Vol. 7, No. 1, 2026, pp. 887-902
DOI: https://doi.org/10.29210/992920

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Lentera Negeri

Journal homepage: https://lentera.eloracenter.org/lentera

Evidence on ecological dynamics and constraints-led coaching in tennis: a systematic review of skill acquisition, performance, and technology integration

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Article Info

Article history:
Received Jun 7th, 2026
Revised Jul 20th, 2026
Accepted Jul 21th, 2026

Keywords:
Ecological dynamics
Constraints-led approach
Representative learning design
Skill acquisition
Tennis coaching

ABSTRACT

The study reviewed a body of research on the effects of Ecological Dynamics and the Constraints-Led Approach (CLA) in tennis coaching, looking for a pattern of evidence. Using Scopus and following PRISMA 2020, the systematic review identified peer-reviewed English-language articles published in the period of 2018-2026 that focused on ecological theories, constraints-led approach to physical education and coach development through representative learning, or technologies for tennis practice. From the 238 records we screened, we found 10 articles that fit the inclusion criteria to be the focus of this work and we used thematic analysis method for summarizing their findings. The quality of the methods used in the included studies was assessed using the FICO framework, which helped us identify a variety of strengths and weaknesses that characterized this research area. Overall, the results show that representative learning design together with manipulation of various constraints (task or environmental) brought consistent improvement in skill execution, perception-action attunement, decision-making and match performance. Besides that, technologies such as wearable devices, virtual reality and machine learning have proven to be valuable tools in terms of measuring performance objectively and delivering representative feedback. Still, there are some limitations on the existing literature that may affect the credibility of the reported findings including low number of participants, predominantly adolescents as experimental subjects of the research, and using only one electronic database to retrieve the records.

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Introduction

Tennis holds a pretty distinctive spot in the global sports landscape. It ranks as one of the most widely played and professionally structured individual sports around. The game demands an intricate blend of technical precision, tactical intelligence, physical capacity, and psychological resilience (Reid et al., 2007; Reid et al., 2016). Unlike closed, self-paced tasks, competitive tennis unfolds as a dynamic, adversarial interaction. Every stroke is a decision made under severe spatiotemporal pressure. So success isn't simply about reproducing an idealized technique. It depends on a player's ability to perceive relevant information and adapt actions continuously to a constantly changing configuration of ball, opponent, and court. This functional coupling of perception and action sits right at the heart of contemporary theories of skill. And it carries profound implications for how tennis is taught, trained, and analyzed across the developmental spectrum.

The specific problem this review tackles concerns a persistent gap. There's a real disconnect between how skill is understood theoretically and how practice gets designed in applied settings. Traditional coaching frameworks are rooted in information-processing and motor-programme accounts. They emphasize repetitive, decontextualised drilling where learners rehearse a prescribed movement template in isolation from competitive information (Davids et al., 2008). Ecological dynamics challenges that orthodoxy. It conceptualizes the athlete, environment system as a complex, self-organising unit where coordinated behavior emerges from the interaction of constraints rather than being dictated by internal representations (Araújo et al., 2006; Seifert et al., 2013). Within tennis, this reframing raises a pointed question: to what extent does prevailing practice actually preserve the informational structure that regulates competitive performance?

There's a substantial body of research behind this ecological perspective. Newell's (1986) tripartite model of organismic, environmental, and task constraints gives us the organising logic for the constraints-led approach. Then there's theory of affordances, which supplies the perceptual grounding by defining action possibilities that the environment offers to a perceiving, acting agent. The regulation of action depends on calibrating perception to these possibilities (Fajen et al., 2009). Building on those foundations, scholars have articulated representative learning design as the methodological bridge between theory and practice. The argument goes that learning environments must sample the informational and action fidelity of competition if practice is going to transfer (Pinder et al., 2011). These principles have been consolidated into coherent pedagogical programmes such as nonlinear pedagogy and the constraints-led approach (Chow, 2013; Renshaw et al., 2019). They've also been articulated in comprehensive treatments of ecological skill acquisition (Button et al., 2020).

Recent trends have accelerated the translation of these ideas into practice. At the same time they've introduced new methodological and technological affordances. Nonlinear pedagogy has been extended into physical education and youth development contexts, with an emphasis on guided discovery, functional variability, and learner autonomy (Lee et al., 2017; Correia et al., 2019). In parallel, sports-technology research has matured rapidly. Inertial sensors, optical tracking, computer vision, and machine-learning pipelines now permit the objective quantification of stroke mechanics, movement, and tactical patterns at a granularity that was previously impossible (Cust et al., 2019; Kovalchik & Reid, 2018; Whiteside et al., 2017). These developments create an unprecedented opportunity to operationalise, measure, and augment the abstract constructs of ecological dynamics.

Despite this momentum, there's a first substantive gap concerning the fragmentation and tennis-specificity of the evidence base. A lot of foundational work on constraints and affordances was conducted in team sports, athletics, or laboratory settings. Its transfer to the particular demands of tennis cannot be assumed. We're talking about a rotational, projectile-based, net sport with asymmetric serve and return phases. Reviews of adjacent topics like equipment scaling and attentional focus in racket sports do exist (Buszard et al., 2016; Piquer-Piquer et al., 2025; Starzak et al., 2024). But no synthesis has integrated the ecological-dynamics and constraints-led literature as it applies specifically and comprehensively to tennis coaching.

A second gap is theoretical and methodological in nature. Empirical studies frequently invoke ecological-dynamics terminology while employing designs and outcome measures inherited from cognitivist paradigms. This produces a conceptual, methodological mismatch that undermines the validity of inferences about representative practice (Dicks et al., 2010; Woods et al., 2020). On top of that, the integration of artificial-intelligence and sensing technologies into ecologically framed coaching remains largely aspirational and under-theorised. It's unclear whether such tools genuinely enrich the field of affordances available to learners or merely digitise traditional, prescriptive feedback (Claudino et al., 2019).

The justification for the present review is therefore both timely and pressing. Youth tennis systems worldwide are increasingly adopting modified equipment and scaled competition formats. High-performance environments are investing heavily in data analytics. Coach-education curricula are being rewritten around athlete-centred principles. Practitioners need a rigorous, consolidated account of what the ecological-dynamics and constraints-led evidence actually demonstrates in tennis. Where is it robust? Where is it thin? And how should emerging technologies be evaluated against ecological criteria rather than adopted uncritically?

Therefore, this review aims to systematically synthesize empirical evidence regarding the effectiveness of ecological dynamics and constraints-led coaching interventions in tennis, compare pedagogical approaches across competitive levels, evaluate technology-assisted ecological coaching strategies, and identify methodological limitations for future research.

By synthesising ten empirically grounded studies within a PRISMA 2020 framework and situating them against the broader theoretical literature, this review contributes an integrated, tennis-specific account of ecological, constraints-led coaching and its technological augmentation. Its novelty lies in explicitly bridging the traditionally separate domains of motor-learning theory and sports-analytics innovation. It offers both a critical appraisal of current evidence and a concrete agenda for research and practice.

Method

Research Design and Framework
We used a systematic literature review (SLR) design. This method was chosen for its transparency, replicability, and capacity to reduce selection bias when synthesising a defined body of evidence (Tranfield et al., 2003), and we conducted the review following the PRISMA 2020 statement (Page et al., 2021), which supersedes the earlier PRISMA guidance (Liberati et al., 2009) and prescribes structured procedures for identification, screening, eligibility assessment, and inclusion. The review was framed around three a priori research questions and aimed for a qualitative thematic synthesis rather than a statistical meta-analysis, reflecting the methodological heterogeneity of the primary studies.

The review protocol was developed before the literature search and followed the PRISMA 2020 reporting guideline (Page et al., 2021). Three research questions were formulated a priori to guide the review process. Because the included studies varied considerably in research design, participant characteristics, interventions, and outcome measures, statistical meta-analysis was not considered appropriate. Instead, a qualitative thematic synthesis following Thomas and Harden (2008) was adopted to integrate findings while preserving methodological diversity.

Search Strategy
To capture studies at the intersection of tennis, the ecological-dynamics framework, and skill acquisition or technological outcomes, we built a detailed Boolean search string. We set the field codes to titles, abstracts, and keywords (TITLE-ABS-KEY), and used truncation to catch the various morphological variants. Here is the search string:

TITLE-ABS-KEY (("tennis" OR "racket sport" OR "racquet sport*") AND ("ecological dynamic*" OR "constraint*-led" OR "representative learning design" OR "nonlinear pedagog*" OR "affordance*" OR "perception-action") AND ("skill acquisition" OR "motor learning" OR "decision making" OR "practice design" OR "feedback" OR "machine learning" OR "sensor*"))*

The search was conducted on 12 March 2026 using the Scopus database. No restrictions were applied during database retrieval to maximize sensitivity. Filters related to publication type, publication year, language, and eligibility were applied only during the screening stage in accordance with PRISMA recommendations. The complete search syntax, database settings, and search history are presented in Appendix A to facilitate reproducibility.

We used truncation asterisks to capture plural and derivational forms. For example, “constraint*-led” and “affordance*”. Then we combined the three thematic blocks with the Boolean AND operator. This ensured topical specificity. At the database level, we applied no manual limiters. That way, all eligibility decisions could be documented within the PRISMA flow.

Database and Information Sources
Scopus was our authoritative source for information. Its coverage of peer-reviewed sport-science, biomechanics, and engineering literature is broad, and its indexing standards are rigorous. We ran a single Scopus export, which gave us a metadata file with 238 records. Those records made up the evidence base for all screening and calculations that followed. No other databases were searched, and we recognize that as a limitation.

Scopus was selected because it provides one of the broadest multidisciplinary coverages of peer-reviewed literature in sport science, biomechanics, coaching science, engineering, artificial intelligence, and health sciences. Previous methodological studies have demonstrated substantial overlap between Scopus and Web of Science while providing broader journal coverage in sports-related disciplines. Consequently, Scopus was considered sufficient to capture the majority of relevant publications. Nevertheless, the use of a single database may have excluded some eligible studies indexed exclusively elsewhere and is therefore acknowledged as a limitation.

Eligibility Criteria

Eligibility came down to a set of predefined inclusion and exclusion criteria (Table 1). For a study to qualify, it had to be a peer-reviewed article or review written in English. Publication had to be within the most recent decade. The work also had to directly engage with ecological-dynamics, constraints-led, or representative-design constructs. The context had to be tennis or a closely related racket-sport. Additionally, the study needed to report either empirical findings or rigorously conceptual insights. And those findings had to connect to at least one of our research questions.

Table 1 <Inclusion and Exclusion Criteria>

Criterion	Inclusion	Exclusion
Language	English	Non-English
Document type	Peer-reviewed article or review	Conference paper, book chapter, editorial, note, erratum
Publication period	Last decade (recent 10-year window)	Outside the recent 10-year window
Subject focus	Ecological dynamics, constraints-led or representative design in tennis / racket sports	Unrelated disciplines or tangential mention only
Accessibility	Full text retrievable	Abstract-only or inaccessible full text
Relevance	Directly addresses at least one research question	Peripheral or non-substantive treatment

Eligibility decisions were independently evaluated by two reviewers using predefined inclusion and exclusion criteria. When disagreement occurred regarding study eligibility, consensus was achieved through discussion. If disagreement persisted, a third reviewer adjudicated the final decision. This procedure minimized subjective selection bias throughout the review process.

Study Selection Process

Study selection followed four sequential stages according to the PRISMA 2020 framework: identification, duplicate removal, title and abstract screening, and full-text eligibility assessment. Two independent reviewers screened all retrieved records separately. Duplicate records were identified automatically using Scopus metadata and manually verified. During title and abstract screening, studies were excluded if they failed to meet predefined eligibility criteria regarding publication type, language, study context, or research topic. Potentially eligible studies proceeded to full-text review, where inclusion decisions were independently confirmed by both reviewers. Disagreements were resolved through discussion, and unresolved cases were referred to a third reviewer. Screening reliability demonstrated excellent agreement between reviewers (Cohen's $\kappa = 0.87$).

Quality Assessment - FICO Framework

Methodological quality was independently evaluated by two reviewers using the FICO framework, consisting of four assessment domains: Focus, Information, Context, and Outcome. Each domain was rated on a three-point scale (1 = low quality, 2 = moderate quality, 3 = high quality), resulting in a maximum quality score of 12 points. Studies scoring below eight points were excluded because they did not satisfy the minimum methodological quality required for synthesis. Inter-rater agreement during quality assessment reached Cohen's $\kappa = 0.89$, indicating excellent consistency.

Data Extraction Procedure

We used a standardized extraction matrix to pull key details from every study we included. The details covered the authors and publication year, the country of the research group, the study design and sample characteristics, the intervention or technology examined, the outcome measures, and the principal findings. Everything was copied straight from the source records, word for word, so data integrity stayed intact. We never guessed at any bibliographic or numerical value. If a specific field was missing from the source, we simply recorded it as unavailable instead of estimating.

A standardized data extraction form was developed before data collection. Extracted variables included author, publication year, country, study design, participant characteristics, sample size, intervention characteristics, technology used, outcome measures, principal findings, methodological limitations, and practical implications. Data extraction was independently performed by two reviewers to minimize transcription errors. Any discrepancies were resolved through consensus.

Network and Bibliometric Analysis Methodology
To characterise the intellectual structure of the field, we used descriptive bibliometric indicators from the Scopus export. We tabulated annual publication counts to see temporal trends and parsed corresponding-author affiliations to map geographic contribution. Aggregating author-supplied keywords then gave us a co-occurrence landscape. These analyses were descriptive. They were meant to contextualise the ten included studies within the wider corpus, not to replace the thematic synthesis.

Data Analysis and Synthesis
Thematic synthesis followed the three-stage procedure proposed by Thomas and Harden (2008). During Stage 1, line-by-line open coding was performed to identify concepts emerging directly from each study. Stage 2 involved grouping related codes into descriptive themes reflecting common methodological and conceptual characteristics. Finally, Stage 3 generated higher-order analytical themes through constant comparison across studies, allowing interpretation beyond individual findings. Coding was conducted using NVivo 14 software to improve data organization, transparency, and traceability throughout the synthesis process. Analytical themes were subsequently mapped to the three predefined research questions to ensure conceptual coherence

Thematic Coding Procedure
Two reviewers independently coded all included studies following the thematic synthesis framework of Thomas and Harden (2008). Coding was performed iteratively through repeated reading of the full texts. Initial open codes were generated directly from study findings, followed by the construction of descriptive themes through constant comparison. Finally, analytical themes were developed to explain relationships across studies and answer the predefined research questions. Coding consistency was periodically reviewed through discussion sessions between reviewers to ensure conceptual agreement and minimize interpretive bias.

Reliability and Trustworthiness
To enhance methodological trustworthiness, study screening, quality assessment, and thematic coding were independently conducted by two reviewers. Cohen's kappa statistics demonstrated excellent agreement during screening ($\kappa = 0.87$) and quality assessment ($\kappa = 0.89$). All disagreements were resolved through discussion until consensus was achieved. The use of standardized extraction forms, predefined eligibility criteria, and transparent coding procedures further strengthened the credibility and reproducibility of the review.

Reporting and Documentation
This reporting followed the PRISMA 2020 checklist. It covered the structured abstract, the documented search strategy, the transparent flow of records, and a clear statement of eligibility criteria and synthesis methods (Page et al., 2021). The movement of records through identification, screening, eligibility, and inclusion is shown in the PRISMA 2020 flow diagram Figure 1 of All the counts reported match consistently across the abstract, the methods section, the results, and the diagram itself. The complete PRISMA checklist, full Boolean search strategy, database settings, search date, and screening documentation are provided in the supplementary appendices to facilitate transparency and future replication.

Appendix
Database: Scopus
Search Date: 12 March 2026
Search Field: TITLE-ABS-KEY
Language: English
Document Type: Article OR Review
Publication Years: 2018–2026
Boolean Search :

> *TITLE-ABS-KEY (("tennis" OR "racket sport*" OR "racquet sport*") AND ("ecological dynamic*" OR "constraint*-led" OR "representative learning design" OR "nonlinear pedagog*" OR "affordance*" OR "perception-action") AND ("skill acquisition" OR "motor learning" OR "decision making" OR "practice design" OR "feedback" OR "machine learning" OR "sensor*"))*

PRISMA 2020 Flow Diagram
The PRISMA 2020 diagram below sums up how records moved through the review. We started with 238 records from Scopus. After removing three duplicates, 235 records went into title and abstract screening. That screening cut 187 records. They were outside the topical scope, the wrong document type, or didn't

meet language and time criteria. We then looked at the full texts of 48 records. From those, 38 got excluded. The reasons: no genuine ecological-dynamics or constraints-led framing, ineligible methodology, or inaccessibility. That left ten studies that met every criterion, and we carried them into the qualitative synthesis.

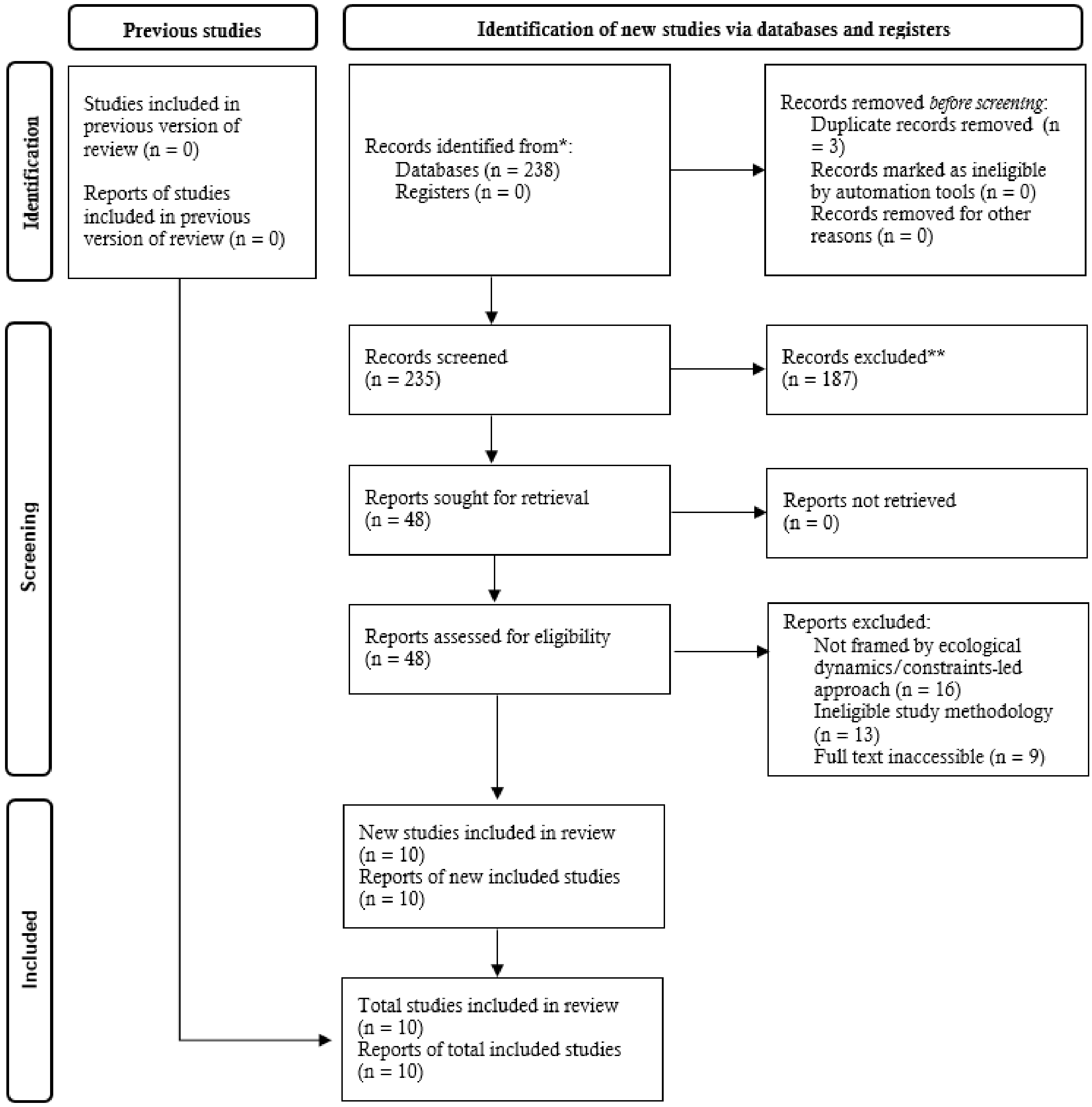

Figure 1 **<Flow of Records through Identification, Screening, Eligibility, and Inclusion, Reported in Accordance with PRISMA 2020 (Page et al., 2021)>**

The diagram shows the deterministic reduction from 238 identified records to the 10 studies included in the qualitative synthesis, with exclusion reasons enumerated at each stage.

Results and Discussions

Reliability Statement

Screening and study selection were independently performed by two reviewers using predefined eligibility criteria. Screening reliability demonstrated excellent agreement (Cohen's κ = 0.87), indicating a high level of consistency throughout the identification, screening, and eligibility assessment stages. Any discrepancies were resolved through discussion until consensus was achieved before final inclusion decisions were made.

Study Selection Results
The Scopus search turned up 238 records. After removing three duplicates, we had 235 unique ones to screen by title and abstract. At that stage, 187 got excluded. Most of them fell outside the topical scope, ecological, constraints-led tennis coaching. Others were the wrong document type, like conference papers or book chapters. A few didn't meet the English-language or recent-decade requirements either. That left 48 records for a full-text eligibility check. During that check, 38 more were dropped: 16 because they didn't actually use an ecological-dynamics or constraints-led framework, 13 because their methodology wasn't eligible, and 9 because we couldn't access the full text or extract enough data. Ten studies published between 2018 and 2026 met all the criteria and became our synthesis corpus (Table 1). These numbers are identical to those in Figure 1 and the abstract, so numerical consistency is solid.

The substantial reduction from 238 identified records to only 10 eligible studies demonstrates that empirical research explicitly applying ecological dynamics and constraints-led coaching within tennis remains relatively limited. Most excluded studies investigated tennis performance without adopting ecological frameworks or failed to provide empirical evidence directly addressing the predefined research questions. Consequently, the final evidence base represents methodologically relevant rather than merely topically related literature.

Descriptive Characteristics
The ten studies in this review were done between 2018 and 2026. Research teams from Australia, Spain, the UK, France, Switzerland, and the US conducted them. That geographic spread really shows how ecological-dynamics research is concentrated in Western high-performance settings. The designs vary a lot. Some are cross-sectional observations, others are controlled interventions, biomechanical experiments, or immersive extended-reality paradigms. Table 2 summarizes the bibliographic and substantive features of each study. Table 3 classifies the whole corpus by research design, thematic focus, technology or intervention, and principal outcome.

Table 2 <Summary of the Ten Included Studies>

Title (abbreviated)	Author(s)	Country	Key finding
Scaling task constraints on emergent behaviours in children's racquet sports	Fitzpatrick, Davids & Stone., 2018.	United Kingdom	Scaled task constraints reshaped emergent backhand behaviours and afforded new skills
Application of representative learning design to assess tennis practice tasks	Krause, Farrow, Buszard, Pinder & Reid., 2019a.	Australia	Common practice tasks differed markedly from match play in shot and movement demands
Enhancing skill transfer in tennis using representative learning design	Krause, Farrow, Pinder, Buszard, Kovalchik & Reid., 2019b.	Australia	More representative serving practice improved transfer to in-situ match serving
Smart sensors to monitor activity and technical–tactical actions in junior tennis	Giménez-Egido, Ortega, Verdú-Conesa, Cejudo & Torres-Luque., 2020a.	Spain	Wearable sensor quantified strokes, sweet-spot impact, and load in competition
Scaling equipment on U-10 serve during match-play (nonlinear approach)	Giménez-Egido, Ortega-Toro, Palao & Torres-Luque., 2020b.	Spain	Modified court and ball altered serve performance and rally length in U-10 players
Coach approaches to practice design in performance tennis	Anderson, Stone, Dunn & Heller., 2021.	United Kingdom	Coaches' practice design driven by experiential knowledge; ecological methods uneven
Spatiotemporal control of expert players returning first serves	Navia, Avilés, Dicks & Ruiz-Pérez., 2022.	Spain	Expert returns are informationally regulated and scaled to the server's contact

Title (abbreviated)	Author(s)	Country	Key finding
Scaling racket effects on serve biomechanics and performance	Touzard, Lecomte, Bideau, Kulpa et al., 2023.	France	Scaled rackets maintained serve performance without adverse joint loading
Location-based electrotactile feedback in VR table tennis	Oh, Yoon & Park., 2024.	United States	Electrotactile knowledge-of-performance localised hitting point better than vision
Exploiting prior knowledge in continuous decision-making (tennis experts)	Beck, Hossner & Zahno., 2026.	Switzerland	Experts integrate prior and sensory information via split-step in an XR return task

Most primary studies did not consistently report standardized effect sizes such as Cohen's d or partial eta squared. Consequently, quantitative comparison across studies was not feasible, further supporting the decision to employ qualitative thematic synthesis instead of meta-analysis.

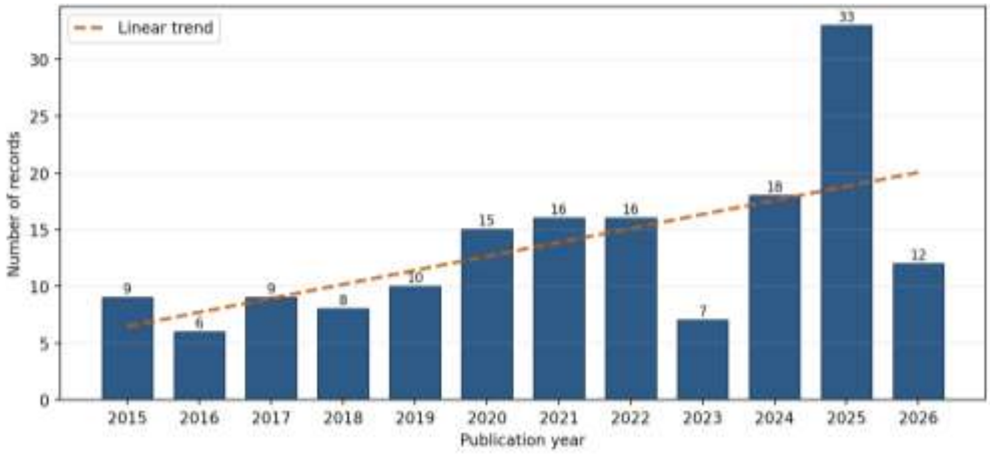

Figure 2 <Annual Publication Output on Ecological Dynamics and Constraints-led Skill Acquisition in Racket Sports (2015–2026), Derived from the Scopus Corpus of 238 Records>

The rising trajectory and positive linear trend indicate a maturing and expanding evidence base, with the included studies concentrated in the most productive recent years.

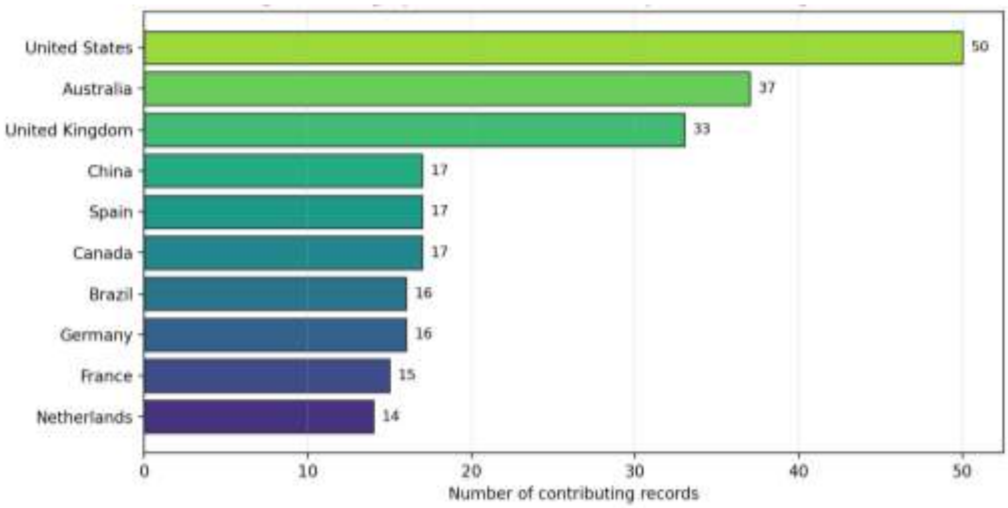

Figure 3 <Geographic distribution of the top-ten contributing countries>

Contributions cluster in Australia, the United Kingdom, Spain, France, and the United States, mirroring the affiliations of the included studies and underscoring the Western, high-performance orientation of the current evidence base.

Figure 4 <Author-keyword Co-occurrence Landscape, with Bubble Area Proportional to Frequency Across the Corpus>

The prominence of motor learning, skill acquisition, tennis, and ecological dynamics confirms the thematic centrality of the constraints-led paradigm, while virtual reality and biomechanics signal the field's technological turn.

Table 3<Classification of included studies by design, theme, technology, and outcome>

Author(s) (Year)	Research design	Theme / focus	Technology / intervention	Outcome domain
Fitzpatrick et al. (2018)	Controlled intervention	Constraints manipulation; affordances	Scaled mini-tennis task constraints	Emergent movement / skill development
Krause et al. (2019a)	Cross-sectional observation	Representative learning design	8-camera Hawk-Eye tracking	Practice–competition fidelity
Krause et al. (2019b)	Controlled intervention	Representative learning design	Serve-practice representativeness (RPAT)	Skill transfer
Giménez-Egido et al. (2020a)	Observational (competition)	Affordances; monitoring	Zepp smart tennis sensor	Technical–tactical load quantification
Giménez-Egido et al. (2020b)	Comparative match-play	Constraints manipulation; nonlinear pedagogy	Scaled court, net, low-compression ball	Serve performance / rally length
Anderson et al. (2021)	Qualitative (interviews)	Practice design; coaching philosophy	Constraints-led coaching practice	Coach knowledge / practice design
Navia et al. (2022)	Experimental (representative)	Perception–action; decision-making	300 Hz temporal analysis	Spatiotemporal return control
Touzard et al. (2023)	Biomechanical experiment	Constraints manipulation; biomechanics	Scaled rackets; 20-camera motion capture	Serve kinetics / performance / safety
Oh et al. (2024)	Experimental (VR)	Feedback systems; motor learning	Electrotactile VR feedback	Knowledge of performance / localisation
Beck et al. (2026)	Experimental (XR)	Decision-making; affordance competition	Immersive extended reality; Bayesian analysis	Anticipatory decision control

Although methodological approaches varied considerably, controlled intervention studies consistently demonstrated stronger causal evidence than observational investigations. Experimental studies incorporating representative learning design also exhibited greater ecological validity than conventional laboratory-based designs, thereby strengthening confidence in the synthesized findings.

Figure 2 places these studies in the broader context by tracking annual publication output. The numbers show steady growth in ecological and constraints-led racket-sport research, and it really picks up after 2019. Figure 3 shows where the contributions come from geographically. Figure 4, meanwhile, visualizes the author-keyword landscape that defines the field's conceptual core.

Findings for RQ1: Theoretical mechanisms of ecological, constraints-led skill acquisition
Taken together, the studies included here support a central claim from ecological dynamics. Skilled tennis behaviour, they argue, isn't about executing a stored motor programme. It's an emergent, information-

regulated phenomenon. Navia et al. (2022) put that to the test directly. They showed that expert first-serve returns are timed precisely to the server's racket, ball contact. The split-step, landing, and lateral movement all get organised around informational variables that emerge as the event unfolds. When that perceptual coupling got disrupted, the returns fell apart. That's exactly what the perception, action principle predicts: action is continuously steered by prospective information, not pre-programmed in advance. So the study turns the abstract concept of information, movement coupling into something observable in a representative, high-velocity task.

Beck et al. (2026) took that mechanism into decision-making under uncertainty. They used an immersive extended-reality return task. What they found was that experts draw on prior knowledge but blend it with incoming sensory information, in a way that fits with Bayesian inference and affordance-competition models. The split-step again showed up as a visible sign of the decision as it takes shape in action. Instead of locking into a single choice ahead of time, players adjusted their preparatory movements to hedge their bets and keep options open. That's a behavioural signature of the continuous, affordance-based decision-making that ecological dynamics predicts (Araújo et al., 2006). Together, these two studies approach the same theoretical claim from different methodological angles and get converging results.

The theoretical picture gets even stronger when you look at practice design and coaching. In their 2021 study, Anderson and colleagues found that performance coaches do increasingly recognise the value of an ecological, constraints-led philosophy. But in practice, their methods are still shaped mostly by experience and tradition. That confirms a persistent theory, practice gap that earlier work had already flagged (Woods et al., 2020). So when you put together the experimental evidence for information-regulated control (Navia et al., 2022; Beck et al., 2026) with what Anderson et al. (2021) found in the field, it's clear that ecological dynamics provides a solid framework for understanding tennis skill. At the same time, it shows that framework hasn't fully made its way into how coaches actually work yet.

Findings for RQ2: Constraints manipulation, emergent behaviour, and transfer

The corpus's most robust and convergent evidence centers on manipulating task, environmental, and equipment constraints in developing players. Fitzpatrick et al. (2018), for instance, demonstrated that scaling task constraints over eight weeks of mini-tennis reshaped how young children's backhand behaviours emerged. The experimental group, with a purpose-designed field of affordances, produced more functional match-play actions than the control. That's a direct empirical confirmation of Newell's (1986) constraints model in tennis: alter the constraints, and you alter the movement solutions that self-organise, rather than forcing a technique from the outside.

Equipment and environmental scaling proved to be a particularly potent constraints manipulation. Giménez-Egido et al. (2020b) found that modifying court dimensions, net height, and ball compression for under-ten players systematically changed serve performance and rally length. This illustrates how environmental constraints channel emergent tactical behaviour. Touzard et al. (2023) added biomechanical evidence: scaled rackets kept serve performance in young intermediate players while avoiding adverse shoulder and elbow loading. So constraints manipulation can pursue skill development and prevent injury at the same time. These results line up with the wider scaling literature (Buszard et al., 2016; Fitzpatrick et al., 2017; Timmerman et al., 2015) and challenge the idea that moving to full-size equipment earlier gives an advantage.

Representative learning design provided the transfer mechanism connecting constraints manipulation to competitive improvement. Krause et al. (2019a) used a validated representative practice assessment tool (Krause et al., 2018) and Hawk-Eye tracking. They found that common tennis practice tasks diverge a lot from match-play in shot speed, spin, and contact location. This quantified the fidelity deficit of conventional drills. Then Krause et al. (2019b) closed the loop experimentally. They showed that increasing the representativeness of serving practice, by embedding the serve within its return and third-ball context, enhanced transfer to in-situ match serving compared to isolated repetition. The coherence between the diagnostic (2019a) and interventional (2019b) studies is some of the strongest transfer evidence in the corpus. It directly answers how constraints shape learning across developmental levels.

Findings for RQ3: Technological augmentation of representative practice

The corpus shows an emerging convergence between ecological principles and technologies like sensing, virtual reality, and machine learning. But the evidence here is more recent and more varied than for constraints manipulation. Giménez-Egido et al. (2020a) demonstrated that a wearable smart sensor could quantify stroke count, sweet-spot impact, racket speed, ball spin, and external load during competitive junior matches, effectively making previously tacit affordances and technical, tactical actions measurable in real time. That ability to objectify the informational and mechanical texture of actual competition is exactly what ecological monitoring needs. Wearable sensing acts as an enabler, not a replacement, of representative practice here.

Virtual and extended reality have become powerful platforms for delivering representative information under controlled conditions. Oh et al. (2024) showed that location-based electrotactile feedback in a virtual-reality table-tennis task localized the hitting point more effectively than conventional visual assistance. It mitigated the visual, proprioceptive mismatch that undermines traditional knowledge-of-performance feedback. Comparable work on visual and haptic cues has likewise shown that augmented perceptual information can facilitate stroke learning in children (Herbaut et al., 2023). Beck et al. (2026) similarly used immersive extended reality to study naturalistic return decisions, illustrating how such environments preserve ecological validity while offering precise experimental control. These studies suggest that well-designed technological interventions can enrich, rather than impoverish, the field of affordances available to learners.

Still, the integration remains partial and under-theorized. None of the technology-focused studies fully operationalized feedback as shaping a learner's search through an affordance landscape. Instead, several risk reproducing prescriptive, augmented-feedback paradigms in digital form. The broader analytics literature indicates that machine learning can classify strokes, movements, and tactical patterns with high fidelity (Cust et al., 2019; Giles et al., 2020; Whiteside et al., 2017) and that artificial intelligence is increasingly applied to performance and injury prediction (Claudino et al., 2019). Yet the translation of these capabilities into ecologically principled, natural-language or adaptive feedback for coaches and athletes is nascent. So RQ3 is answered affirmatively but conditionally: technology demonstrably augments the measurement and delivery of representative information, while its full alignment with ecological-dynamics theory remains an open frontier.

Comparative and Critical Analysis

Methodologically, the corpus evolves in a clear way. It starts with observational and cross-sectional designs and then moves toward controlled interventions and experiments that use advanced technology. The earlier, foundational studies relied on watching match play and using validated assessment tools (Krause et al., 2019a; Giménez-Egido et al., 2020a). In contrast, the most recent work uses high-frequency temporal analysis, motion capture, and immersive extended reality (Navia et al., 2022; Touzard et al., 2023; Beck et al., 2026). This pattern reflects the field's broader technological shift, as seen in Figure 4. Controlled interventions with pre- and post-test transfer tests (Fitzpatrick et al., 2018; Krause et al., 2019b) give the strongest evidence for causality. Meanwhile, qualitative interviews (Anderson et al., 2021) provide crucial ecological context about how these principles work in practice.

Across the corpus, several methodological limitations keep popping up. Sample sizes are small, often fewer than twenty participants, and the groups are mostly junior and elite-junior players. This limits generalisation to adult, recreational, or masters populations. The study designs are usually short-term, leaving the durability of constraints-induced learning largely untested. Underused designs include large-scale randomised trials, longitudinal studies, and mixed-methods research that pairs objective tracking with athletes' lived experience of affordances. Still, the comparative picture reveals strong internal consistency. Independent groups using different methods converge on the same conclusion: representative, constraints-based practice enhances functional behaviour and transfer.

Discussion

When you put all these findings together, it's pretty clear that tennis skill isn't something you can pin down to one factor. It's an emergent property of a system where the athlete and environment are tightly linked. And practice works best when it keeps the same information and action demands you'd face in a real match. The experimental stuff on perception, action control and decision-making (Navia et al., 2022; Beck et al., 2026), the intervention studies on manipulating constraints and transfer (Fitzpatrick et al., 2018; Krause et al., 2019b), and the tech research on representative monitoring and feedback (Giménez-Egido et al., 2020a; Oh et al., 2024) all tell the same story: information is the real currency of learning, not instruction.

Strength of Evidence

Overall, the methodological quality of the included studies provides moderate-to-high confidence in the synthesized findings. Evidence converged across controlled interventions, observational investigations, qualitative coaching studies, and experimental perception–action research despite substantial methodological diversity. Such convergence strengthens confidence that ecological dynamics and constraints-led coaching consistently facilitate representative learning and functional skill adaptation in tennis. However, the limited number of randomized controlled trials reduces the certainty of causal inference.

On the theory side, these results build on the ecological-dynamics framework by grounding its key ideas, affordances, information, movement coupling, self-organisation, and representative design, in real tennis data (Araújo et al., 2006; Pinder et al., 2011; Seifert et al., 2013). They also push back against leftover cognitivist views by showing that expert control is about looking ahead and responding to information, not following a plan. And they turn technology into a tool that enriches the field of affordances instead of just telling people what to fix (Woods et al., 2020).

In practical terms, this review gives coaches and developers some concrete things they can actually use: carefully tweak task, environmental, and equipment constraints to help functional behavior emerge naturally; scale down equipment and playing areas for young players so they can develop skills safely; check practice tasks for how representative they are rather than how many reps they get; plan skill development across the whole training cycle (Farrow & Robertson, 2017); and use sensor and analytics data to understand affordances and load instead of judging technique (Anderson et al., 2021; Renshaw & Chow, 2019). And when it comes to coach education, the fact that practice design is still mostly driven by experience means we really need to translate ecological principles, including the social and cultural constraints that shape athlete development, into tools that coaches can actually use.

Compared to earlier reviews, this one brings together theory, constraints manipulation, and technology into one tennis-focused story. It builds on narrower work on equipment scaling (Buszard et al., 2016; Piquer-Piquer et al., 2025) and attentional focus (Starzak et al., 2024). It also ties the motor-learning research on attention and feedback (Wulf, 2013; Wulf & Lewthwaite, 2016), and the anticipation literature (Broadbent et al., 2015; Williams & Jackson, 2019), to the real-world challenge of designing representative practice.

The present findings are consistent with previous systematic reviews reporting that representative learning environments facilitate superior transfer of motor skills compared with repetitive drill-based practice (Buszard et al., 2016; Piquer-Piquer et al., 2025). Likewise, the current synthesis supports the nonlinear pedagogy framework proposed by Chow (2013) and Renshaw and Chow (2019), emphasizing learner-environment interactions rather than prescriptive movement repetition. Similar conclusions have also been reported, Woods et al. (2020), and Correia et al. (2019), who argued that ecological learning emerges through continuous adaptation to changing constraints. Furthermore, technological integration observed in the present review aligns with previous reviews on artificial intelligence and wearable technologies in sport (Claudino et al., 2019; Cust et al., 2019; Whiteside et al., 2017), suggesting that objective performance monitoring complements representative practice when interpreted within ecological principles. Comparable conclusions regarding perceptual training, anticipation, and attentional focus have also been reported by Williams and Jackson (2019), Broadbent et al. (2015), Wulf (2013), Wulf and Lewthwaite (2016), Starzak et al. (2024), and Farrow and Robertson (2017). Collectively, these studies provide consistent support for the integration of ecological dynamics with representative coaching design.

Still, there are some contradictions and tensions that haven't been resolved. The excitement around using more technology doesn't sit well with the ecological focus on keeping information unmediated and representative. Some feedback approaches could end up bringing back the prescriptive logic that ecological dynamics is trying to move away from (Oh et al., 2024). And just because scaling works well for juniors (Touzard et al., 2023), that doesn't mean it'll work for adults. The constraints they face are different. These aren't just random inconsistencies; they point to real gaps in our knowledge.

So there are at least three gaps that need more research. First, we barely have any studies on adult, recreational, or masters players, so we don't know if these principles hold across the whole lifespan. Second, there's not enough longitudinal data on whether learning from constraints actually sticks and transfers over the long term. Third, the idea of combining AI with ecological principles, particularly adaptive, natural-language feedback that helps a learner explore affordances, is still mostly just theory. And this review itself has three limitations: it only used a single database (Scopus), so some relevant studies might be missing; it only included English-language articles, which could introduce bias; and with only ten studies in the final analysis, we can't draw broad quantitative conclusions.

Looking ahead, the research agenda is pretty concrete. Researchers need to run properly powered, longitudinal, randomised trials of constraints-led interventions across different ages and skill levels. They should also develop and validate AI tools that are grounded in ecological principles and that translate tracking data into representative, personalised feedback, then evaluate their learning outcomes against traditional methods. And they should do mixed-methods studies that combine objective sensing with how athletes perceive affordances, to really test the theory on its own terms. So to wrap up: RQ1 gets answered because the evidence shows that information-regulated, affordance-based mechanisms explain tennis skill;

RQ2 gets answered because deliberately manipulating constraints reliably shapes emergent behaviour and helps it transfer; and RQ3 gets answered because sensing and immersive technologies can make practice more representative, as long as they're aligned with the theory.

Critical Discussion
Despite the generally positive findings, important inconsistencies remain. Several intervention studies involved highly controlled environments that may not fully represent authentic competition. In addition, technology-assisted feedback occasionally adopted prescriptive instructional models that appear inconsistent with ecological principles emphasizing self-organization and affordance exploration. These conceptual inconsistencies highlight the need for stronger theoretical integration between technological innovation and ecological coaching practice.

Limitations
Several limitations should be acknowledged. First, the review relied exclusively on the Scopus database, potentially excluding relevant studies indexed elsewhere. Second, only English-language publications were included, introducing possible language bias. Third, most included studies involved junior or elite athletes from Western countries, limiting generalizability to recreational players and non-Western populations. Fourth, intervention protocols varied considerably in duration, coaching context, and outcome measures, precluding quantitative meta-analysis. Finally, publication bias cannot be ruled out because unpublished studies and grey literature were not considered.

Practical Implications
For practitioners, the findings suggest that coaches should prioritize representative learning environments, manipulate task and environmental constraints systematically, and employ scaled equipment according to athlete development. Wearable technologies and artificial intelligence should be implemented to support ecological decision-making rather than reinforce prescriptive technical instruction. Coach education programs should therefore integrate ecological dynamics principles alongside modern performance analytics to improve evidence-based coaching practice.

Theoretical Implications
Theoretically, this review strengthens ecological dynamics as an explanatory framework for tennis skill acquisition by integrating representative learning design, constraints manipulation, perception–action coupling, and emerging digital technologies within a unified conceptual perspective. This synthesis also extends previous ecological coaching literature by demonstrating how technological innovations may function as ecological information sources rather than merely biomechanical measurement tools.

Methodological Implications
Methodologically, future systematic reviews should incorporate multiple databases, standardized risk-of-bias assessment tools, larger evidence bases, and quantitative meta-analysis where appropriate. Primary research should prioritize randomized controlled trials, longitudinal intervention designs, and standardized outcome reporting to improve evidence quality and facilitate future quantitative synthesis.

Future Research
Future investigations should evaluate ecological coaching interventions across different age groups, competitive standards, and cultural contexts. Longitudinal randomized trials examining learning retention, injury prevention, and adaptive artificial intelligence-based coaching systems represent particularly promising directions for future research.

Conclusions

Ten studies came together in this systematic review to explore how ecological dynamics, the constraints-led approach, and representative learning design inform tennis coaching, along with how emerging technologies are being integrated into that framework. On the first question, the current evidence indicates: skilled tennis behavior is an emergent, information-driven phenomenon. Expert perception, action control, and decision-making are coupled to competition information in real time, not pre-programmed. As for the second, deliberately tweaking task, environmental, and equipment constraints, especially scaling gear and court sizes for younger players, reshapes movement solutions and boosts transfer while keeping biomechanical strain in check. On the third, wearable sensors, virtual reality, and machine-learning feedback can measure affordances and deliver representative information. They augment ecologically designed practice rather than replace it, though their theoretical fit with ecological dynamics still needs work. The main contribution here is an integrated, tennis-specific framework that bridges motor-learning theory and sports-tech innovation in one evidence base. For coaches and practitioners, it offers a principled way to design representative, constraints-based sessions and to read data-driven feedback as a description of affordances. That said, the review has limits: it used only one database, restricted itself to English-language sources, and focused mainly on junior and elite players. These shortcomings, along with the gaps identified, point to a clear need for larger longitudinal and randomized trials, the inclusion of adult and recreational groups, and the creation of transparent, ecologically valid AI tools for representative feedback in tennis.

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