International Journal of Innovative Research in Engineering and Management (IJIREM)
ISSN (Online): 2350-0557, Volume 13, Issue 4, August 2026
DOI: https://doi.org/10.55524/ijirem.2026.13.4.9
Article ID IJIRE-1471, Pages 75-79
www.ijirem.org

PUSH and PULL Strategies in the Tennis Forehand: A Short Review in Biomechanical Perspective

Daewon Kim[1], Minho Kim[2], and *Sukwon Kim[3]

[1, 2, 3] Department of Physical Education, Jeonbuk National University, Jeonju, Republic of Korea

Correspondence should be addressed to *Sukwon Kim; rockwall@jbnu.ac.kr

Received: 31 July 2026; Revised: 15 August 2026; Accepted: 29 August 2026

ABSTRACT- The tennis forehand is a complex multisegment movement in which racket velocity and ball behavior emerge from coordinated contributions of the body and upper extremity. A recent approach has described forehand stroke organization using two broad strategies: PUSH and PULL. The PUSH strategy is characterized by a relatively direct and linear racket path, whereas the PULL strategy involves greater multiplanar movement and rotational contributions. However, these strategies should not be regarded as mutually exclusive techniques or interpreted in terms of a simple inferior–superior relationship. Rather, they may represent different positions along a biomechanical continuum of forehand organization. This short review examines the PUSH–PULL concept in relation to existing research on tennis forehand biomechanics, segmental coordination, racket-head velocity, spin production, and muscle activation. Previous biomechanical studies demonstrate that effective forehand performance can be achieved through different combinations of proximal and distal segment motion and that stroke organization varies according to skill level, stroke direction, stance, spin intention, and other task constraints. Electromyographic differences between strategies may indicate different neuromuscular organizations, but EMG amplitude alone cannot establish differences in muscle force, joint power, mechanical efficiency, or intersegmental energy transfer. Accordingly, PUSH and PULL are proposed as descriptive endpoints of a flexible movement continuum rather than fixed technical categories. Future research combining continuous kinematics, joint kinetics, racket and ball outcomes, and neuromuscular measures is required to establish the mechanical significance of this framework.

KEYWORDS- Tennis, Forehand, Biomechanics, Push, Pull, Segmental Coordination, EMG

I. INTRODUCTION

The tennis forehand is a fundamental stroke in modern tennis and requires the coordinated motion of multiple body segments to generate racket-head velocity while maintaining control of racket orientation and ball trajectory. Considerable variation exists in the way players organize this movement. Some players employ a relatively direct movement of the hitting arm and racket, whereas others demonstrate greater trunk rotation, upper-limb segmental motion, and a more multiplanar racket trajectory.

A recent studied by Wang proposed a practical distinction between these patterns using the terms PUSH and PULL [1]. In this framework, the PUSH strategy was defined as a relatively linear and single-plane forehand, whereas the PULL strategy was characterized by a steeper, multiplanar swing trajectory [1]. The study further compared wrist, elbow, and shoulder kinematics and selected muscle activation patterns between players exhibiting the two strategies.

This distinction has conceptual similarities with the earlier comparison of single-unit and multisegment forehand techniques. Elliott et al. [2] distinguished players whose hitting limb moved predominantly as one unit from those demonstrating greater relative motion among individual upper-limb segments. Their findings demonstrated that different segmental organizations can produce different racket and ball velocities. More broadly, contemporary reviews of forehand mechanics emphasize contributions from pelvis and trunk rotation, shoulder horizontal movement and internal rotation, and distal upper-limb motion rather than identifying a single movement as responsible for racket speed [3]. Elliott [4] similarly emphasized that biomechanical principles should allow individual variation in stroke production rather than impose one universal technique.

Therefore, PUSH and PULL should not be interpreted as two completely separate stroke types or as inferior and superior techniques. A more appropriate interpretation may be that they represent different positions along a biomechanical continuum of forehand organization. The purpose of this short review is to discuss this continuum from the perspectives of segmental coordination, racket velocity and spin production, muscle activation, and whole-body mechanics.

II. PUSH AND PULL AS A CONCEPTUAL BIOMECHANICAL CONTINUUM

The principal difference between PUSH and PULL concerns how the player organizes the movement of the body, hitting arm, and racket as the stroke develops. At the PUSH-like end of the continuum, the racket trajectory can be described as relatively direct, with the hitting arm moving toward the ball in a comparatively linear manner. The upper-limb segments may exhibit less obvious relative movement, making the action conceptually similar to a single-unit organization. At the PULL-like end, greater relative movement among segments, body rotation, and multiplanar racket motion become more apparent.

Importantly, these descriptions represent relative tendencies rather than absolute characteristics. A PUSH-like forehand still requires joint rotation, and a PULL-like forehand necessarily includes forward racket translation. Thus, the two terms should describe the relative organization of movement rather than the presence or absence of particular motions.

This interpretation is illustrated conceptually in Figure 1. Instead of placing players into two discrete groups, the figure positions PUSH-like and PULL-like organizations at opposite ends of a continuum. The central region represents mixed strategies in which linear racket progression, trunk rotation, and upper-limb segmental motion are combined to different degrees. A player's position on this continuum may also change according to the requirements of a particular stroke.

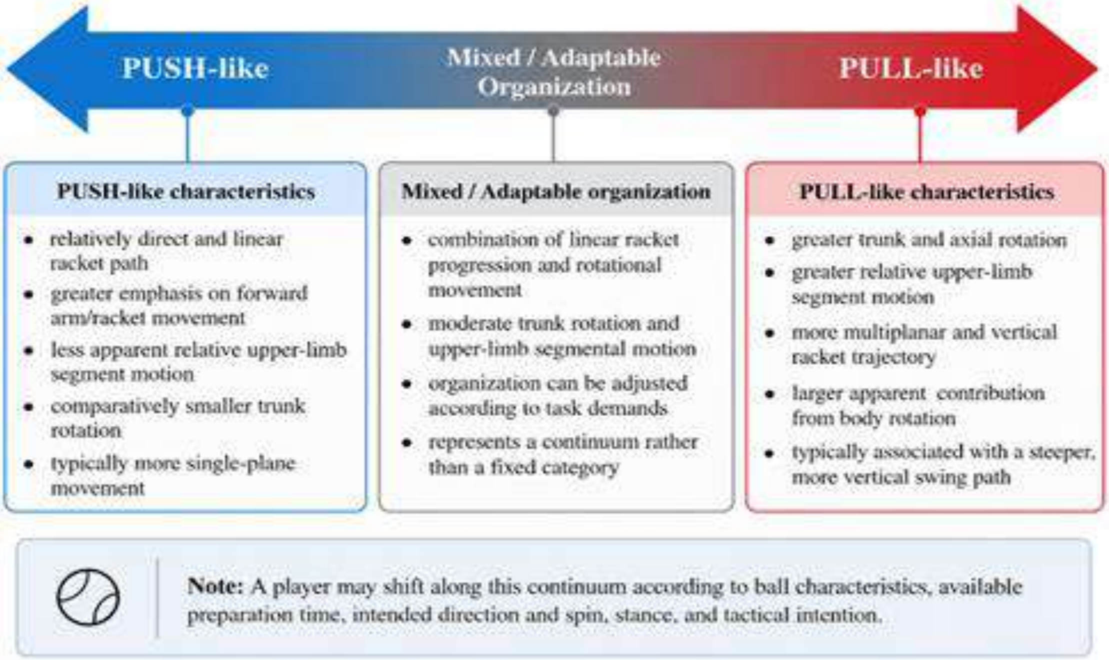

Figure 1: Conceptual Biomechanical Continuum of PUSH and PULL Forehand Strategies

Figure 1: Conceptual representation of PUSH and PULL as endpoints of a continuum of tennis forehand organization. The continuum is **descriptive rather than hierarchical** and does not imply that the PULL-like end represents better or more advanced technique. An individual player may shift along the continuum according to ball characteristics, available preparation time, intended direction and spin, stance, and tactical intention.

III. SEGMENTAL COORDINATION AND FOREHAND KINEMATICS

Forehand performance depends not merely on the magnitude of movement at individual joints but also on the temporal organization of multiple body segments. This is particularly relevant to the PUSH–PULL framework because a visually more rotational stroke should not automatically be interpreted as a more coordinated stroke.

Landlinger et al. [5] examined forehand kinematics across skill levels and highlighted the importance of both movement magnitude and timing patterns. Their results demonstrated differences in the temporal characteristics of segmental motion between players of different performance levels, reinforcing the importance of coordination rather than simply maximal segment velocity. In a related study, Landlinger et al. [6] reported differences in full-body kinematics between elite and high-performance players and between cross-court and down-the-line forehands. Elite players displayed greater shoulder linear velocity and pelvis and upper-trunk angular velocities at impact, while movement characteristics also varied according to shot direction.

These observations are important when interpreting PUSH and PULL. Wang [1] reported differences in wrist, elbow, and shoulder positions between the two strategies. For example, differences were identified in wrist extension, elbow flexion-extension, and shoulder flexion-extension and abduction-adduction during the backswing and impact phases. Such findings establish that the two groups displayed different upper-limb configurations. They do not, however, demonstrate that one coordination pattern is inherently more effective.

The earlier work of Elliott et al. [2] offers an important biomechanical context. In their comparison of single-unit and multisegment topspin forehands, the multisegment group demonstrated greater relative upper-limb motion and greater racket-tip and post-impact ball velocities [2]. Nevertheless, this finding should not be interpreted as evidence that all strokes should maximize segmental separation. A player must coordinate segmental motion under the temporal and spatial constraints imposed by an incoming ball.

Consequently, future investigation of PUSH and PULL should extend beyond discrete joint angles at backswing and impact. Continuous measures of pelvis, trunk, upper-arm, forearm, hand, and racket motion would make it possible to examine whether the strategies actually differ in temporal sequencing and intersegmental coordination. Such analyses would help distinguish a genuine coordination strategy from a simple difference in joint posture or range of motion.

IV. RACKET-HEAD VELOCITY, TRAJECTORY, AND SPIN PRODUCTION

The functional consequence of any forehand movement strategy must ultimately be considered in relation to the racket and ball. Upper-limb movements are important because they determine the instantaneous position and velocity of the racket at impact.

Elliott et al. [7] investigated upper-limb contributions to racket-head velocity and showed that shoulder linear velocity, upper-arm horizontal movement, and internal rotation made important contributions to racket speed, while the relative contribution of distal motion varied with grip position. This finding reinforces the idea that racket acceleration emerges from multiple interacting motions rather than from a single joint.

Spin production introduces an additional mechanical requirement. Takahashi et al. [8] demonstrated that increasing topspin involves changes in upper-limb segment rotations together with increases in the vertical trajectory and velocity of the racket head. Thus, a more multiplanar racket path may facilitate a different combination of forward and vertical racket velocity than a relatively direct trajectory.

This observation is relevant to the PULL-like organization described by Wang [1], which was associated with a more vertical and multiplanar swing pattern. However, this should not be interpreted as evidence that a PULL-like trajectory is universally preferable. The desired combination of horizontal and vertical racket velocity depends on the intended shot. A heavy topspin forehand, a flatter attacking forehand, and a rapidly prepared return may place different constraints on racket trajectory.

Rogowski et al. [9] further demonstrated that players altered both racket-face velocity and muscular activation when changing from flat to topspin forehands. Players who substantially increased vertical racket-face velocity did not simply increase activation across all shoulder and forearm muscles. Instead, the organization of both kinematics and muscle activation changed according to the stroke requirement.

Accuracy and margin for error also need to be considered. Knudson and Blackwell [10] examined racket and ball kinematics around impact in advanced players and emphasized that successful forehand production involves controlling impact conditions rather than maximizing a single kinematic variable. Accordingly, the mechanical significance of PUSH and PULL cannot be determined from joint motion alone. Direct measures of racket-head velocity, vertical-to-horizontal racket velocity, racket-face orientation, ball speed, and spin rate would provide a more complete assessment of the functional consequences of the two strategies.

V. MUSCLE ACTIVATION AND INTERPRETATION OF EMG FINDINGS

Wang [1] also reported differences in muscle activation between PUSH and PULL players. In particular, lower activation of selected upper-extremity muscles was observed in the PULL group, and the original study suggested that these players may rely more on body rotation than on isolated arm action. This interpretation is biomechanically plausible as a hypothesis, but the physiological meaning of EMG amplitude must be carefully distinguished from mechanical variables.

Surface electromyography provides information about the electrical activity associated with muscle activation. It does not directly measure muscle force, joint moment, mechanical power, mechanical efficiency, or energy transfer between segments. Vigotsky et al. [11] emphasized that differences in surface EMG amplitude are frequently overinterpreted and that caution is necessary when drawing mechanical or functional conclusions from EMG amplitude alone.

Therefore, lower EMG amplitude in selected muscles of PULL players should not be described as direct evidence that they were mechanically more efficient or that they transferred more energy from the trunk to the racket. A more conservative interpretation is that PUSH and PULL players demonstrated different patterns of muscle activation in the muscles that were measured.

This distinction is particularly important because the original PUSH – PULL study assessed selected upper-extremity muscles, including the pectoralis major, latissimus dorsi, biceps brachii, triceps brachii, and wrist flexor and extensor muscles [1]. Whole-body energy transfer cannot be established without corresponding information about lower-limb and trunk kinetics, joint power, and mechanical work.

The findings of Rogowski et al. [9] illustrate the same issue. Changes from flat to topspin forehands were accompanied by different muscle activation patterns, but the responses were not uniform across muscles or players. Their results support the idea that stroke demands can alter neuromuscular organization without implying that lower activation necessarily represents superior efficiency. Thus, the EMG evidence is valuable for characterizing PUSH and PULL, but it should remain one component of a broader biomechanical interpretation.

VI. WHOLE-BODY MECHANICS AND MULTIPLE SOLUTIONS TO THE SAME TASK

The idea of a PUSH–PULL continuum is also supported by research showing that tennis players can achieve similar racket outcomes through different mechanical solutions.

Bahamonde and Knudson [12] compared open- and square-stance forehands and demonstrated that stance influenced upper-extremity kinetics and racket velocity. Shoulder horizontal adduction, internal rotation, elbow loading, and wrist kinetics contributed differently depending on stance and skill level. Importantly, the results did not support a simple assumption that one stance universally imposed greater upper-extremity loading.

More recently, Kawamoto et al. [13] demonstrated that advanced players achieved similar racket-head velocities during open- and square-stance forehands despite different mechanisms of mechanical work at the shoulder. In the open stance, reduced work in the hitting direction was compensated by greater work in other directions associated with torso motion.

This is particularly relevant to the interpretation of PUSH and PULL. Different stroke organizations may produce comparable performance outcomes by redistributing mechanical contributions among segments and directions.

Therefore, a more rotational movement cannot automatically be considered mechanically superior to a more direct movement. Instead, each organization should be evaluated in relation to the performance outcome and the constraints of the specific stroke.

From a broader training perspective, Roetert et al. [14] emphasized the sequential coordination of body segments in tennis groundstroke production and the importance of training the musculature involved in both force generation and stabilization. Knudson and Elliott [15] similarly described tennis strokes as coordinated biomechanical actions in which several segments contribute to racket motion rather than as movements governed by a single universal pattern.

Collectively, these studies provide a strong rationale for viewing PUSH and PULL as alternative organizations within a common biomechanical system rather than competing techniques.

VII. PRACTICAL INTERPRETATION AND FUTURE RESEARCH

From an applied perspective, the PUSH–PULL continuum may offer coaches and researchers a useful descriptive framework. A PUSH-like pattern could describe a stroke characterized by a relatively direct racket trajectory and more compact upper-limb organization, whereas a PULL-like pattern could describe a stroke with greater rotational and multiplanar characteristics. The middle of the continuum would include strokes combining elements of both.

The value of this framework lies in describing how a player solves the hitting task, rather than prescribing a preferred solution. For example, limited preparation time may encourage a shorter or more direct stroke, whereas an opportunity to produce greater topspin may permit a more pronounced vertical and rotational racket path. Similarly, stroke direction and stance have been shown to affect forehand kinematics and mechanics [6,12,13]. Thus, it is reasonable to expect an individual player to shift along the PUSH–PULL continuum according to the demands of the situation.

The original study included professional and amateur players with substantially different training histories [1], which also requires caution when interpreting strategy differences. PUSH－PULL difference observed between groups may reflect stroke strategy, experience, skill-related coordination, or a combination of these factors. Future research should therefore examine PUSH and PULL within players as well as between players.

Several measurements could strengthen this framework. First, continuous three-dimensional kinematics of the pelvis, trunk, upper arm, forearm, hand, and racket could determine whether the strategies differ in intersegmental sequencing. Second, inverse dynamics and joint-power analyses could identify how mechanical work is distributed across the kinetic chain. Third, racket-head velocity, racket-face orientation, ball velocity, and spin rate should be measured directly to link movement strategy to performance. Finally, EMG should be interpreted alongside these mechanical variables rather than used independently as evidence of mechanical efficiency.

Such an approach would allow researchers to move beyond asking whether PUSH or PULL is “better.” A more meaningful question is under what conditions each organization is used, how players transition between them, and what mechanical consequences arise from those adaptations.

VIII. CONCLUSION

The PUSH–PULL concept provides an intuitive framework for describing variation in tennis forehand biomechanics. A PUSH-like strategy is characterized by a relatively direct and linear organization of the racket and hitting arm, whereas a PULL-like strategy involves greater rotational, multiplanar, and relative segmental motion. These characteristics have parallels with previously reported single-unit and multisegment forehand techniques and with established research on segmental coordination, racket-head velocity, and spin production.

However, the available evidence does not support treating PULL as inherently superior to PUSH. Different forehand organizations may represent different mechanical solutions to the same hitting task, and the appropriate solution is likely to depend on the incoming ball, available preparation time, intended direction and spin, stance, and tactical objective. Accordingly, PUSH and PULL are more appropriately considered positions along a biomechanical continuum than discrete or hierarchical techniques.

Similarly, differences in EMG amplitude should be interpreted specifically as differences in measured muscle activation. They do not directly establish differences in muscle force, joint power, mechanical efficiency, or whole-body energy transfer. Future research integrating continuous segmental coordination, joint kinetics, EMG, racket-head behavior, and ball performance is needed to determine how movement along the PUSH–PULL continuum influences tennis forehand performance.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

[1] S. Wang, "Comparisons of Upper Limbs Kinematics and Muscle Activity During Forehand Strokes in Professional and Amateur Tennis Players: PUSH or PULL?" M.S. thesis, Jeonbuk National Univ., Jeonju, South Korea, 2024.

[2] B. Elliott, T. Marsh, and P. Overheu, "A biomechanical comparison of the multisegment and single unit topspin forehand drives in tennis," Int. J. Sport Biomech., vol. 5, no. 3, pp. 350–364, 1989. Available from: https://doi.org/10.1123/ijsb.5.3.350

[3] M. Reid, B. Elliott, and M. Crespo, "Mechanics and learning practices associated with the tennis forehand: A review," J. Sports Sci. Med., vol. 12, no. 2, pp. 225–231, 2013. Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC3761830

[4] B. Elliott, "Biomechanics and tennis," Br. J. Sports Med., vol. 40, no. 5, pp. 392–396, 2006. Available from: https://doi.org/10.1136/bjsm.2005.023150

[5] J. Landlinger, S. Lindinger, T. Stöggl, H. Wagner, and E. Müller, "Key factors and timing patterns in the tennis forehand of different skill levels," J. Sports Sci. Med., vol. 9, no. 4, pp. 643–651, 2010.

Available from: https://pmc.ncbi.nlm.nih.gov/articles/PMC3761808

[6] J. Landlinger, S. J. Lindinger, T. Stöggl, H. Wagner, and E. Müller, "Kinematic differences of elite and high-performance tennis players in the cross court and down the line forehand," Sports Biomech., vol. 9, no. 4, pp. 280–295, 2010. Available from: https://doi.org/10.1080/14763141.2010.535841

[7] B. Elliott, K. Takahashi, and G. Noffal, "The influence of grip position on upper limb contributions to racket head velocity in a tennis forehand," J. Appl. Biomech., vol. 13, no. 2, pp. 182–196, 1997. Available from: https://doi.org/10.1123/jab.13.2.182

[8] K. Takahashi, B. Elliott, and G. Noffal, "The role of upper limb segment rotations in the development of spin in the tennis forehand," Aust. J. Sci. Med. Sport, vol. 28, no. 4, pp. 106–113, 1996. Available from: https://pubmed.ncbi.nlm.nih.gov/9040900/

[9] I. Rogowski, D. Rouffet, F. Lambalot, O. Brosseau, and C. Hautier, "Trunk and upper limb muscle activation during flat and topspin forehand drives in young tennis players," J. Appl. Biomech., vol. 27, no. 1, pp. 15–21, 2011.
Available from: https://doi.org/10.1123/jab.27.1.15

[10] D. V. Knudson and J. Blackwell, "Variability of impact kinematics and margin for error in the tennis forehand of advanced players," Sports Eng., vol. 8, no. 2, pp. 75–80, 2005.
Available from: https://doi.org/10.1007/BF02844005

[11] A. D. Vigotsky, I. Halperin, G. J. Lehman, G. S. Trajano, and T. M. Vieira, "Interpreting signal amplitudes in surface electromyography studies in sport and rehabilitation sciences," Front. Physiol., vol. 8, art. 985, 2018. Available from: https://doi.org/10.3389/fphys.2017.00985

[12] R. E. Bahamonde and D. Knudson, "Kinetics of the upper extremity in the open and square stance tennis forehand," J. Sci. Med. Sport, vol. 6, no. 1, pp. 88–101, 2003.
Available from: https://doi.org/10.1016/S1440-2440(03)80012-9

[13] Y. Kawamoto, Y. Iino, S. Yoshioka, and S. Fukashiro, "Directionally compensated mechanical work provided by the shoulder leads to similar racket velocities during open and square stance forehand groundstrokes in tennis," Eur. J. Sport Sci., vol. 19, no. 7, pp. 902–912, 2019.
Available from: https://doi.org/10.1080/17461391.2018.1552720

[14] E. P. Roetert, M. S. Kovacs, D. Knudson, and J. L. Groppel, "Biomechanics of the tennis groundstrokes: Implications for strength training," Strength Cond. J., vol. 31, no. 4, pp. 41–49, 2009. Available from: https://doi.org/10.1519/SSC.0b013e3181aff0c3

[15] D. Knudson and B. Elliott, "Biomechanics of tennis strokes," in Biomedical Engineering Principles in Sports, G. K. Hung and J. M. Pallis, Eds. New York, NY, USA: Kluwer Academic Publishers, pp. 153–182, 2004. Available from: https://doi.org/10.1007/978-1-4419-8887-4_7