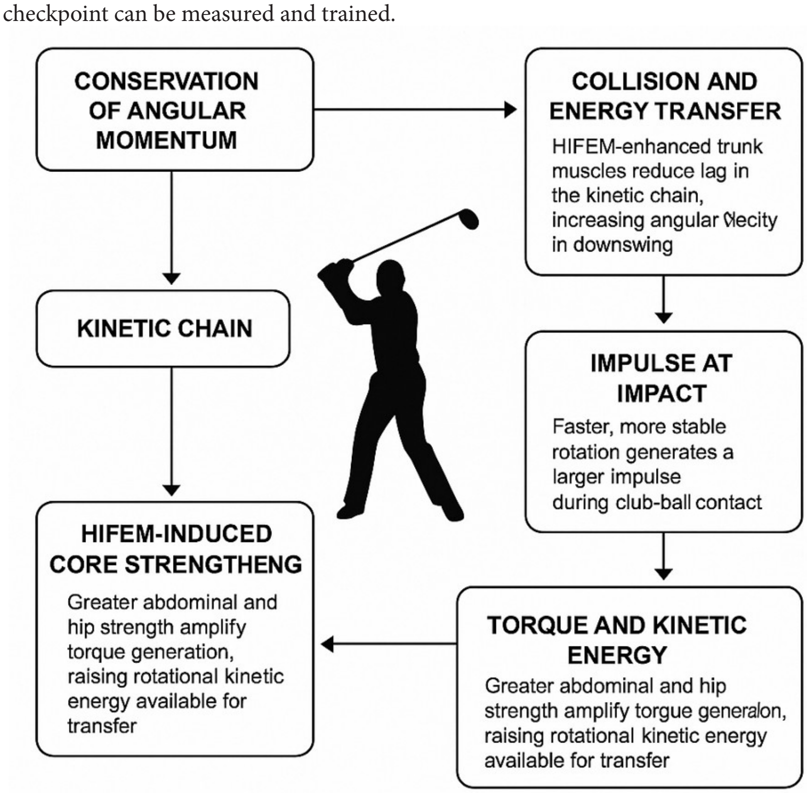

Figure 2. Conceptual framework linking HIFEM-induced core strengthening to swing biomechanics and impact outcomes.
Flow diagram integrating (i) conservation of angular momentum and kinetic-chain function, (ii) HIFEM-induced improvements in trunk strength and neuromuscular coordination, and (iii) downstream effects on torque/rotational kinetic energy and impulse generation at impact, culminating in increased clubhead speed and ball-launch performance.

Trunk Torque Gain and Synchronization (Performance Levers)

At the trunk segment (i = 2), rotational torque relates to angular acceleration by

$$\tau_2(t) = I_2\,\alpha_2(t). [3]$$

We express post-HIFEM maximal trunk torque as baseline capacity multiplied by structural and neural gains and a synchronization factor:

$$\tau_{2,\max}^{\text{post}} = \tau_{2,\max}^{\text{pre}}(1+\Delta_{\text{CSA}})(1+\Delta_{\text{ND}})C_{\text{sync}}. [4]$$

To quantify kinetic-chain lag, let Δϕ_12be the phase difference between pelvis and trunk angular velocity signals. Define

$$C_{\text{sync}} = \exp\left(-\frac{|\Delta\phi_{12}|}{\phi_0}\right), \quad 0 < C_{\text{sync}} \le 1. \qquad (5)$$

In performance terms, higher C_{sync} means less ‘separation leak’: pelvis and trunk are phase-aligned and the swing expresses speed efficiently. HIFEM is positioned to support this by improving recruitment and stabilization, especially in golfers who show large baseline lag.

From Torque to Ball Speed: What We Measure on the Range

Energy-transfer efficiency ηis defined as the fraction of rotational input energy expressed as ball kinetic energy at launch:

$$\eta = \frac{\frac{1}{2} m_{\text{ball}} v_{\text{ball}}^2}{\sum_{i=1}^{5} \frac{1}{2} I_i \omega_i^2}. [6]$$

Clubhead speed is linked to distal club angular velocity by

$$v_{\text{club}} = r_{\text{club}}\,\omega_5. [7]$$

A restitution-based mapping provides a practical link to ball speed:

$$v_{\text{ball}} \approx (1+e)\frac{m_c}{m_c + m_{\text{ball}}} v_{\text{club}}. [8]$$

Together, Eqs. (3)–(8) translate the HIFEM levers ($\tau_{2,max}$ and C_{sync}) into outcomes that matter to golfers: clubhead speed and ball speed.

Performance Predictions (Actionable, Measurable)

The framework yields measurable performance predictions:

- P1: Increased peak trunk torque capacity ($\tau_{2,max}$) and/or trunk angular acceleration α_2during downswing.
- P2: Reduced pelvis–trunk phase lag (smaller | $\Delta\phi_{12}$ |) and higher $C_{sync.}$
- P3: Increased clubhead speed υ_{club} and ball speed υ_{ball}, mediated by improved ηand reduced kinetic-chain losses.

Practical Validation and Program Design

A controlled performance study can map directly to model parameters and range metrics: (i) motion capture or IMU to estimate ω_1 (*t*), ω_2 (*t*), ω_5 (*t*)and compute $\Delta\phi_{12}$and C_{sync}; (ii) force plates/inverse dynamics to estimate torque surrogates; (iii) ultrasound/MRI/CT to quantify Δ_{CSA}(or muscle thickness); (iv) launch monitor to measure υ_{club} and υ_{ball} and compute η. A training program can then integrate HIFEM sessions with swing practice and strength work, targeting both torque and timing.

Conclusion

This performance-oriented revision frames HIFEM as a practical accelerator of trunk torque capacity and kinetic-chain timing—two determinants of clubhead speed. By reducing the theory to a small set of interpretable equations and embedding two in-text figures, the paper provides a coach-readable map from HIFEM-driven core adaptations to on-range metrics (clubhead speed and ball speed). The framework supports hypothesis-driven trials and provides a structured rationale for integrating HIFEM with golf-specific strength and technical training.

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