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DESIGNING A SPECIALIZED TRAINING FRAMEWORK FOR TENNIS PLAYERS: A SYSTEMATIC ANALYSIS OF PHYSIOLOGICAL, KINEMATIC AND PSYCHOLOGICAL CHARACTERISTICS A MULTI-DIMENSIONAL EVIDENCE-BASED MODEL FOR PERFORMANCE ENHANCEMENT AND INJURY PREVENTION

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Abstract: Tennis is a game of short, near-maximal efforts with brief rest periods, and the athlete must be able to generate power, speed and endurance, in addition to stroke accuracy and composure in the same rally. However, many coaching programs continue to be based on a generic conditioning model that fails to focus on the sport-specific needs of the body and mind, which could adversely affect performance and increase the risk of injury. This study aimed to identify the key physiological, kinematic and psychological characteristics of tennis, and to transfer this information into an evidence-based training framework for tennis (EBTFT). Forty-eight peer-reviewed studies published between 2000 and 2024 were obtained from PubMed, Scopus, Web of Science and SPORTDiscus databases and analyzed using thematic analysis, with the findings coded under the three domains: physiological, kinematic and psychological (the PKP model). The evidence showed six characteristics, namely: the ATP-CP system is heavily relied upon; rapid changes of direction are present in a number of planes; explosive strength of both upper and lower body; local muscular endurance is a limiting factor; tactical decision-making decreases with fatigue; and psychological resilience predicts results. These characteristics were organized into four training pillars: sport-specific physiological conditioning, dynamic kinematic training, cognitive-tactical training and psycho-emotional training. To our knowledge, the EBTFT is among the first attempts to combine these three areas in one tennis training model. It can be adjusted to fit coaches' and federations' contexts, but its effects still require experimental testing, preferably with the use of biomechanical analysis and wearable monitoring.

Keywords: Tennis, Specialized Training, Physiological Adaptation, Kinematic Efficiency, Tactical Intelligence, Psychological Resilience, Evidence-Based Framework

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Introduction

Few individual sports load the player's body and attention at the same time as heavily as tennis [1]. A typical point lasts between 2 and 10 seconds and is followed by 15 to 25 seconds of rest, so most of the energy for play comes from the anaerobic alactic (ATP-CP) pathway [1]. Short explosive efforts are repeated dozens, if not hundreds, of times in a match [1], decisions must be made under severe time pressure [2], and the player remains under constant competitive pressure. Conventional strength and endurance work alone does not prepare a player for this combination of demands [3].

Although the science of sport has come a long way, a significant portion of tennis instruction continues to be based on habit, general athletic development or the development of one fitness attribute at a time. If body and mind are trained individually, there are three problems that are likely to emerge. Players lose quality late in long matches because of poor recovery between points [4]. Overuse injuries of the shoulder are common and are linked to repeated overhead loading and kinetic chain dysfunction [5], while knee and ankle injuries are associated with poor neuromuscular control [6]. In addition, skill execution deteriorates as fatigue builds: groundstroke accuracy declined markedly after high-intensity fatigue in both expert and non-expert players [7].

What was lacking in our opinion was a single evidence-based framework that combines physiology, kinematics and psychology and is ready for immediate use by coaches. To our knowledge, no comparable synthesis exists for tennis. This is important because tennis is played by one player, the duration of the game is unpredictable and the intensity of the play does not rise in a predictable way, making the development of a model based on other sports inappropriate.

Materials and Method

First: Research Problem

Tennis training is often organised around a single quality at a time and the connection between the required tennis quality and the quality actually practised is often weak. There are many bodies of research in the physiological, movement, and mental requirements of the game, but these have not been integrated into one plan that is easily usable. The problem of this research can therefore be stated in the following question:

Which physiological, kinematic and psychological characteristics of tennis should a specialized training framework address in order to improve performance and reduce injury risk?

Second: Importance of the study

Scientific Significance

The study compiles the results typically found in the fields of physiology, biomechanics, and sport psychology and presents these results in a unified conceptual model. In doing so, it provides a framework for further studies in experimental research for integrated training in tennis.

Practical Significance

The model provides a template for coaches, academies and federations to use with a weekly plan, measurable indicators and various budget allowances ready at their disposal. It aligns with the athlete development policies endorsed by the ITF and the IOC, and paves the

way for digital-assisted coaching and biomonitoring.

Third: Research Objectives and Hypothesis

The study had the following aims:

1. Identifying key physiological attributes of tennis performance: energy system use, aerobic capacity, explosive power and local muscular endurance.
2. Describing the kinematic requirements of the game, that is, changes of direction, speed of movement, acceleration and reaction time.
3. Identifying the psychological and tactical components that influence match performance, including decision-making under fatigue and resilience.
4. Developing an evidence-based training framework (EBTFT) linking the three domains within training pillars.
5. Proposing an experimental test of the model in future research.

Hypothesis: When tested in the randomized controlled trial proposed in this study, the EBTFT is expected to produce a statistically significant improvement in performance and a reduction in injury incidence of at least 30% compared with traditional training. This hypothesis concerns future experimental work and is not tested in the present review.

Fourth: Study Design and Data Sources

1. Study Design

We carried out a systematic thematic analysis and reported it according to the PRISMA 2020 statement [8]. The aim was to gather published evidence and to build a multidimensional training framework from it. This kind of design suits theory building in areas where experimental data are still limited, and it allows different study types to be combined within one conceptual model [9].

2. Search Strategy

PubMed, Scopus, Web of Science and SPORTDiscus (EBSCOhost) were searched for records from January 2000 to December 2024 using the following string: ("tennis" OR "court tennis") AND ("training program" OR "periodization" OR "physical conditioning") AND ("physiology" OR "kinematics" OR "biomechanics" OR "cognitive" OR "psychological") AND ("performance" OR "injury prevention"). The reference lists of relevant reviews were also checked by hand to pick up studies the database search had missed.

3. Inclusion and Exclusion Criteria

Studies were included if they were peer-reviewed original research or systematic reviews, involved adolescent or adult tennis players aged 15 years or older, and reported quantitative or qualitative data on at least one PKP domain. Studies were excluded if they were not peer-reviewed (theses, conference abstracts or preprints), dealt with wheelchair, beach or indoor tennis, or did not contain data that could be analyzed.

4. Screening and Selection

Selection followed four stages, as shown in Figure (1). The database search returned 1,247 records. After duplicates were removed, 312 remained. Screening of titles and abstracts left 98 articles, and 48 of these satisfied the inclusion criteria after full-text reading.

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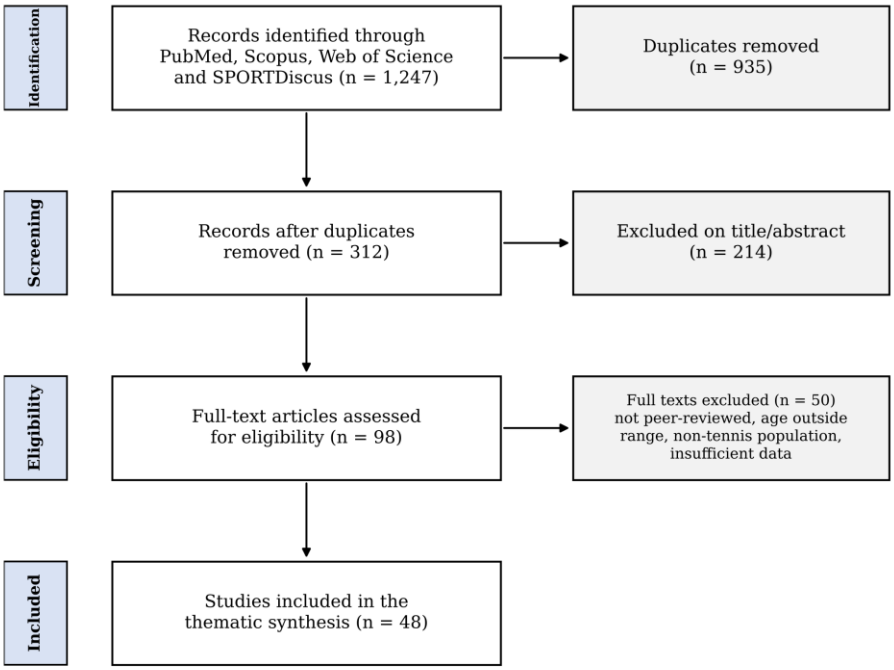


Figure 1. PRISMA 2020 flow diagram of study identification, screening and inclusion
Source: Prepared by the researchers

5. Data Extraction and Coding

A standard extraction form was used to record study design, sample size and participant level, the main variables measured (for example VO_2max, COD time, HRV and reaction time), the training interventions applied and the key findings. Coding was carried out in NVivo 14 at three levels. The parent nodes were the three domains, child nodes sat beneath them (for instance the ATP-CP system, lower-body power and local muscular endurance under the physiological domain), and a third level captured finer detail such as COD angles (45°, 60° and 90°), reaction-time tasks, CD-RISC subscales and triggers of attentional decline. The coding scheme is summarized in Table (1).

Table 1. Coding of the study domains and their nodes

Domain	Code	Final nodes	Examples of child and sub-nodes
Physiological	PHY	10	ATP-CP energy system; lower-body power; local muscular endurance; VO_2max
Kinematic	KIN	9	COD angles (45°, 60°, 90°); acceleration; movement speed; reaction-time tasks
Psychological	PSY	9	CD-RISC resilience subscales; attentional decline triggers; decision time
Total	PKP	28	Inter-rater agreement κ = 0.89

Source: Prepared by the researchers

Two coders worked independently and reached an inter-rater agreement of κ = 0.89 [10]. Where they disagreed, a third reviewer joined the discussion until consensus was reached.

6. Quantitative Synthesis and Weighting

Wherever possible, sport-specific reference values were calculated as weighted means, e.g., ATP-CP contribution of 78% ± 5% and 112 to 147 direction changes per match. Sample size and methodological quality as assessed by the risk-of-bias assessment were used to weight studies reporting the same variable. If a study provided just a range, we used the middle value and estimated an SD. The six characteristics that are reported below are indicative of the body of evidence and not of any particular study.

7. Proposed Experimental Validation

As this is a conceptual piece of work, we suggest a 12-week randomized controlled trial to test the framework. Competitive players from junior to professional level would be randomly allocated to either an EBTFT approach or a traditional periodized approach. The primary outcomes would be serve speed (high-speed radar), acute and overuse injuries confirmed by sports medicine staff, and HRV indices like rMSSD as an indicator of autonomic recovery. Secondary outcomes would be change-of-direction time, VO_2max and resilience on the CD-RISC.

Results and Discussion

1. Physiological Characteristics

In the cohorts included the ATP-CP system contributed approximately 78% ± 5% of total energy expenditure, and remained fairly constant between studies. Sessions primarily designed to match the intensity of a match typically included 8 to 10 sprints (10s, 95%+ of maximal effort) with 50s active recovery. VO_2max ranged from 45 to 52 mL/kg/min for elite players and 4x4 min at 85-90% HRmax has been repeatedly correlated with quicker recovery between points and between sets.

The vertical jump, which is a lower-body measure of power, averaged 1.8 to 2.2 W/kg for elite samples. High-performance programs commonly used back squats at 80% 1RM, together with box jumps and medicine ball slams. Endurance of the deltoid, gluteus medius and tibialis anterior has been mentioned repeatedly as a determinant of whether technique holds up when players are fatigued. These physiological results are summarized in Table (2).

Table 2. Physiological characteristics of tennis players drawn from the 48 included studies

Parameter	Typical range / main finding	Suggested training prescription
Main energy system contribution	ATP-CP ≈ 78% ± 5%	8–10 × 10 s sprints at ≥95% maximal effort, 50 s active recovery
VO_2max (elite adults)	45–52 mL/kg/min	4 × 4 min intervals at 85–90% HRmax, 3 min active recovery
Lower-body explosive power	1.8–2.2 W/kg	Back squat (80% 1RM), box jumps, medicine ball slams, 3 sessions/week
Local muscular	Marked fatigue in	Eccentric holds (4 × 30 s),

Parameter	Typical range / main finding	Suggested training prescription
endurance (deltoid, gluteus medius, tibialis anterior)	long rallies; 68% of studies found it a stronger predictor than absolute strength	isometric lunges, resisted lateral shuffles

Source: Prepared by the researchers based on the included studies

2. Kinematic Characteristics

A match involved between 112 and 147 changes of direction, and players moved at an average of 3.2 to 4.1 m/s during rallies. More than 60% of movements reached accelerations above 4 m/s². Change-of-direction ability, tested with the T-test and the 5-cone shuttle, was more closely related to match results than straight-line sprint speed. Visual reaction time ranged from 0.32 to 0.45 seconds, and many programs used shadow drills with visual cues or reaction light systems to sharpen anticipation (Table 3).

Table 3. Kinematic characteristics of tennis players drawn from the 48 included studies

Parameter	Typical range	Suggested training prescription
Changes of direction per match	112–147	T-drill, zig-zag ladder, 5-cone shuttle (3 sessions/week)
Mean movement speed in rallies	3.2–4.1 m/s	Acceleration sprints over 5, 10 and 20 m
Main change-of-direction angle	45°–90°	COD drills at 45°, 60° and 90° with graded load
Visual reaction time	0.32–0.45 s	Vizual Trainer, reaction lights, shadow play with visual cues

Source: Prepared by the researchers based on the included studies

3. Psychological and Tactical Characteristics

Players typically had less than 0.5 seconds to decide on a shot during a point. In 87% of players, attention dropped noticeably in the closing stages of long matches. Higher-ranked players scored significantly better on the CD-RISC than players who lost more often, and the quality of tactical decisions explained 63% of the variance in match performance. Video analysis three times a week and game-based simulations such as "win by 3 points" were the usual tools for developing tactics (Table 4).

Table 4. Psychological and tactical characteristics of tennis players drawn from the 48 included studies

Parameter	Main evidence	Suggested training prescription
Decision time per shot	< 0.5 s	Serve-and-react drills, video-based anticipation scenarios
Loss of attention late in matches	Observed in 87% of players	Mindfulness (10 min/day), biofeedback training
Resilience (CD-RISC score)	72% of winners in the upper range of the CD-RISC-10 (0–40)	Cognitive-behavioral techniques, visualization scripts, self-talk diaries
Share of performance variance explained by tactics	63%	Video analysis (3×/week), "win by 3 points" game simulations

Source: Prepared by the researchers based on the included studies

4. Traditional Training Compared with the EBTFT

Traditional programs relied on the coach's intuition, and on general fitness preparation, they tended to separate physical, mental and tactical preparation. Training weeks were split into days (e.g. strength day, endurance day) and performance was assessed primarily by visual means, while any injuries were treated after occurring. The EBTFT is different.

In each session the physiological, kinematic, cognitive and psychological requirements are achieved within four pillars: (a) training for the physiological requirements of the sport; (b) dynamic training of the kinematic requirements of the sport; (c) cognitive-tactical training of the sport; (d) psycho-emotional training of the sport. Objective measures, such as COD time, HRV, reaction time and perceived exertion are used to track progress. Programs are modified according to player's age, sex, recovery load, training load, injury history and level (Table 5).

Table (6) provides an example of a four-week cycle following these principles.

Table 5. Traditional training models compared with the proposed EBTFT

Aspect	Traditional models	EBTFT
Basis of the program	Coach experience and custom	Synthesis of 48 peer-reviewed studies
Main focus	Separate physical qualities (strength, endurance, speed)	Integrated physiological, kinematic and psychological domains
Session structure	Separate days (e.g., strength day, endurance day)	All four pillars covered in each session
Individualization	Uncommon; one program for all	Adjusted for age, sex, level, injury history and biomarkers
Assessment	Subjective (coach observation, perceived effort)	Objective indicators: COD time, reaction latency, HRV, CD-RISC, shot accuracy
Injury prevention	Reactive, after injury occurs	Preventive: eccentric loading, stability work, asymmetry screening
Technology	Basic (stopwatch, cones, HR monitor)	Wearable sensors, motion capture, video analysis, AI feedback
Cognitive component	Missing or in a separate session	Built into every session, including decisions under fatigue
Psychological component	Occasional weekly session	Daily: mindfulness, biofeedback, emotional regulation under load
Transfer to matches	Limited	High; sessions reproduce match structure and pressure
Scalability	Simple to apply but less effective at elite level	Needs initial investment; adaptable from junior to professional

Source: Prepared by the researchers

Table 6. Sample four-week EBTFT training cycle

Week / day	Focus	Intensity (% max)	Main session content
W1 Mon	Physiological and power	75	Back squat (80% 1RM), box jumps, medicine ball slams, eccentric holds
W1 Tue	Kinematic and agility	60	T-drill, zig-zag ladder, 5-cone shuttle, multi-angle COD drills
W1 Wed	Cognitive-tactical simulation	70	Video anticipation, serve-and-react under fatigue
W1 Thu	Psycho-emotional recovery	50	Mindfulness, diaphragmatic breathing, self-talk journal
W1 Fri	Integrated match simulation	90	Short matches (3 × 15 min) with tactical rules (e.g., win by 3 points)
W1 Sat	Active recovery	45	Light jog, dynamic stretching, foam

Week / day	Focus	Intensity (% max)	Main session content
			rolling
W1 Sun	Rest	–	Full rest or light walk
W2 Mon	Explosive strength and stability	70	Plyometrics on unstable surfaces, resisted sprints, isometric lunges
W2 Tue	Tactical pattern recognition	80	Film study, shadow play, break-point simulations
W2 Wed	Aerobic capacity (HIIT)	80	4 × 4 min at 85–90% HRmax, 3 min active recovery
W2 Thu	Local muscular endurance	60	Lateral shuffles (5 × 30 s), resisted sled pulls, tibialis eccentrics
W2 Fri	Integrated session	90	Eccentric squats + COD ladder + video decision drill + breathing
W2 Sat	Friendly match	90	Full match with tracked speed, COD and reaction time
W2 Sun	Rest	–	–
W3 Mon	Neuromuscular power	75	Depth jumps, weighted-vest sprints, overhead medicine ball throws
W3 Tue	Tactical adaptability	85	Drills forcing shot variation, predicting opponent patterns
W3 Wed	Recovery and mobility	50	Yoga-based mobility, joint mobilization, optional cold immersion
W3 Thu	Reaction and coordination	60	Vizual Trainer, blindfolded shadow drills, ball-drop tests
W3 Fri	Integrated match simulation	90	Pressure scenarios: second-set tie-break, serving under fatigue
W3 Sat	Low-intensity aerobic	60	30 min steady jog at 70% HRmax + mobility circuit
W3 Sun	Rest	–	–
W4 Mon	Peak load simulation	80	Consecutive high-intensity physiological and kinematic blocks to mimic a tournament
W4 Tue	Mental resilience training	50	CBT, visualization of comeback scenarios
W4 Wed	Taper and fine-tuning	60	Reduced volume, technical precision and rhythm
W4 Thu	Final assessment	70	Full EBTFT battery: sprint, COD, vertical jump, HRV, reaction time, resilience
W4 Fri	Rest	–	–

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Week / day	Focus	Intensity (% max)	Main session content
W4 Sat	Competition (optional friendly match)	90	Friendly match to check final readiness
W4 Sun	Rest	–	–

Source: Prepared by the researchers

Note: Every session starts with a 10–15 min warm-up and ends with a 10 min cool-down. Intensity and volume are modified according to HRV, DOMS and TQR readings.

Section Three: Discussion of Results

Our synthesis indicates that performance in tennis comes from the way physiological, kinematic and psychological systems work together under severe time pressure. The EBTFT turns this into four practical pillars: physiological conditioning, kinematic agility, cognitive-tactical decision-making and psycho-emotional resilience, and the resulting model can be scaled for both elite and developing players. Figure (2) shows how load is distributed across the proposed four-week cycle: high-intensity days (85–90% of maximum) alternate with recovery or psychological sessions (45–60%), and the mean planned intensity rises in the second week before tapering toward the final assessment.

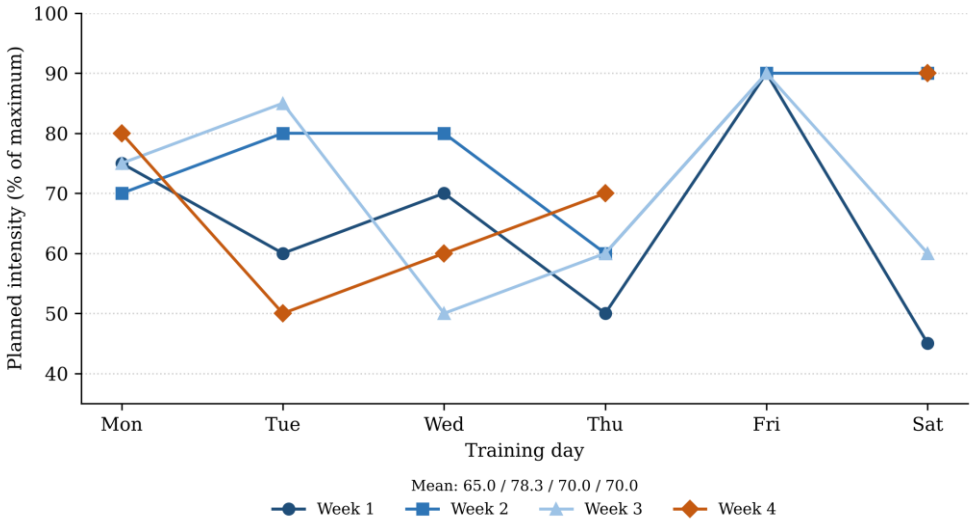


Figure 2. Planned daily training intensity (% of maximum) across the four-week EBTFT cycle

Source: Prepared by the researchers based on Table (6)

Note: Rest days are omitted. Values are prescribed targets, not measured player data.

1. Physiological Conditioning

An ATP-CP contribution of approximately 78% supports the fact that tennis is not a steady aerobic event, and is of a much more explosive nature. Interval training, particularly 4×4 minutes at 85-90% HRmax, can help recover phosphocreatine and reactivate the neuromuscular system between intervals [1]. The interference that endurance training can impose on strength and power depends on its modality, frequency and duration [11], so careful sequencing of strength, power and recovery should limit it. This allows for the development of lower body power (1.8–2.2 W/kg) simultaneously with the development of endurance, rather

than negatively affecting it.

2. Kinematic Efficiency and Injury Prevention

Players change direction 112 to 147 times during a match, mostly at angles between 45° and 90°. Linear sprints and predictable L drills do not simulate multiplanar movement and repeated braking that occurs in real play. The EBTFT is therefore based on COD drills at multiple angles combined with eccentric strengthening, such as eccentric tibialis anterior and resisted lateral shuffles, in order to enhance the neuromuscular control and reduce the risk of non-contact injuries [6]. Squash and badminton place similar multidirectional demands on players, and comparable eccentric-based agility work may be relevant there, although this needs to be confirmed.

3. Cognitive-Tactical and Psycho-Emotional Integration

Perceptual and decision-making skills such as anticipation distinguish better players from weaker ones [2], and visual reaction times in the included studies ranged from 0.32 to 0.45 seconds. For this reason the framework incorporates video based anticipation drills and serve-and-react drills in daily sessions. These exercises are designed to create an interconnection between perception and action (ecological dynamics) [12] and are grounded in motor learning theory [13]. But resilience is important as well; top performers scored in the upper range of the 10-item CD-RISC, whose scores range from 0 to 40 [14], and resilience helps to account for much of the individual differences in performance between matches. Daily mindfulness and biofeedback (Appendix D) enable coaches to help individuals follow these mental skills through quantifiable metrics like HRV rMSSD and attentional stability [15], [16].

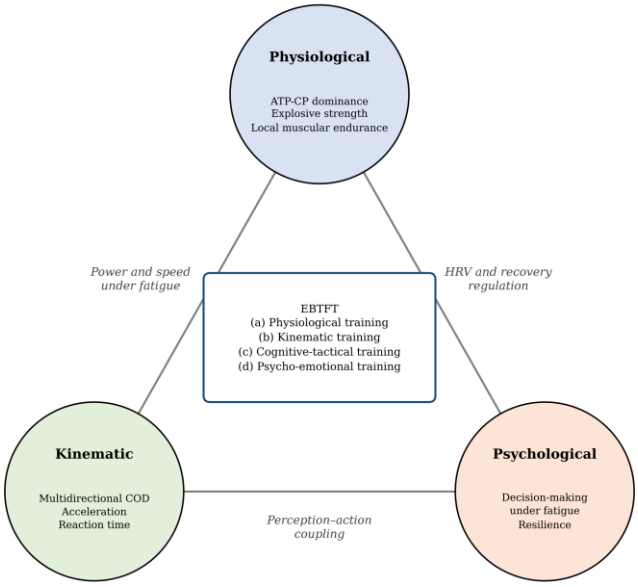


Figure 3. Conceptual map of the PKP domains, their main characteristics and points of interaction, with the four EBTFT pillars at the centre

Source: Prepared by the researchers

4. Implementation in Different Resource Settings

The framework is not reliant on expensive equipment. Federations and private academies can build on the weekly structure in Appendix A, and continue to incorporate more advanced tools as they wish. In the case of limited budgets, the presence of smartphone

reaction apps, cones with random cues, and simple heart-rate monitors can replace commercial systems like the Vizual Trainer, without compromising the essential principles. This flexibility is consistent with consensus recommendations on monitoring athlete training load [15].

5. Digital Twin and Future Development

The digital twin design presented in Appendix E integrates the data from the wearable sensors with AI-driven analysis and simulation tools like Unity. It, in principle, enables coaches to modify loads as they happen, anticipate injury risk and simulate game scenarios, creating a dynamic cycle of data, decision and in-game adjustments [15].

6. Benefits over the Traditional Models

Traditional programs focus on training strength, endurance and mental abilities separately. All four pillars are incorporated in every session of the EBTFT, so hopefully this will help promote coupling between the neuromuscular and cognitive aspects and facilitate transfer to match play. Agility that involves perception and decision-making is a different quality from pre-planned change-of-direction speed [17], which supports training the two together rather than separately. The framework thus provides a data-based alternative to traditional training.

7. Limitations

There are a few cautions to be taken. The framework is based on published studies and has not been tested in a controlled trial and therefore the effects on performance and injury rates have yet to be confirmed. The studies included varied in their design, sample size and player level, and some reference values were estimated from reported ranges. These points should be considered when the framework is applied in practice.

Conclusion

First: Conclusions

1. In tennis, all three aspects need to be nurtured simultaneously and not independently as each domain is present in every point.

2. Most of the energy for play comes from the ATP-CP system (about 78%), therefore conditioning should focus on repeated high intensity movements of short duration with incomplete recovery, rather than long aerobic activity.

3. Multidirectional movement, with 112 to 147 changes of direction per match mainly at 45°–90°, is more closely related to match outcome than linear sprint speed.

4. Decision quality under fatigue and psychological resilience explain a large portion of the variance in performance, which supports placing cognitive and mental work within daily sessions.

5. EBTFT combines the six key characteristics in four actionable pillars and shifts the coaching question from "what" into "how, when and why" to train each quality.

Second: Recommendations

1. Player preparation is recommended to be based on the four pillar weekly structure (Appendix A), and tennis federations and academies are encouraged to adopt it.

2. Coaches should use objective measures (COD time, HRV, reaction time and CD-RISC scores) and follow a KPI checklist in Appendix D rather than primarily use observation to monitor training.

3. The risk of lower-limb and shoulder injuries may be reduced by implementing eccentric strengthening and multi-angle COD training in regular training.

4. Low budgets can be accommodated with cheap alternatives like smartphone reaction

apps and simple heart rate monitors, and still maintain the framework's principles.

5. Researchers are encouraged to evaluate the framework via the proposed 12-week randomized controlled trial; and also to explore the digital twin architecture (Appendix E) for real-time load management.

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