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Editorial

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Welcome to the 94th edition of the ITF Coaching and Sport Science Review. This is the final issue for 2024 in its 31st year. You can find this issue in the ITF Academy and on the journal's new webpage, which is accessible here. This edition features articles from contributors, authors, researchers, coaches, and experts worldwide, covering a range of topics including: players at the centre of the development process and the elite player development, a heart rate variability study of a top player, the expectations of tennis officials, the fundamentals of the optimal ready position and of skill acquisition, and a research on the ITF WTN, among others. This editorial will share some of the most relevant activities and issues that the ITF has delivered throughout 2024.

ITF GLOBAL TENNIS REPORT 2024

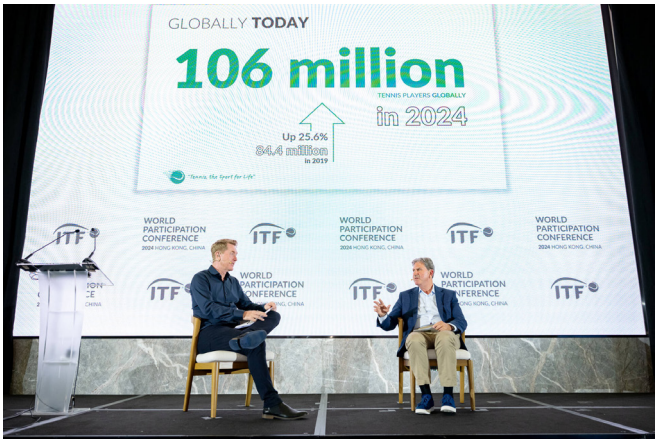
The International Tennis Federation (ITF) has released its 2024 Global Tennis Report, revealing a significant surge in global tennis participation. The report highlights that 106 million people are now playing tennis worldwide, marking a 25.6% increase over the past five years. This growth translates to an additional 21.6 million players compared to the 84.4 million recorded in the 2019 report, prior to the COVID-19 pandemic.

Regionally, Asia leads with 35.3 million tennis players, representing 33.4% of the global tennis-playing population. Europe follows with 29.6 million players (27.9%), and North America with 28.8 million (27.2%). Other regions include South America with 8.8 million players (8.3%), Oceania with 1.8 million (1.7%), Africa with 892,000 (0.8%), and Central America & the Caribbean with 665,000 (0.6%).

Several factors have contributed to this surge in tennis participation. The ITF attributes the increase to the growing popularity of tennis, strategic growth initiatives by National Tennis Associations in collaboration with the ITF, and the influence of role models such as Qinwen Zheng, Carlos Alcaraz, Naomi Osaka, and Jannik Sinner. Additionally, substantial investments in tennis infrastructure, including courts and coaching, have played a crucial role.

The report also notes a 13.6% rise in the number of tennis coaches, with over 175,000 coaches now working globally, up from 154,367 in 2019. This increase underscores the need for qualified instructors to support the growing number of players and ensure the availability of training across all levels of the sport.

The ITF's commitment to rigorous data collection across 199 nations has been instrumental in producing this comprehensive



report. As the only study of its kind, the ITF Global Tennis Report aims to provide a clear picture of global tennis participation and serves as a foundation for decision-making in the ITF's mission to grow and develop the sport worldwide. This report is available in the ITF Academy.

ITF WORLD PARTICIPATION CONFERENCE 2024

The ITF World Participation Conference stands as a pivotal event in tennis, offering a unique platform for global representatives to convene and deliberate on strategies to enhance sports participation. Since its inception in 2018 in London, the conference has consistently aimed to unite key decision-makers in tennis to foster a dialogue on increasing global participation in the sport. This initiative is not just about discussing participation but about creating actionable strategies that can be implemented worldwide to grow the sport of tennis.

Historically, the conference has hosted experts who share their knowledge on a wide range of topics. These experts come from both within and outside the sport, providing a well-rounded perspective on the issues at hand. The conference has featured an impressive roster of international speakers who shared their insights and experiences. These speakers included notable figures from within the tennis community and beyond, such as Judy Murray, Billie Jean King, and Martina Hingis. Their participation highlights the conference's commitment to bringing diverse perspectives to the table.

The fifth edition of the conference, held in 2024, was themed 'Tennis, the Sport for Life.' This theme underscores the lifelong benefits of tennis, promoting it as a sport that can be enjoyed

by individuals of all ages. The 2024 conference topics included 'Tennis the Sport for Life,' 'Tennis for All,' 'Gender Equality & Inclusion to Drive Participation,' 'Impact of a Champion on National Participation,' 'Digitalising Participation,' and the 'ITF Global Tennis Report 2024.' Each of these topics addresses a critical aspect of sports participation, offering insights and strategies to enhance engagement at all levels.

The 2024 event, held on October 9 in Hong Kong, China, featured 21 speakers who discussed various aspects of participation, gender equality, and digitalisation. The speakers included Kelly Fairweather, David Haggerty, Mark Woodforde, Mark Eade, Sun Wen Bing, Cem Tinaz, Giorgio Di Palermo, Christer Sjöö, Jonas Alberton Junior, Terri-Ann Scorer, Salma Mouelhi, Cristy Campbell, Brian Hainline, Mark Eade, Peter Johnston, Vicki Reid, Roger Davids, Torgun Smith, Herman Hu, and David Ernesto Samudio Gomez. Each of these speakers brought their unique perspectives and expertise to the conference, contributing to a rich and diverse dialogue.

One of the key aspects of the ITF World Participation Conference is its accessibility. To view the presentations from the event, individuals must be registered as ITF Academy users. This registration not only grants access to the conference stream but also provides users with over 245 tennis courses and a vast library of educational resources. This comprehensive access ensures that participants can continue to learn and grow within the sport long after the conference has concluded.

In conclusion, the ITF World Participation Conference is a vital event for the global tennis community. It brings together key decision-makers, experts, and enthusiasts to discuss and develop strategies for increasing participation in tennis. The conference's focus on inclusivity, gender equality, and digitalisation ensures that it addresses the most pressing issues facing the sport today. By providing a platform for sharing knowledge and experiences, the ITF World Participation Conference plays a crucial role in shaping the future of tennis and promoting it as a sport for life.

ITF REGIONAL COACHES CONFERENCES 2024

More than 1000 coaches from all continents took part in the 8 ITF Regional Coaches Conferences that were organised this year, showcasing a range of topics from the development of high-level players to strategies for increasing tennis participation. The conferences were held in South Africa from 20 to 22 September, Trinidad & Tobago and Vietnam from 27 to 29 September, Argentina from 3 to 5 October, Bahrain, Mexico, and Cyprus from 1 to 3 November, and Tunisia from 4 to 6 November 2024. These events featured leading coaches and experts in the game, providing valuable insights and knowledge.

The conferences were open to coaches, tennis professionals, and anyone interested in tennis or sports in general, with attendees required to be in good standing with their National Association. All participants received a certificate of attendance and Continuous Professional Development points, which were added to their personal profiles on the ITF Academy. We extend our heartfelt thanks to the coaches, the host nations' organizers, and the regional associations involved for their dedication and support in making these conferences a success.

The recordings of all the presentations delivered by the experts are already available in the ITF Academy for registered users.

OFF-COURT COACHING

Following a majority vote from National Association delegates at the 2024 ITF AGM in Hong Kong, the ITF Rules of Tennis will be updated to permit off-court coaching starting January 1, 2025. Since 2017, trials of off-court coaching have been conducted, and since 2023, these trials have included events managed by all international sanctioning bodies, such as the four Grand Slams, the ATP and WTA tours, the ITF World Tennis Tour (WTT), and the ITF UNIQLO Wheelchair Tennis Tour. Feedback from these trials has been overwhelmingly positive, leading all international sanctioning bodies to support a proposal to the ITF Rules of Tennis Committee for a permanent rule change. This change aims to allow sanctioning bodies the flexibility to permit off-court coaching in their competitions.

The Committee endorsed this proposal, believing that allowing off-court coaching will:

- Harmonize coaching approaches across international tennis bodies.
- Reduce the burden on Chair Umpires to enforce the current coaching restrictions.
- Decrease subjectivity in the enforcement of coaching rules.
- Support player development.
- Potentially make tennis fairer and more entertaining.

Under the revised Rule 30, 'Coaching' is defined as any form of communication, advice, or instruction given to a player. Here is a summary of the changes effective from January 1, 2025:

- Off-court coaching may be allowed in events governed by the sanctioning body's rules.
- In team events, where a team captain is on-court, they may coach players at times permitted by the sanctioning body.
- On-court coaching remains prohibited in all other competitions.
- Sanctioning bodies may allow players to use approved Player Analysis Technology during permitted coaching times.

If coaching is permitted by the event's sanctioning body:

- Coaching is allowed between points, at changeovers, set breaks, and any other times specified by the sanctioning body, except during the play of a point.
- Communication for off-court coaching and on-court coaching between points can be verbal (when the coach and player are at the same end of the court) or via hand signals (at any time when coaching is allowed).
- Off-court coaching and on-court coaching between points must be brief and discreet, except during breaks in play.

The following details are at the discretion of each event's sanctioning body:

- Whether coaching is allowed in events under its jurisdiction.
- Whether a Chair Umpire must be present for coaching to be permitted.

- Whether both players must have a coach for coaching to be allowed.
- Eligibility criteria for coaches (e.g., qualifications, accreditation) and the use of approved Player Analysis Technology.
- The number of people eligible to coach a player/team.
- The location of coaches during coaching.
- Who enforces the coaching rules (e.g., Chair Umpire, off-court official).
- Whether coaching is allowed during breaks not covered by the Rules of Tennis (e.g., medical time-outs, toilet breaks, change of attire breaks, weather or light-related suspensions, wheelchair repairs, spectator medical conditions).
- Penalties for unauthorized coaching.

For more information, download the ITF Rules of Tennis by searching 'Rules of Tennis' on Google Play for Android devices or the App Store on Apple devices.

The 2024 ITF WTT Junior Finals provided further clarity on the implementation of off-court coaching. Here are some key points from the Officials Q&A:

- Coaches must remain in designated seats to use off-court coaching.
- Verbal coaching is only allowed when the coach is on the same side of the court as the player.
- Coaches cannot move closer to the player during allowed conversations.
- Chair Umpires are responsible for ensuring coaches adhere to these rules and can issue Code Violations for breaches.

These guidelines ensure that off-court coaching is conducted in a controlled and professional manner, maintaining the integrity of the game while supporting player development.

ITF WORLD TENNIS NUMBER

The International Tennis Federation (ITF) has announced that the World Tennis Number (WTN) will be used as a secondary entry criterion for regional junior tournaments by several major regional tennis federations starting January 1, 2025.

From this date, the Asian Tennis Federation (ATF), Oceania Tennis Federation (OTF), Confederation of Tennis of Central America and the Caribbean (COTECC), Confederation of African Tennis (CAT), and South American Tennis Confederation (COSAT) will incorporate the WTN into their 14-and-under and 16-and-under regional tours. Tennis Europe is also planning to adopt this system soon.

The decision to integrate the World Tennis Number at the regional tour level follows its successful implementation in the ITF World Tennis Tour Juniors (WTTJ) in 2022. For entry into the ITF World Tennis Tour Juniors tournaments, the primary acceptance method remains the ITF Junior Ranking. However, players without an ITF Junior ranking can now be accepted based on their World Tennis Number, providing a global, objective rating measure for entry.

As of September 2024, over 6,000 players have gained tournament acceptance through their WTN. With an accuracy rate exceeding 72% in ITF Junior tournament matches this year, the WTN has proven more effective than previous criteria.

Regular competitors who perform well will be recognized through their WTN, facilitating their acceptance into Regional Tour events at the 14U and 16U levels, and subsequently into entry-level tournaments on the 18-and-under ITF WTTJ. This initiative aims to strengthen regional competition, offering more young players the chance to compete closer to home. This collective move highlights the growing significance of the WTN in the global tennis community.

Regional tennis associations acknowledge the importance of promoting the World Tennis Number to enhance its adoption and development. As a dynamic and evolving tool, the WTN continues to drive development and participation in tennis, with the collaboration of federations being crucial for its widespread use. Since its launch in 2020, the WTN has seen exponential growth, with nearly 2 million players across 80 nations now equipped with their unique World Tennis Number.

The ITF World Tennis Number is a real-time skill level rating system designed for tennis enthusiasts of all levels. Similar to a golf handicap, the WTN provides a numerical representation of a player's ability, enabling them to find opponents who match their skill level anywhere in the world. This global rating system simplifies the process of identifying suitable playing opportunities, making tennis more accessible and enjoyable for everyone. It also serves as a tool to track the development of one's game over time.

As the World Tennis Number continues to evolve, the ITF remains committed to refining and expanding this system. Collaboration with national and regional associations is vital in this ongoing process, and the ITF is enthusiastic about future enhancements that will further benefit the global tennis community. To find out more about ITF World Tennis Number please visit www.worldtennisnumber.com

We trust that you have found this editorial informative. Its purpose was to highlight some of the initiatives the ITF is undertaking to promote the growth of tennis globally.

We invite you to submit new articles to the ITF CSSR via the new platform. We extend our gratitude to all the authors for their contributions and to everyone who submitted proposals. Detailed guidelines for article acceptance and publication are available on the latest issue page in the ITF Academy. We hope you enjoy reading the 94th edition of the ITF Coaching and Sport Science Review.

RECOMMENDED ITF TENNIS ACADEMY CONTENT (CLICK BELOW)

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Are our tennis players at the center of the process and are they the focus of decisions?

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ABSTRACT

This essay shares insights that we consider relevant when thinking about long-term sport formation and development processes from the perspective of tennis players. We acknowledge that learning and development do not occur linearly, making everyone's journey of experiences unique. While there are no ready-made recipes that can cater to everyone, we have a series of guidelines that can assist coaches and sports agents in making their decisions accurately and effectively. Specifically, in this article, we will discuss some elements related to tennis initiation, the long-term sport development process, and the pursuit of significant results during this stage, aiming to train tennis players for high performance.

Key words: development path, elite sport context, youth athlete development.

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INTRODUCTION

The journey of developing high-performance tennis players consists of a series of phases and stages that complement each other and present very particular characteristics. Throughout this process, athletes' expectations regarding practice change significantly, accompanied by an increase in the specificity of training contents, demands, and workloads present in both training sessions and competitions (Cortela et al., 2020a; Sanz & Soler, 2019; Tennis Canada, 2011).

Examining the trajectory of tennis players who have reached this level of sportsmanship reveals that this journey is unique, with various paths leading to the international tennis elite. While there are no one-size-fits-all formulas capable of ensuring success, we currently rely on a series of evidence that can assist sports agents in making this journey more precise and effective (Cortela et al., 2024). In this regard, understanding in-depth the demands required at each stage and being able to tailor them to the individual characteristics of each person is key for coaches working with children and youth aiming for high performance (COB, 2022; Gilbert, 2016).

With these considerations, this essay focuses attention on certain elements related to tennis initiation, the long-term athlete development (LTAD) process, and the role of competitions and sports results, which should be carefully weighed when aiming to develop tennis players for high performance.

Delving into these discussions, highlighting topics that are part of coaches' and athletes' daily lives but often remain in the background due to routines, can enhance the creation of more conducive environments for the integral development of children and youth, respecting their particularities and expectations regarding competitive tennis, which vary across different stages of LTAD.

SPORTS INITIATION

Sports initiation in tennis, understood as the initial guided contacts that practitioners experience with the sport, should occur early. Looking at the trajectory of successful tennis players who have reached the Top 10 in WTA and ATP rankings, it is observed that this process begins around the age of 5-6 years (Li et al., 2018).

With a long journey ahead until reaching the international elite (Top 100), of approximately 15 years (Kovalchik et al., 2017; Li et al., 2018; Reid & Morris, 2013), nations focused on optimizing their results have devoted time to constructing common working guidelines for different stages/phases of sports development, appropriate to their contexts (Figure 1) (Gilbert, 2016).

Despite presenting minor variations in the number of phases, distribution of training/competition loads, definition and order of presentation of content, among others, these models share fundamental common principles, such as the centrality of the athlete in the process and recognition of the complex and dynamic nature of the sports context, which requires a perspective that goes beyond the tactical-technical aspects of practice (Gilbert, 2016).

Particularly regarding the sports initiation process, respect for children/young people and the quality of the relationships and experiences provided at this stage are highlighted, regardless of the expected long-term outcomes, whether they be Performance, Participation, or Personal Development (Côté et al., 2014). In this sense, the traditional sports pyramid, at this phase, gives way to a rectangular block, composed of various stages that promote

Figure 1: *Examples of documents containing guiding principles for long-term sport development.*

the diversification of practices and sports contexts, as well as the development of love for the sport (Figure 2) (Côté et al., 2012; Hainline, 2013).

One of the main dilemmas inherent to this phase lies in defining the path between diversifying or specializing in the practice, when aiming for significant results in adulthood (Güllich et al., 2021). This becomes even more pronounced in sports like tennis, where engagement with the practice starts early and athletes like Cori Gauff and Carlos Alcaraz emerge as prominent figures on the circuit at an extremely early age.

Based on the success of exceptional athletes, various sports agents have intensified and specialized their efforts to shorten pathways. The term "Race to the Yellow Ball," reported by Gould et al. (2016) in a study conducted for the United States Tennis Association (USTA), in analogy to the acceleration in transitioning stages in Tennis 10's, illustrates this scenario well.

However, is this the path followed by most elite tennis players, the most assertive?

Reference models suggest that for sports where the best career results occur later, such as tennis, the initial stages should emphasize diversification of sports experiences and contexts (Tennis Canada, 2011).

When discussing the concept of diversification, we refer not only to practicing different modalities but also allowing children to occupy distinct roles in sports contexts, confronting practice scenarios with less or greater adult mediation (Côté et al., 2014). In this scenario, deliberate play emerges as a frequent practice during this developmental phase and should be widely encouraged.

Retrospective studies with athletes who have achieved significant international results emphasize the importance of diversification and deliberate play in the preliminary stages of development (Gilbert, 2016). A comprehensive systematic review with meta-analysis conducted by Güllich et al. (2021) indicates that international-level athletes, among other elements: participated in other sports during childhood/adolescence; started practicing their main sport later; accumulated less main sports practice during the formative period; and achieved performance milestones at a slower rate than national-level athletes.

Specifically concerning Grand Slam winners, Oršolić et al. (2023) describe similar paths where diversification and a love for tennis have always been present from the early stages. According to the aforementioned authors, these tennis players:

- Emphasized that between the ages of 8 and 14, the most important aspect was training and having fun.
- Even though they started early, they did not specialize prematurely or accelerate the training process.
- Demonstrated dedication and unconditional love for tennis from the early years of their journey.

As final considerations for this section, it becomes evident that a careful approach is necessary during this phase, on the part of all stakeholders, respecting the harmonious development of children in the sports context through diversification of experiences and deliberate play to foster a love for the sport.

LONG-TERM ATHLETIC DEVELOPMENT (LTAD)

As previously mentioned, when we focus on LTAD models applied to tennis developed by different authors, countries, and internationally recognized institutions, we can identify common

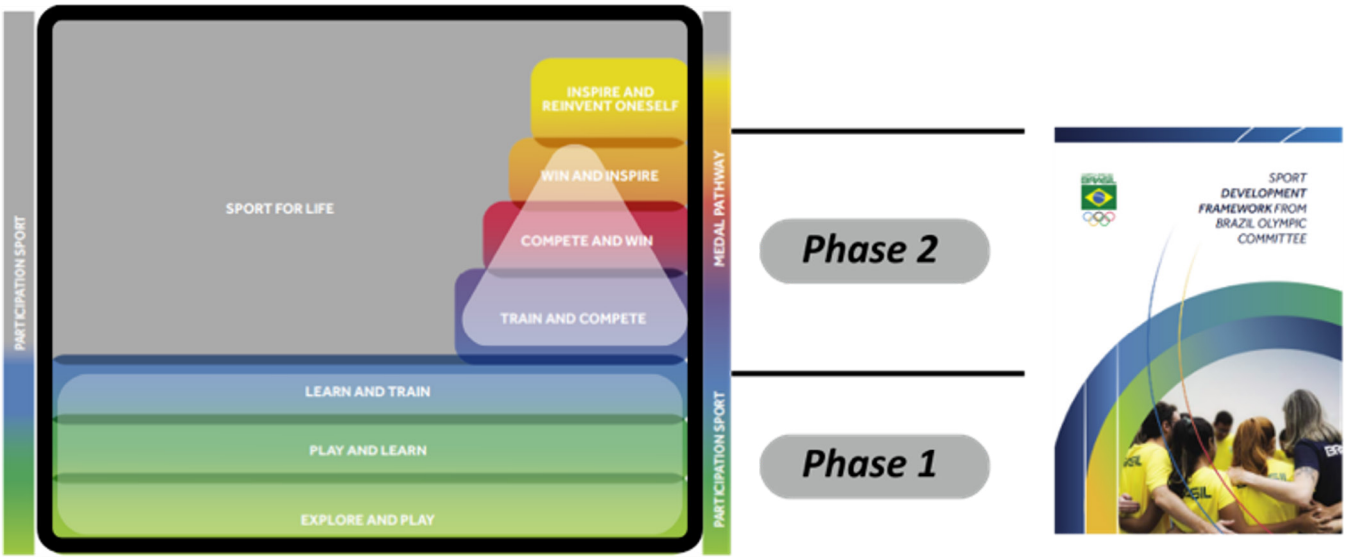

Figure 2: *Athlete Development Path, adapted from the Brazilian Development Model (COB, 2022).*

principles that underpin all developmental work (Tennis Australia, 2008; Tennis Canada, 2011; Sanz & Soler, 2019; Hainline, 2013). According to Cortela et al. (2024):

> *" ... this standardization occurs because nowadays everyone has access to a body of evidence that guides, or should guide, long-term development work. These concern both the dimensions of human development analysis (cognitive, physical, motor, psychosocial, among others), as well as the tactical-technical aspects of the sport itself, which, despite presenting temporal variations, are inherent to the process ..." (Cortela et al., 2024, p. 15).*

While we have well-defined general guidelines on the work to be done, we understand that there are no ready-made recipes or formulas that apply to everyone. As coaches, our greatest challenge is to understand clearly when, where, how, and with whom these principles apply (Gilbert, 2016).

We know that the learning process is individual, resulting from the interaction of the individual with practice and the environment (Malhotra et al., 2022; Parry & O'Rourke, 2023). This particularity makes the journey unique and non-linear, with similar training stimuli and environments producing different results based on individual characteristics and experiences, and the timing at which they are presented to the tennis players (Parry & O'Rourke, 2023).

With this scenario, one of the main challenges faced by professionals working with tennis players in the development phase is to reconcile, throughout the stages, performance in competitions with the learning demands and training required to perform at a high level of tennis (Cortela et al., 2016; 2020a).

Performance and learning are distinct concepts and treating them as synonyms can lead to misunderstandings. While performance is momentary and can lead to victories in matches, learning is longstanding and requires time to be achieved (Malhotra et al., 2022). Experienced professionals understand the non-linear dynamics of learning and the fact that it is preceded by periods of instability, where current performance may be inferior to previous performances (Hodges & Lohse, 2022).

This awareness leads coaches to redefine errors and unstable performances as inherent to the learning process, not punitive or to be avoided at all costs. Regardless of the area to be developed (e.g., tactical, psychological, physical, technical, among others), for learning to occur, the tennis player will need to operate for a considerable period outside of their comfort zone, which may cost them short-term performance. The key for coaches is to identify the optimal challenge zone for each person, where the best possible relationship is established between the difficulty level of the task, the impact on performance, and the readiness state presented by the tennis player to respond to the proposed demands (Gilbert, 2016; Hodges & Lohse, 2022).

The lack of understanding of the nature of this process, combined with the expectation of short-term results (Pacharoni & Massa, 2012), not only from coaches but also from all agents and sports institutions involved in the tennis ecosystem (COB, 2022), directly impacts LTAD, causing coaches to neglect what really needs to be done to perform at high performance, to focus on work that makes it possible to perform, at the current stage they are in (Cortela et al., 2024).

This becomes even more evident when dealing with a sport like tennis, where competition is prevalent from the early LTAD stages (Tennis Canada, 2011; Hainline, 2013), and managing results every week becomes crucial. However, coaches need to understand what needs to be built throughout the journey to perform in high performance tennis, where what defines results often is not consolidated in the early stages of the process (Balbinotti et al., 2005).

In professional tennis, the ability to win points with up to four balls (serve +1 and return +1) and the percentage of points won playing with the first serve are two fundamental variables for players aiming for victory (Fitzpatrick et al., 2019). To perform these conditions against high-level opponents, tennis players need to be capable of generating precise and/or powerful shots under pressure, which requires training time and opportunities to put this into practice in real game situations, until consistent response patterns are acquired (Balbinotti et al., 2005).

For this reason, significant differences in performance capacity and game statistics are observed between junior and professional tennis players of all age groups, even at the highest-level events like Grand Slams (Fernández-García et al., 2021; Klaus et al., 2017; Kovalchik & Reid, 2017; Schmidhofer et al., 2014). Even in such events, it is possible to verify differences in performance capacity between junior players and professionals, who demonstrate higher performance and capacity to produce points (Fernández-García et al., 2021; Kovalchik & Reid, 2017).

However, the fact that it does not generate direct performance gains in the first stages does not exempt coaches from the need to frequently work on certain strokes and situations, in order to offer the necessary conditions for tennis players to respond consistently, in the long term, to the demands of the game under pressure conditions (Balbinotti et al., 2005; Rodríguez Campos & Martínez-Gallego, 2024).

By recognizing high-performance tennis as predominantly a game of up to four ball exchanges per point, we understand that the serve and return form the basis of these actions, being decisive for the success of tennis players (Rodríguez Campos & Martínez-Gallego, 2024). Unfortunately, this information has not been converted into work guidelines for planning and conducting more representative training focused on preparing players for future demands. As highlighted by Fleming et al. (2023), training sessions, in general, do not meet the workload and physiological and perceptual demands observed in competitions.

This lack of attention to data, critical components of the game and representativeness, witnessed in the training context, has been described in the literature. The study conducted by Klering et al. (2019), with Brazilian male tennis players, participants in one of the main South American international competitions up to 14 years old, identified that the frequency of training reported for the main play initiatives differed significantly from the actions involving the return, receiving less attention and the initiatives through the rally, the greater load.

Similarly, Krause et al. (2019) analyzed 213 training sessions performed by Australian junior tennis players in the weeks leading up to the Australian Open. The evaluation, in a real context of practice, indicated that the time dedicated to work involving the serve and return was less than 13% of the total practice and occurred, primarily, in an isolated and decontextualized way from the demands found in the game.

More than the training load and frequency, highlighted by coaches as some of the main challenges for training players for performance (Cortela et al., 2024), how one trains and the quality of practice have been the current focus of debates (Gilbert, 2016, Parry & O'Rourke, 2023).

Obviously, respecting the minimum training loads required to achieve high performance is important (Cortela et al., 2016, 2020a). But training goes far beyond training a lot! It involves providing practices that require players to be 100% connected to the present, while preparing them for future performances (Gilbert, 2016).

For this, the structuring of representative practices, which respect the specificities of the game and can approximate the perceptual demands, the decision-making, and the physical and emotional loads, present in the competitive context, is the key (Krause et al., 2019). The premise that training is training and game is game, stems precisely from the lack of ability to structure learning environments that provide opportunities for practices that reproduce, in an appropriate way, the stage of development and the playing capacity momentarily presented by tennis players, to the demands encountered in competition and to which they are able to respond if they have support and commitment (Hodges & Lohse, 2022).

This does not mean training under future conditions, reproducing high-performance adult tennis on a small scale, but rather preparing these players, respecting their individual development process and their time for learning, providing an Optimal Challenge for their journey (Gilbert, 2016, Reid et al., 2007).

The simple act of using adapted courts, balls, and rackets contributes to this, leading to the adoption of distinct tactical-technical behaviors that are favorable to learning (Buszard et al., 2016). The use of the Lemon Stage for children in transition from the Orange Stage (Schmidhofer et al., 2014, Bayer et al., 2017), doubles games using the singles court for players up to 14 years old (Dell'Edera et al., 2018), and contextualized service and return training (Krause et al., 2019), are some examples of how we can enhance the learning process through representative practices, regardless of competitive regulations set for this age group.

We conclude this section by highlighting that the LTAD process should be focused towards developing courageous players who are able to perform well under pressure and who accept error as a step that precedes reaching new levels of performance. We understand that training players under the mantra of not failing does not pave the way for them to have the tools to succeed on the WTA and ATP tours.

ATTENTION TO THE ROLE OF COMPETITION AND THE IMPORTANCE ATTRIBUTED TO RESULTS IN YOUTH'S TENNIS

Despite being considered a modality of late specialization, that is, the one where the results, in general, occur later, in tennis, the first stages of the competition occupy a key role in player development (Tennis Canada, 2011).

Very few sports offer as many opportunities for an athlete to be able to add prizes and points to the world ranking as tennis.

When we analyze the reference models in LTAD, we found that from the age of 14 onwards, the percentages of hours spent on training and competitions become similar, and the number of games played and the scope of competition begin to influence the choice of the path to be followed, until the professional circuit (Tennis Canada, 2011, Hainline, 2013).

As part of the LTAD process, competition should be seen as a pedagogical tool in favor of coaches, helping them in the development of tennis players (Cortela et al., 2020b, Gonlçalves et al., 2016). In this sense, especially in the preliminary stages, the focus should be on competing to train and not training to compete.

A clear alignment in this regard has practical and important implications for training and competitions. If we compete a lot and compete to train, significant adjustments in the training content and loads to meet the demands of the weekend competitions should not be made frequently, under penalty of failing to work on what is really important for the integral development of tennis players in the LTAD process, to respond to the demands of the next opponents (Cortela et al., 2020b).

In the same way, competitions with different formats and rules of action should be made available to challenge tennis players and favor the complete game development, in order to allow tennis players to select, in the future and based on their individual characteristics, the styles and patterns that best meet their specificities (Gonlçalves et al., 2016).

Results in youth's tennis: a cause-and-effect relationship?

If the competitive role during the development process is a means and not an end, why do we continue to look at results and base our decisions on achievements at these stages as a predictor variable for success on the professional circuit?

The studies that have been dedicated to understanding this relationship point out that the existing correlation and the results in youth's tennis and professional success is low (Brouwers et al., 2012, Cortela et al., 2012). Drawing a parallel between the tennis players' journey and that of a marathon, when we look at the results of junior tennis as predictors of future success, we are predicting the finishing podium based on the order in which the athletes crossed the first 500 meters.

When we adopt this type of approach, we invest time, human and financial resources in the wrong way, leaving athletes who have the potential to succeed off the radar (Brouwers et al., 2012, Cortela et al., 2012). With these considerations in mind, the question to be answered becomes: what are the factors that affect performance in young tennis and that lead to this low association with the results in professional rankings?

We understand that the answer is complex, since it involves several factors, which, individually or in combination, influence the results presented by tennis players in the various stages of LTAD. Although it is not a simple task to solve, it is verified that the differences in the results in this period are linked to the differences in the maturational stages and in the experience presented, translated by the time of practice, accumulated workload of training and competitions, among others (Unierzyski, 2003).

Figure 3: *Intervening factors in the youth's tennis results.*

In current youth's tennis, the categories of dispute are divided into two-year age intervals, with the cut-off criterion only the chronological age presented by the athletes. This model favors individuals considered advanced in relation to the maturational stage, since, for the same chronological age, they may be taller, heavier, faster, stronger, and more resistant than their peers (Mirwald et al., 2002). These initial competitive advantages can interfere with the motivation and perceived competence of those who do not have them, generating frustrations in athletes (Musch & Grondin, 2001), pointed out as one of the main burnout factors indicated in junior elite tennis players (Gould et al., 1996).

If we think about a long-term developmental process, as is the case with tennis, it is common to find differences of up to three years between biological age and chronological age (Bojikian et al., 2011). In practice, this means that within a competition for tennis players up to 14 years old, we can find players with biological ages ranging from 11 to 17 years old, which obviously interferes with the momentary performance capacity.

It is added to these factors the experiences and exposure practice time experienced by each person. In these stages, it is common to find great variability in the training and competition loads accumulated in the LTDA (Unierzyski, 2003). When we consider the competitive model used in tennis, we find individuals with up to 24 months of chronological difference, participating in the same age group, which, in simple mathematics, can mean more than 40% difference in training and competition loads (Tennis Canada, 2011), assuming the two had the same practice conditions since they started the LTAD process, which is not the case in reality. If we consider the cases in which there is excessive exposure to training and competitions, common in our sport, these differences can be even more accentuated (Cortela et al., 2016).

These are some of the reasons associated with the incidence of the Relative Age Effect youth's tennis, where, in general, we find a significantly higher number of tennis players born in the first two quartiles of the year in important competitions rankings and/or brackets, alerting to possible errors that may be occurring in the sports training and selection models (Agricola et al., 2024, Ribeiro Júnior et al., 2013; Pacharoni et al., 2014).

Even playing styles and patterns can influence the results achieved in youth's tennis. The slower speed of the game, in these stages, makes it possible for purely defensive athletes to obtain good performances in outstanding competitions (Fernandéz, 2007).

The eagerness to achieve results quickly, combined with the inability to consistently generate powerful and/or accurate shots, leads many tennis players to refrain from using offensive strokes, seeking to force errors from opponents, without taking risks. If, on one hand, these athletes end up winning many matches because they make few mistakes, on the other hand, they fail to develop the necessary tools to perform well at the highest performance, dissociating their training process from the demands necessary to obtain expressive results in the future (Balbinotti et al. 2005).

But, if we are not able to equate all these factors, how can we evaluate "weight by weight" the true potential presented by two young tennis players, considering only the results achieved momentarily?

It is with this question and from this perspective that we close this section, inviting all stakeholders and institutions involved in LTAD to reflect on their role, the way they see competition and the weight they attribute to the results achieved in this period.

CONCLUSION

The diversity of factors that influence the performances achieved in youth's tennis demands caution in the analysis of the results obtained in this period. This is because, just by eliminating the momentarily advantages obtained by a more advanced maturational stage or by greater experience, for example, these may not be repeated in adulthood.

Developing tennis players for high performance requires a careful approach from all the stakeholders involved, respecting the children/young people, their needs, and expectations throughout the various stages of development, before the tennis athlete.

CONFLICT OF INTEREST AND FUNDING

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RECOMMENDED ITF TENNIS ACADEMY CONTENT (CLICK BELOW)

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7 Important Lower Body Muscles for High Performance Tennis Players

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ABSTRACT

This article specifically focuses on the muscle groups of the tennis player's lower body. Although multi-joint exercises such as squats and lunges are very important and often highlighted in the development of a lower body exercise program for tennis players, they often focus primarily on the major muscle groups such as quadriceps, hamstrings, gastrocnemius and soleus. This article, however, focuses on muscles that coaches and players may not be as familiar with but may be just as important for success on the court. These, often lesser known muscles help tennis players with the development of important strength, stability and joint integrity, as well as overall performance enhancement and injury prevention.

Key words: strength and conditioning, lower body muscles, stability, preserving joint integrity.

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INTRODUCTION

Studies have explored the processes associated with successful on-court movement including insight into the physical demands of tennis movement and the requisite physical skills. Further descriptive research through interviews of strength and conditioning coaches involved in the development of tennis-specific movements in professional men's and women's tennis has highlighted concepts representative of "good" tennis movers. The established themes showed three "styles" of "good" movers in modern professional tennis: those who were "fast" around the court, those who "read the play" well, and those who were "efficient" in their movement (Kovacs et al., 2008; Giles et al., 2018; Roetert & Kovacs., 2019). The results of these previous investigations can assist and support the further design of a training work-out for the lower body, in addition to the often recommended exercises such as squats and lunges. Both those are multi-joint exercises and form the basis of many overall exercise programs. They certainly also serve a significant purpose in training tennis players, because they involve the major muscle groups of the lower body. The muscle/muscle groups highlighted are not the only ones that could have been selected, but in our opinion they certainly qualify for a "top 7" list. The functionality of each of these muscles is described in further detail throughout the text in this article.

1. Gluteus Medius
2. Illiacus
3. Psoas
4. Gemelles (Superior and Inferior)
5. Obturator (Internus and Externus)
6. Peroneus Longus
7. Peroneus Brevis

PROVIDING STABILITY WHILE CHANGING DIRECTION

Virtually everyone has heard of the gluteus maximus, the muscle that forms most of the buttock in humans and upright walking animals. However, many of you may not know one of the other important muscles called the gluteus medius. This muscle arises off the side of the pelvic girdle and inserts into the top of the femur or thigh bone. In addition to playing a huge role in abduction, moving our legs to the side (away from the midline of the body), such as during lateral movements on the tennis court, this muscle also stabilizes the pelvis and trunk during virtually all movements, such as lunging and squatting. Weakness in this muscle can lead to stability issues in the hip and an inability to keep the pelvis and spine aligned properly during all movements.

RECOMMENDED EXERCISES

Exercise #1 – Stand on One Leg

Tennis Focus

The gluteus medius muscle is a stabilizer of the pelvis and activates to keep the pelvis level when standing on one leg. Failure to keep the pelvis level whist standing on one leg leads to a hip drop (opposite side hip dropping downward relative to the stance limb) a deviation called a Trendelenburg deficit. This deficit is tested by doing a single leg stability test which involves standing on one leg and doing a mini (1/3rd) squat. A hip drop in a player doing this maneuver indicates weakness of the gluteus medius and highlights the need to do the exercises below to optimize lower body movement and stability and also protect the lumbar spine in tennis players.

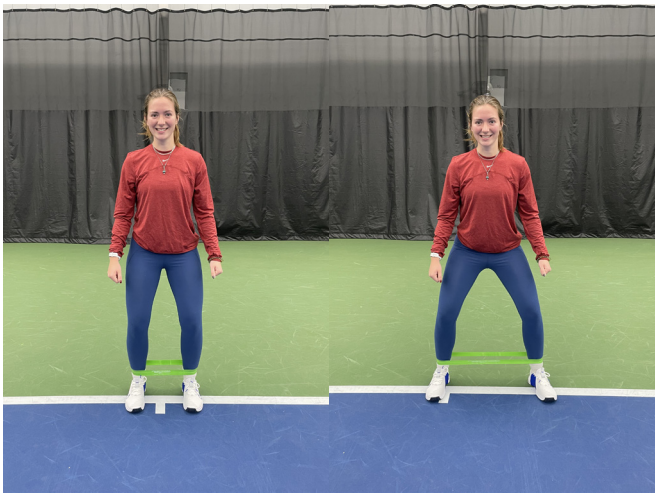
Execution

- Perform this exercise holding the position of standing on one leg for 30 seconds and then switch legs
- As a variation (slightly more advanced), add hip flexion, extension, abduction and rotation
- Another variation is to add a 1/3 squat to the original standing position (focus on the level of the opposite hip)

Exercise #2 - Monster Walk

Tennis Focus

The purpose of this exercise is to strengthen the hips and core. Strengthening the lower body muscles equally is a good idea since research with elite tennis player has indicated that lower body strength is most often equal between right and left sides of the body. Performing the monster walk in both directions allows for the player to focus on each leg yet not simultaneously, therefore ensuring a bi-directional training stimulus (Kovacs et al., 2016).



Execution

- Stand with feet slightly closer than shoulder-width apart in an athletic stance. Loop an elastic band just above your ankles.
- Assume an athletic stance/posture with the knees slightly bent, and chest upright while looking forward.
- Take a lateral step with one leg while keeping tension on the band. Keep your head up and keep an upright posture.
- Bring the other leg toward the one you initially stepped with, planting the foot while maintaining tension in the band. Your goal is to maintain a shoulder-width hip position throughout the steps.
- Repeat for 10-15 steps in one direction, then change direction and perform 10-15 steps in the opposite direction. Perform this movement in a slow and controlled manner..
- In addition to doing the lateral (side) movements, players can keep the band with tension between the legs whilst simulating forehand and backhand movements to make the exercise very tennis specific.

FLEXING THE HIP AND STABILIZING THE TRUNK

Illiopsoas

The iliopsoas muscle group is the primary hip flexor and assists in external rotation of the hip joint, playing an important role in maintaining the strength and integrity of the hip joint. It is essential for correct standing or sitting lumbar posture and plays a critical role during walking and running. This muscle group is not all that well known, but like many sports teams is best recognized when performing in synchrony. This group, called the illiopsoas, actually comprises two key muscles: the psoas and the illiacus. Together, these muscles share an identical function, they flex our hip and provide key stabilization for our trunk. Stretching the hip flexors is an important part of preventing hip and lower back injuries. Athletes with chronically tight hip flexors often stand and move with a sway back or excessively curved posture, increasing injury risk. Tightness in the hip flexors also limits hip extension, creating greater loads on the lumbar spine to make up for a lack of hip motion when extending. To illustrate this by example, when hitting a serve, which requires extension of the hips and trunk, a player with tight hip flexors will have to extend the lumbar spine more due to a lack of hip extension to achieve the desired and necessary position, thereby loading the lumbar spine to a greater extent.

Exercise #1 – Hip Flexor Stretch

Tennis Focus

One of the frequent problems in tennis players is not weakness, but rather tightness of these muscles. Playing tennis places the trunk and hips in an often forward flexed or bent position. For example, the ready position causes shortening of the illiacus. This, coupled with the time spent sitting in school or travelling on planes, trains and automobiles in a bent posture, often leads to tightness of this muscle group.

Execution

- Use a table for this exercise. Lie on your back so that the edge of the table hits your legs in the middle of the hamstrings. Bring both knees to your chest.
- While holding one knee tightly toward your chest, slower lower the other leg toward the table. Let the leg hang, and flex the knee to 90 degrees. You should feel the stretch in the front of the thigh and hip region.

HIP STABILITY AND ROTATION STRENGTH

Gemelles and Obturator Muscles: This may be cheating, as these two actually consists of four muscles: the gemelles superior and gemelles inferior as well as the obturator internus and externus. These muscles all work together to provide essential stability to the hip joint and also belong to the lateral hip rotator group. Larger, more commonly mentioned muscles, such as the gluteals and rectus femoris, help to move our leg at the hip joint, but the gemelli and obturator muscles provide much needed hip stability, and help the femur in rotating the hip joint. These muscles are active during virtually all lower extremity movements and are located deep within the hip joint under the gluteal muscles, spanning from your pelvic girdle to the femur or thigh bone. Some people liken these muscles to the rotator cuff in the shoulder. They are muscles you never see, but they work tirelessly to stabilize your hip joint.

Exercise #3 – Hip Rotation Exercise (Alley Hops with 45 Degree Jab Step)

Tennis Focus

Research has indicated the importance of muscular strength balance between dominant and non- dominant side of the lower body (Colomar et al., 2022) as well as adductor/abductor muscular activity as it relates to the tennis player's lower body. This is important for performance as well as injury prevention purposes. In healthy athletes, countermovement jumps were found to be a training method in relation to change of direction performance (Castillo-Rodriguez et al., 2012). Regarding tennis players recovering from a groin injury, adductor/abductor strength ratio deficits may suggest that adductor muscle strength may not fully recovered in these players and are potentially increasing their risk of a repeat groin injury (Moreno-Perez et al., 2017).

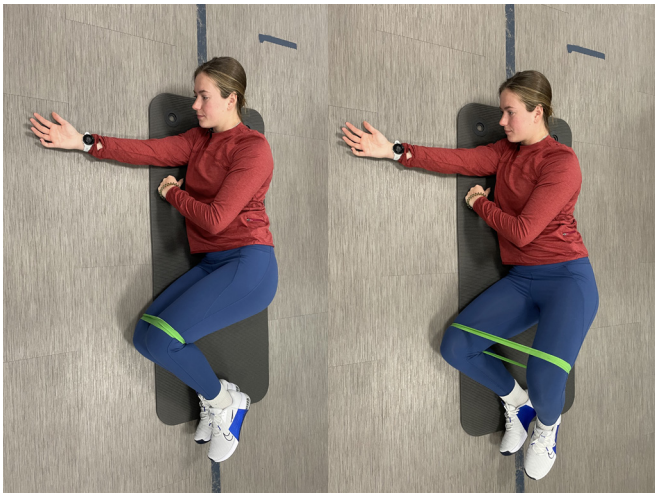
Execution

- Starting on the baseline and facing forward, hop from doubles sideline to singles sideline while making progress toward the net.
- After each fourth hop, make a 45-degree jab step by rotating the right hip externally.
- Turn and face the baseline. Repeat procedure, except on each fourth hop, rotate the left hip externally.
- After each 45-degree jab step push back with the same foot to repeat hopping forward.

Exercise #4 – Clamshell

Tennis Focus

A clamshell is a strengthening exercise that has multiple benefits. This exercise activates several hip, leg, and includes activation of the gluteus muscles, which can increase overall mobility as well as stability. Specifically, it plays a significant



role in abduction as well as some adduction of the hip, which is critical for direction changes of tennis players at all levels.

Execution

- This is a hip abductor and external rotation strengthening exercise. Loop a mini-band or tie an exercise band around the thighs just above the knees.
- Lie down on your side with your knees bent and feet planted together. Raise the top knee without lifting the heel to spread the band apart and to activate the outer hip muscles.
- Two variations of this exercise are recommended. One involves repeating 10-15 repetitions of the movement as pictured with slow controlled movements in both directions.
- The second variation involves raising the leg as pictured and holding that position for pre-set period of sustained time (i.e. 30 seconds). Then repeating several sets of that sustained hold. Both are great variations for a tennis players' training programme.

STABILIZING THE LOWER LEG AND ANKLE

Peroneus Longus & Brevis (ankle stability): Muscles such as the gastrocnemius and soleus in the back of the lower leg seem to get all the credit and recognition as they are very large and visible, but don't forget the peroneals, as they perform a vital function to stabilize your lower leg and ankle. The fibularis longus and fibularis brevis, commonly known as the peroneals, comprise the outside of the lower leg or shin and provide stability to the ankle joint. Both muscles move the sole of the foot outward, away from the midline of the body (eversion) and extend the foot downward away from the body (plantar flexion). Therefore, they play a major role in preventing ankle sprains. Ankle sprains usually refer to injury of the lateral ligaments of the ankle and occur with forced inversion. Since the ankle is less stable in plantar flexion (toes pointed down) sprains often occur when the foot is in this position.

Exercise #5 – Ankle eversion exercise – Two-Foot Slide Shuffle

Tennis Focus

Research indicates that the lower extremities are susceptible to acute injuries such as ankle sprains. In fact, injuries to the lower extremities significantly outnumber injuries to the trunk and the upper extremities, with the ankle being the most common location of acute injuries (Fu et al., 2018; McCurdie et al., 2017; Sell et al., 2014). Therefore, the peroneals, are extremely important to a tennis player, as they act primarily during sudden changes of direction, cutting motions and side-to-side movements. These muscles often become stretched or injured when a player sprains his or her ankle and the foot rolls inward, taking these muscles and the important ligaments on the outside of the ankle joint to (beyond) their limit. When active, these muscles keep the ankle and foot from buckling inward, and without them, your ankle would turn inward with virtually every lateral push-off step or recovery step you take while playing tennis. The fibularis longus and fibularis brevis

are two muscles that help to evert the foot and protect against inversion ankle sprains. Because of this, when the ankle is sprained often the fibularis muscles are strained.

Execution

- This exercise can be performed with shoes on a clay court, or socks on a surface that allows for sliding. Front and back of the feet have to stay connected to the floor/court. Don't be afraid to initiate the movement using your hips.
- Keeping both feet together throughout the exercise, slide heels, then toes to the right for a distance of approximately 10 feet. Repeat the exercise moving to the left.

Exercise #6 – Bosu Ball Squat

Tennis Focus: The peroneal muscles are active stabilizing the ankle during virtually all tennis specific movements. To

increase the activation of the peroneal exercises in a tennis players' training program, performing common traditional exercises (like a one leg squat) on an unstable surface or cushion achieves this goal automatically

Execution:

- Stand on one leg on a Bosu ball or foam (cushion) pad. Ensure use of an athletic posture looking straight ahead (not down) and chest up as pictured.
- Perform whilst maintaining balance, a 1/3rd single leg squat using sets of 10-15 repetitions. Repeat multiple sets.

- You will notice as you fatigue significant wavering of the ankle. The peroneals are an important stabilizer of the ankle and are working very hard to maintain balance and ankle stability during this exercise on the unstable surface.

CONCLUSIONS

This article was developed to increase your awareness of some very important muscles, muscles that often are not given enough credit for what they do for us as tennis players. We have to keep in mind that the larger muscle groups such as the hamstrings, quadriceps, gastrocnemius and soleus play a major role in training the lower body. However, the muscle groups highlighted in this article should certainly not be overlooked even though they may not be addressed in the current literature as often as the larger muscle groups. The related exercises that were selected, complement the training of the highlighted muscle groups and enhance the performance as well as prevent injuries of all players. The exercises were chosen specifically with high performance players in mind and mimic many of the on court related movement patterns.

CONFLICT OF INTEREST AND FUNDING.

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Expectations of tennis officials towards the 32nd Olympic Games: a qualitative study based on the case of certified japanese tennis officials

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ABSTRACT

This study aimed to clarify what expectations tennis officials, as natural persons, held regarding their officiating roles in the 32nd Olympic Games. The participants were 194 Japan Tennis Association certified officials who agreed to participate in the survey. They were asked to describe their expectations for the 2020 Tokyo Olympics. A qualitative inductive analysis of their responses was conducted, and their expectations were divided into five categories: (1) willingness to participate and contribute, (2) difficulties in participation, (3) efforts towards participation, (4) interaction with the world's top players and officials, and (5) future expectations. While many studies have been conducted on the Olympic Games, focusing mainly on athletes and spectators, there have been no studies on those who support the sport, specifically tennis officials. Through this study, it has become clear that the Olympic stage is a rare opportunity for officials, just as it is for athletes, and they harbor high motivation and strong expectations to participate. On the other hand, it was also revealed that officials face challenges and demands.

Key words: tennis, officials, expectations, Olympic

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INTRODUCTION

Sports are constituted by players who participate in the game, spectators who watch the matches, and officials who support the game, such as officials. Tennis officials play a vital role in supporting the game of tennis.

One of the events that many of these tennis officials are aiming for is the Olympic Games. In the case of tennis, officials for Grand Slam tournaments, including line umpires, are reserved for a small elite group recommended by the national associations of each country. In contrast, in the Olympic Games, officials from the host country are given priority in the hiring of officials, which means that more officials can participate than in any other world-level competition. In fact, the 32nd Olympic Games in Tokyo became a major goal for many officials to put their officiating careers on the line (Hotta, 2021) and played an important role in the official development of the Japan Tennis Association (Okamura, 2019).

Many studies on the Olympic Games have been accumulated so far, focusing on athletes and spectators. Studies focusing on athletes include, for example, a study that examined the impact of Olympic performance on athletes' well-being (Bennie et al., 2021) and a study that discussed the impact of the surrounding environment on the performance of Olympic athletes (Gould et al., 2002). And studies focusing on spectators include a study that clarified people's interest in the Olympics, their expectations and concerns, and their demands for broadcasting services (NHK, 2020), as well as a study on the media covering the Olympics (Geurin et al., 2020).

On the other hand, there has been little examination of the significance of the Olympics for those who play a role in supporting sports, especially officials, and what their expectations

were. In this regard, Hotta (2021) indicated that the possibility of participating in the Olympics is one of the most significant motivations for participation in officiating activities, and it is important to clarify what their expectations are as their specific content.

Therefore, this study aimed to clarify what expectations Japanese certified tennis officials had for the 32nd Olympic Games. This study was approached using qualitative methods to focus on the expectations that tennis officials had for the Olympics, which cannot be approached quantitatively.

It is hoped that the expectations that tennis officials had for major events, as revealed by this study, will provide a reference for future policy decision-making regarding tennis officials. Furthermore, in

2023, the Association of Tennis Professionals (ATP) announced the introduction of an automated line-calling system called "Electronic Line Calling Live," which is set to be implemented in all tour tournament programs from 2025 onwards (ATP, 2023). This introduction may reduce participation opportunities for officials in the future (Hotta, 2023). In this context, the insights revealed in this study may serve as important resources for understanding the value that human officials find in their officiating roles.

RESEARCH METHODS

Participants

A survey was conducted on 194 Japan Tennis Association certified officials who consented to participate. The description of the age group, gender, and years of experience as an official are shown in Table 1.

Table 1
Demographics (N = 194).

		Count	%
Age Group	10s	5	2.6
	20s	11	5.7
	30s	5	2.6
	40s	21	10.8
	50s	80	41.2
	60s	56	28.9
	70s	12	6.2
	80s and above	4	2.1
Gender	Men	91	46.9
	Women	103	53.1
Experience(year)	0 - 5	82	42.06
	6 - 10	57	29.23
	11 - 15	17	8.72
	16 - 20	17	8.72
	21 - 25	10	5.13
	26 - 30	8	4.1
	31 - 35	3	1.54

Survey Period

The survey was conducted from October 27, 2017, to April 6, 2018.

Survey Items

The participants were asked to express their thoughts as officials regarding the upcoming 2020 Tokyo Olympics. Participants could opt for either web responses or paper questionnaires based on their age range and the online setting. Web responses were conducted anonymously using a survey page published on the online survey server of the Graduate School of Education at the University of Tokyo. The server employed various security measures and personal information protection protocols. These included SSL/TLS encryption, server certification, firewall access restrictions, and anonymization of input data. Responses to the paper questionnaires were obtained through a self-administered, anonymous postal survey method. The questionnaires were distributed and collected by prefectural tennis associations that consented to cooperate.

Analysis Method

We conducted a qualitative inductive analysis. The reason for choosing this method was to extract common themes from the large and diverse responses of 194 participants and to clarify the structure of the expectations held by officials.

First, we segmented the free-text responses into meaningful units and assigned codes to them. Then, we grouped codes with similar content to create subcategories and assigned names to these subcategories. Further, we grouped subcategories with similar content to create categories and assigned names to these categories.

The analysis was carried out under the guidance of multiple experts in qualitative data analysis to ensure the credibility of the results. Additionally, as demonstrated in the "Discussion" section, we ensured the validity of the analysis by linking the content of the created subcategories and categories to findings from previous studies.

Ethical Considerations

Since the survey was anonymous, the creation of standard consent forms was not feasible. Therefore, an explanatory statement about the purpose of the survey, the voluntariness of responses, and information protection were placed in easily noticeable positions for both web and paper respondents, and responding was considered as consent to participate in the survey.

RESULTS

Table 2 presents the results of the qualitative inductive analysis. The categorized contents included (1) willingness to participate and contribute, (2) difficulties in participation, (3) efforts towards participation, (4) interaction with the world's top players and officials, and (5) future expectations. Representative descriptions of the categorized results are as follows:

Willingness to participate and contribute

The "willingness to participate and contribute" category consists of two subcategories: "desire to participate and contribute to the Olympics" and "desire to contribute to domestic tennis tournaments during the Olympic period." For example, in the "desire to participate and contribute to the Olympics" subcategory, responses included "I have decided to work as an official because I believe it is a once-in-a-lifetime experience, and I want to stand on that stage" and "I would like to help out at the Olympics, which seems like a dream tournament."

Next, in the "desire to contribute to domestic tennis tournaments during the Olympics," responses included "If higher-class officials are called up, I would like to serve as an official at regional tournaments to fill the gap," and "During the Olympics, there will still be tennis-related duties to perform, and I want to do those properly too."

Difficulties in participation

The "difficulties in participation" category consists of three subcategories: "difficulty due to skill-related factors," "difficulty due to age-related factors," and "difficulty due to geographical factors." For example, in the "difficulty due to skill-related factors" subcategory, responses included "I feel anxious about being an official at major tournaments and lack the confidence to participate actively" and "I only have a C-class official's qualification, so I cannot help out."

Table 2

Results of Qualitative Analysis on Officiating Expectations.

Category	Subcategory	e.g.
willingness to participate and contribute	desire to participate in and contribute to the Olympics	I would be happy to be involved in such a significant event in my life.
	desire to contribute to domestic tennis tournaments during the Olympics	If not selected for the Olympics, I want to serve as an official at regional tournaments held during the Olympic period.
difficulties in participation	difficulty due to skill-related factors	I feel anxious about officiating at big tournaments and lack confidence in actively participating.
	difficulty due to age-related factors	I think it is difficult to participate as an official due to my age.
	difficulty due to geographical factors	The distance to Tokyo makes participation difficult.
efforts towards participation	acquisition of knowledge about rules	I want to study more and master the knowledge and rules.
	accumulation of practical experience	I want to participate in many matches, including SCU experience, to increase my experience.
	language learning	I am learning English conversation to become an official.
interaction with the world's top players and officials	watching matches of top world players	Being able to watch games from the perspective of an official is also one of the pleasures.
	observing high-level officials	I want to observe high-level officiating.
future expectations	hiring of officials	Although the development of Hawk-Eye technology is seen, I hope that officials are still hired for the Olympics.
	improvement of the working environment	I hope for a sufficient number of officials to be secured, allowing for more relaxed working hours.
	initiatives to increase the number of officials	I hope for a mechanism to increase the number of officials using the Tokyo Olympics as a keyword.

Next, in "difficulty due to age-related factors," responses included "Due to my age, my judgment and physical abilities are not up to the task, so I probably won't officiate," and "I would like to participate, but I think I will be turned down because of my age."

Lastly, in the "difficulty due to geographical factors" subcategory, responses included "It's difficult to participate because of the distance to Tokyo" and "I mainly limit my activities to local events, so I think it's difficult to contribute."

Efforts towards participation

The "efforts towards participation" category consists of three subcategories: "acquisition of knowledge about rules," "accumulation of practical experience," and "language learning." For example, in the "acquisition of knowledge about rules" subcategory, responses included "I want to study more to master the knowledge and rules" and "First, I want to acquire the qualifications."

Next, in "accumulation of practical experience," responses included "I want to participate in many matches, including SCU experiences, to enhance my experience," and "I need to accumulate experience and train both my skills and mental strength."

Lastly, in the "language learning" subcategory, responses included "I am learning conversational English to be an official" and "I want to study because my vocabulary for dealing with disputes or incidents between players is limited."

Interaction with the world's top players and officials

The "interaction with the world's top players and officials" category consists of two subcategories: "watching matches of top world players" and "observing high-level officials." For example, in the "watching matches of top world players" subcategory, responses included, "Being able to watch the matches from an official's standpoint is also one of the joys," and "If time permits, I would like to watch the games at the venue."

Lastly, in "observing high-level officials," responses included "I would like to see high-level officiating" and "I think it is an opportunity to witness officials from various countries, not just the players."

Future expectations

The "future expectations" category consists of three subcategories: "hiring of officials," "improvement of the working environment," and "initiatives to increase the number of officials." For example, in the "hiring of officials" subcategory, responses included "Despite the development of Hawk-Eye technology, I hope officials will be hired for the Olympics" and "I hope Japanese officials will be hired as much as possible."

Next, in "improvement of the working environment," responses included "I hope a sufficient number of officials are secured, allowing for more relaxed working hours," and "I hope a sufficient number of officials are secured because otherwise, the areas considered to be understaffed will increase, and the quality will decline."

Lastly, in the "initiatives to increase the number of officials" subcategory, responses included "I hope a system to increase the number of officials using the Tokyo Olympics as a keyword is established," and "The Tokyo Olympics is a big motivation as an official, but I think it is important to continue to be active and contribute in the long term, including after the event."

DISCUSSION

In this study, we categorized what expectations tennis officials, as natural persons, have regarding their officiating roles in the 32nd Olympic Games. The participants were 1,580 JTA-certified officials affiliated with prefectural tennis associations who agreed to participate in the survey. They were asked to describe their expectations for the upcoming 2020 Tokyo Olympics. A qualitative inductive analysis of their responses categorized their expectations into five categories: (1) willingness to participate and contribute, (2) difficulties in participation, (3) efforts towards participation, (4) interaction with the world's top players and officials, and (5) future expectations.

Willingness to participate and contribute

The "willingness to participate and contribute" category is composed of two subcategories: "desire to participate and contribute to the Olympics" and "desire to contribute to domestic tennis tournaments during the Olympics." Bernal et al. (2012) reported that financial rewards did not motivate sports officials to continue their activities. The results of this study suggested that financial rewards, the unique opportunity to take part in the Olympics, and the goal of contributing to the tennis community were all motivations for participating as an official.

The "desire to participate and contribute to the Olympics" subcategory showed that officials are motivated to participate in and contribute to the Olympics. Hotta (2018) indicated that one of the motivations of tennis officials is "to support major tournament players (such as Rakuten OP, Tokyo, 2020)." Similarly, this study identified response phrases such as "once in a lifetime" and "like a dream tournament." These indicate that officials recognize the Olympics as a valuable stage for them, not only for athletes, enhancing their willingness to participate and contribute.

Furthermore, the "desire to contribute to domestic tennis tournaments during the Olympics" subcategory demonstrated that officials are motivated to contribute to managing domestic tennis tournaments and the tennis associations' tasks, which continue during the Olympics. As Hotta (2018) shows, one motivation for tennis officials is "to contribute to the tennis community," suggesting that regardless of whether they participate in the Olympics, tennis officials are motivated to contribute to sport.

Difficulties in participation

The "difficulties in participation" category consists of three subcategories: "difficulty due to skill-related factors," "difficulty due to age-related factors," and "difficulty due to geographical factors." This suggests that despite a willingness to participate and contribute to the Olympics, some officials find it difficult to participate because of various factors.

The "difficulty due to skill-related factors" subcategory indicates that officials perceive difficulty in participating in the Olympics due to a lack of skills or qualifications. Tennis officials must have a rich knowledge of rules and advanced judgment skills to respond appropriately and promptly to various problems that arise during matches. Murakami et al. (2017) revealed that higher qualification-level officials possess greater psychological skills than lower-level officials. Thus, a lack of confidence in these skills can lead to the perception that participation as an official is difficult.

The "difficulty due to age-related factors" subcategory indicates that officials perceive Olympic participation as difficult due to the physical and skill deficiencies associated with aging. Murakami et al. (2015) showed that "confidence in physical aspects" affected officials' self-confidence. During the summer Olympics, tennis matches often last over three hours in intense heat. Hence, officials often must make continuous judgments without breaks, necessitating strong physical endurance. Therefore, recognizing physical decline due to aging could hinder participation as an official.

The "difficulty due to geographical factors" subcategory indicates that officials perceive the distance to Tokyo, the Olympic venue, as a barrier to participation. Murakami et al. (2019) reported that long-distance travel could burden officials. Those who work in regions far from Tokyo would need to undertake long-distance travel by plane, making participation in such a tournament a psychological hurdle for officials.

Efforts towards participation

The category of "efforts towards participation" consists of three subcategories: "acquisition of knowledge about rules," "accumulation of practical experience," and "language learning." Anshel and Weinberg (1995) surveyed international basketball referees and identified stressors, including: accusations from players, coaches, and spectators; anxiety about misjudgments; mistakes in positioning; and performance evaluations. Sports officials face various stressors, but acquiring knowledge and practical experience is necessary to overcome these problems and to perform well. The participating officials in the present study seemed highly motivated to gain such experience.

The "acquisition of knowledge about rules" subcategory shows that officials are motivated to learn tennis rules, which are key to officiating. Weinberg and Richardson (1990) indicate that motivation is important for becoming a better official. Murakami et al. (2015) showed that referees who performed domestically and internationally were motivated to stay up to date with the rules. This suggests that officials who wish to participate in the Olympics may be highly motivated to learn, similar to the top referees.

The "accumulation of practical experience" subcategory shows that officials are motivated to accumulate experience by officiating actual matches. Guillen and Feltz (2011) demonstrated that control (success) experiences in actual matches influenced the referees' confidence. Thus, learning rules boosts confidence, and successful performance in real matches also contributes to confidence on the Olympic stage.

The "language learning" subcategory shows that officials are motivated to learn foreign languages. Officials must communicate with players when issues arise during matches. While domestic tournaments in Japan can be managed in Japanese, the Olympic Games are an international event and require communication with foreign players who do not speak Japanese. Okamura (2019) states that communication in foreign languages is necessary when receiving advice from overseas referees. Therefore, language skills are necessary for smooth communication between players and referees in international competitions. Officials are likely to be motivated to acquire these skills.

Interaction with the world's top players and officials

The category of "interaction with the world's top players and officials" consists of two subcategories: "watching matches of top world players" and "observing high-level officials." The Olympics provide an opportunity to engage with famous players and high-level international referees, which may motivate officials to participate.

The "watching matches of top world players" subcategory shows that officials anticipate the opportunity to watch matches of world-class players through their participation in the Olympics. Hotta (2021) indicated that one of the motivations of tennis officials is "to see their favorite players close." With top-ranking players who compete in Grand Slams participating in the Olympics, officials may anticipate a chance to see these players up close.

The "observing high-level officials" subcategory suggests that officials look forward to observing the performance of world-class referees through their participation in the Olympics. Okamura (2019) indicated that there are relatively few international Japanese referees. Given this context, opportunities for Japanese officials to interact with internationally involved referees are expected to be rare; therefore, officials may look forward to such interactions at the Olympics.

Future expectations

The "future expectations" category consists of three subcategories: "hiring of officials," "improvement of the working environment," and "initiatives to increase the number of officials." This implies that officials involved in this study hold certain expectations regarding the Olympics and the future success of domestic tennis officiating post-Olympics.

The "hiring of officials" subcategory suggests that there is an expectation of hiring officials despite the trend towards officiating automation (such as Hawk-Eye). ATP (2023) announced that all tour tournament sites will introduce an automated line-calling system called Electronic Line Calling Live (ELC Live) starting from the 2025 season. Thus, officials must confront the impending development of automated judgment in officiating.

The "improvement of the working environment" subcategory suggests a need to create a space conducive to optimal performance for officials, fostering a surplus of skilled individuals. According to Hotta (2021), JTA-certified officials want better treatment because of their extensive workloads and long hours. Similarly, this study identified requests for improvement, suggesting that many officials hoped for better working conditions.

The "initiatives to increase the number of officials" subcategory suggests a commitment to leveraging the Olympic opportunity to boost the number of officials in the future. Hong and Jeong (2019) highlighted the importance of building a network of officials to maintain the number of soccer referees. Therefore, increasing the number of officials through training courses and events and providing opportunities for referees to interact is essential. Participating officials seem to anticipate maximizing the Olympics' potential to increase their numbers.

CONCLUSION

This study aimed to elucidate the expectations of 194 Japan Tennis Association certified officials regarding their officiating activities at the 32nd Olympic Games. As a result, the expectations of the officials were categorized into five groups: (1) willingness to participate and contribute, (2) difficulties in participation, (3) efforts towards participation, (4) interaction with the world's top players and officials, and (5) future expectations.

While many studies have been conducted on the Olympic Games, focusing mainly on athletes and spectators, there have been no studies on those who support the sport, specifically tennis officials. Through this study, it has become clear that the Olympic stage is a rare opportunity for officials, just as it is for athletes, and they harbor high motivation and strong expectations to participate. On the other hand, it was also revealed that officials face challenges and demands.

Furthermore, this study suggests that officials find joy and value in contributing to others and connecting with others, which becomes a motivation for their officiating activities. Therefore, it is considered important that the use of science and technology in officiating activities should be discussed carefully, taking into account the opinions of the officials.

This study focused on the 32nd Olympic Games held in Tokyo and the Japanese tennis officials as a case study. Therefore, future research examining other Olympic Games and officials from different countries may reveal unique characteristics and challenges specific to those contexts.

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The optimal ready position in tennis

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ABSTRACT

The purpose of this study was to develop a bio-kinematic model for the optimal ready position in tennis by identifying five bio-kinematic variables of the lower limb joints. Additionally, this research aimed to quantify the contribution of these variables to the response time of tennis players. The descriptive method was used in this study based on bio-kinematic analysis as it suits the nature of the study. The study sample consisted of two players who were intentionally selected from high-level tennis players. The study was conducted using video recording with the Kinovea program for five different stances per player in six directions, with a total of sixty attempts for the ready positions. The main findings were: 1- the response time was significantly affected when changing the technique of the ready position, the effectiveness of the ready position significantly impacts the efficiency of the movement, reaching the ball, and performing the stroke well which increases the players' success rate. 2-the angle between thighs is the most contributing bio-kinematic variable in the performance of the ready position, with contribution rate of 88.33%. When the angle between thighs is within range of 70° to 80° the optimal ready position is achieved.

Key words: optimal ready position, bio-kinematic model, bio-kinematic variables, response time.

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INTRODUCTION

The ready position in tennis can be loosely defined as the position a player assumes in preparation for (and during) the split step. The literature agrees that a ready position should be balanced and sufficiently 'active' to allow for a dynamic movement response to any stimuli (Aviles, 2002).Correct body position produces power angles in the lower body, these help produce force and speed of movement (Dawes & Roozen, 2012).All movement production in tennis can be considered to fall into one of four categories: baseline to net, close rang movement, wide ball and recovery and sprint (Farrauti & Weber, 2001), the precursors to all of these tennis movements are the ready position and the split step. (Elliott, Reid & Crespo, 2003, p. 73). Thus, an effective ready position is essential for an effective movement pattern. The ready position in tennis requires an athletic stance with feet positioned shoulder-width apart (Crespo, 2008), however, this study shows that the optimal ready position in tennis requires a wider stance to achieve the best response time. Bio-kinematics is the measurement of the motion of living things. The bio-kinematics of tennis could be useful in providing the coach with more specific and precise information about the timing and motion of the player's body. (Elliott, Reid, & Crespo, 2003, p. 149). Response time is defined as the duration from the appearance of the stimulus until the completion of the movement (Brekaa, 2015). This study employed bio-kinematic analysis to determine the optimal angles at which tennis players should position themselves in the ready position to achieve the most efficient response time, by analyzing five different ready positions and assessing their effectiveness in response time across all six directions (3 forehand and 3 backhand), starting with the feet shoulder-width position and incrementally increasing the distance between feet by 15 cm for each subsequent position, a total 60 ready positions (N=60).

METHODOLOGY AND PROCEDURE

Subjects

The study sample comprised two International Tennis Federation (ITF) players, aged 17, with high national rankings (ranked 1st and 3rd in Egypt under 18 category). Each player executed the five ready positions in six directions, 30 attempts per player.

Materials

2 cameras with 60 frame/sec speed, cones, meter measuring tape to determine the distance between feet in each ready position, the movement analyzing program Kinovea, version 0.9.5 and the statistical program SPSS version 29.

Analysis variables

6 variables were extracted from the lower limp in each ready position.

Table 1
Variables symbols and measuring units.

Variable	symbol	Measuring unit
Front Angle between thighs	A1	degree
Side angle between thigh and tibia	A2	degree
Side angle between tibia and foot	A3	degree
Distance between knees	DK	cm
Distance between feet	DF	cm
Time	T	sec

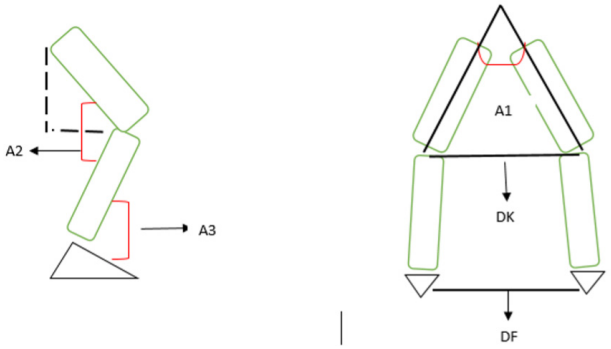

Figure 1. *Kinematic variables of ready position.*

Procedure and statistical analysis

In this study, a customized test was used. The player stood in the middle of the court behind the baseline, approximately 50 cm from the center, surrounded by six cones placed 2.5 meters apart, with three on the forehand side and three on the backhand side. This setup ensured that the player operated within the area where 80% of all shots are played (Kovacs, 2009). The player began in their ready position, executed a split step, and responded to visual stimuli, prompting movement towards any of the cones

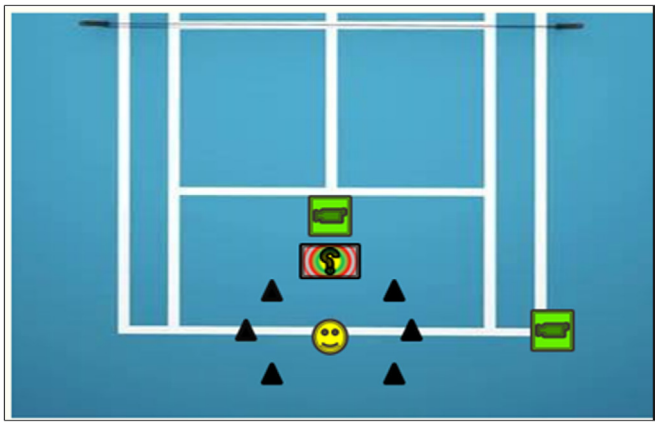

Figure 2. *Study suggested on-court test.*

After completing the on-court test, videos were captured and analyzed using Kinovea software. Each ready position was analyzed to determine the variables, followed by initiating a timing sequence from the moment the player reacted with their split step until their loading leg reached the designated cone. After that the results were statically analyzed using stepwise regression to determine the contribution percentage of variables (A1, A2, A3, DK, and DF) to the response time (T).

RESULTS AND DISCUSSION

Based on the statistical analysis results (Table 2), the average contribution percentage of measured kinematic variables was 99.224%. Variable (A1) achieved an average percentage of 88.334%, while all other measured variables averaged 10.89%. The average response time was 0.944 seconds.

Front Angle between thighs (A1)

Table 2 indicates that angle (A1) is the most contributing kinematic variable, contributing to an average of 88.33%. Comparing the lowest response times achieved by the samples with the angle (A1), as per the bio-kinematic analysis results obtained from Kinovea software (Table 3), we found that the angle (A1) ranged between 70° to 80°, with an average of 77°.

Side angle between thigh and tibia (A2)

Also, table 2 indicates that angle (A2) is the second most contributing kinematic variable, contributing to an average of 8.474% comparing the lowest response times achieved by the samples with the angle (A2), as per the bio-kinematic analysis results obtained from Kinovea software (Table 4), we found that the angle (A2) ranged between 110° to 145°, with an average of 122.5°.

Side angle between tibia and foot (A3)

Also, table 2 indicates that angle (A3) is the third most contributing kinematic variable, contributing to an average 1.828% comparing the lowest response times achieved by the samples with the angle (A3), as per the bio-kinematic analysis results obtained from Kinovea software (Table 5), we found that the angle (A3) ranged between 50° to 95°, with an average of 72.5°.

Distance between feet (DF)

The distance between feet (DF) is considered an unessential and unaffected kinematic variable in widening angle (A1). For instance, while (DF) may be wide, if the distance between knees (DK) is short, it will result in a small angle (A1). However, the opposite is not true; if (DK) widens, (DF) will expand.

Table 2
The percentage contributions of kinematic variables according to the time in the six-performance region.

S	ZONE	Contribution percentage				TIME	TOTAL	RANK
		A1	A2	A3	DK			
1	Cone 1	87.369	9.278	1.743	0.562	1.023	98.952	5
2	Cone 2	87.747	8.647	1.778	0.514	1.002	98.686	6
3	Cone 3	90.126	6.852	2.094	0.714	0.876	99.786	1
4	Cone 4	88.610	8.432	1.782	0.550	0.881	99.374	2
5	Cone 5	87.978	8.922	1.743	0.567	0.951	99.210	4
6	Cone 6	88.172	8.712	1.827	0.623	0.930	99.334	3
	AVERAGE	88.334	8.474	1.828	0.588	0.944	99.224	

Table 3
Comparison between the lowest response times achieved by the samples and the angle (A1).

	Cone6		Cone5		Cone4		Cone3		Cone2		Cone1	
	T	A1	T	A1	T	A1	T	A1	T	A1	T	A1
PLAYER 1	0.69	78	0.66	80	0.69	75	0.69	75	0.85	76	0.85	76
PLAYER 2	0.89	79	0.92	72	0.85	78	0.85	77	0.85	76	0.92	77

Table 4
Comparison between the lowest response times achieved by the samples and the angle (A2)

	Cone6		Cone5		Cone4		Cone3		Cone2		Cone1	
	T	A2	T	A2	T	A2	T	A2	T	A2	T	A2
PLAYER 1	0.69	118	0.66	136	0.69	125	0.69	111	0.85	144	0.85	145
PLAYER 2	0.89	119	0.92	127	0.85	110	0.85	113	0.85	121	0.92	117

Table 5
Comparison between the lowest response times achieved by the samples and the angle (A3)

	Cone6		Cone5		Cone4		Cone3		Cone2		Cone1	
	T	A3	T	A3	T	A3	T	A3	T	A3	T	A3
PLAYER 1	0.69	88	0.66	92	0.69	75	0.69	51	0.85	92	0.85	68
PLAYER 2	0.89	94	0.92	71	0.85	79	0.85	86	0.85	81	0.92	90

Distance between knees (DK)

Statistical analysis reveals that the distance between knees (DK) exerts a greater influence and significance compared to the distance between feet (DF), with (DF) being considered a dependent variable of (DK). (DK) emerges as the pivotal variable for expanding the player base, as it is directly impacted by the angle (A1). Specifically, widening the angle (A1) results in an expansion of the distance between knees (DK), which subsequently leads to a widening of the distance between feet (DF).

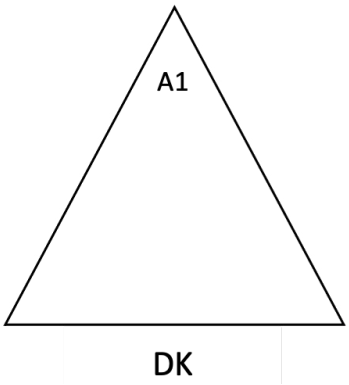

Figure 3. *Relationship between angle (A1) and (DK).*

Balance pyramid

Variables (A1, A2, DK) form a pyramid shape we named it the 'Balance pyramid' (Figure 4), wherein point 1 represents the center of gravity (CG), points 2 and 3 denote the knees, and point 4 lies vertically below CG and horizontally behind the knees. Angle (A1), the angle between sides 1-2 and 1-3, emerges as the most influential variable based on statistical analysis. Changes in this angle alter the base space, represented by the distance between knees (DK) side 2-3. According to biomechanical principles, a widening base enhances body balance and stability. Therefore, angle (A1) is crucial in determining the extent of stability and balance in the ready position, optimizing efficiency and reducing response time

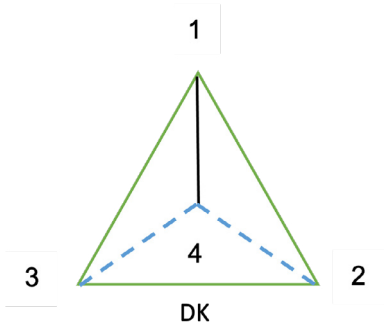

Figure 4. *Balance pyramid.*

Differences between male and female tennis players

There is a difference between male and female tennis players due to the anatomical differences in female thighs, which have inner curves (Q angle) of approximately 5 degrees on each side (Mitani, 2017). This results in their optimal average range for the angle (A1) being between 60° and 70°. However, this research was conducted on male tennis players.

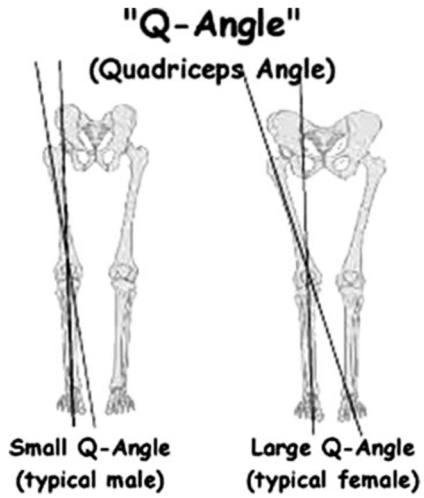

Figure 5. *The difference of Q-angle between male and female (Becker, 2016).*

CONCLUSION

From this study we can conclude:

1-The response time was significantly affected by changes in the ready position technique, which constitutes the initial phase of the tennis footwork pattern for each stroke. The efficiency of the ready position technique influences the entire footwork pattern and enhances the success rate in reaching the ball.

2-The angle between the thighs (A1) emerges as the most influential variable in determining the optimal ready position. When this angle falls within the range of 70° to 80°, the distance between knees (DK) widens, subsequently leading to an expansion of the distance between feet (DF) beyond the width of the player's shoulders. As a result, the ready position becomes more effective.

3-The variables (A1, A2, and DK) form a pyramid shape that we have termed 'The Balance Pyramid'. This structure serves as an indicator of the quality of the player's ready position when controlling for all other variables to achieve the optimal ready position.

SUGGESTIONS FOR FUTURE STUDIES

1. Examine the kinematic variables of the optimal ready position compared to other positions in tennis, with a focus on the kinematic variable angle (A1).

2. Investigate the optimal ready position in other sports that have similar movement patterns.

CONFLICT OF INTEREST AND FUNDING

The author declares that he does not have any conflict of interest and that he did not receive any funding to conduct the research.

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The beneficial effects of a mindfulness programme on self-efficacy, emotion management and tennis performance

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ABSTRACT

This study aimed to test the effects of a mindfulness programme on self-efficacy and performance in the short game of ball-throwing, as well as anxiety and the ability to manage emotions in an official match. Sixteen male players (M = 22.4 years) of regional level, ranked between 30/1 and 15/3 (FFT), volunteered to participate in this study. They were randomly divided into 2 groups: Control and Mindfulness, they carried out 3 experimental phases: Pre-test (30 forehands and backhands with a ball launcher + tournament match), acquisition (6-week programme of mindfulness training or listening to music), and post-test (identical to the pre-test). Pre-competitive anxiety and self-efficacy scores, ball-throwing performance, and the number of positive and negative gestures and speeches during matches were recorded during the pre-and post-tests. The results of this study show that mindfulness training increases the feeling of self-efficacy and the performance of the ball thrower and reduces the number of negative gestures and speeches made by players in competition. Although the results of this experiment need to be confirmed, they show the value of developing tennis players' mindfulness skills.

Key words: mindfulness, tennis, competition, performance, self-talk.

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Tennis is a sport that involves hitting a ball, with a racket, to send it down the court once more than your opponent (Martin, 2018). According to Reid et al (2007), playing tennis requires technical, tactical, perceptive, physical, and mental skills. Whether in training or competition, players have to deal with problems of concentration, anxiety, or stress that can affect their performance (Daino et al., 2021). Therefore, It is important to find strategies for better managing stress, attentional resources, and emotions experienced during matches or training sessions (Crespo et al., 2006; Robin et al., 2023). The development and integration of mental skills and techniques into practice are now widely recognised as a key factor in sports performance (Foster & Chow, 2020; Mamassis & Doganis, 2004). Thus, the use of techniques such as mental imagery (Robin & Dominique, 2022), relaxation (Cece et al., 2020), self-talk (Robin et al., 2021) or mindfulness (Van de Braam & Aherne, 2016) is increasingly common among tennis players and coaches.

Mindfulness is a voluntary meditative practice that consists of being aware of the present moment without judgment (Kabat-Zinn, 2003). It involves three stages: lucidity (i.e. awareness of the thoughts or emotions of immediate experience), acceptance (i.e. a non-critical attitude towards the thoughts, emotions, or bodily sensations experienced), and refocusing (i.e. refocusing on one's objective, strategy, or breathing). In a sporting context, mindfulness can help players improve their concentration and better manage their stress or emotions (Baltzell, 2016; Gardner & Moore, 2007). In addition, it could have an impact on the internal discourse verbalised aloud (Boudreault et al., 2016; Van Raalte et al., 2000) or the body language of players (Martínez-Gallego & Molina, 2019), which can influence performance (Martin, 2018). For example, the 'Mindfulness For Performance' (MFP; Fournier, 2021) programme has been specifically developed to improve sports performance and has shown positive effects in basketball and table tennis (Tebourski et al., 2022).

The aim of this original study was to evaluate the effects of a mindfulness training programme on pre-competitive anxiety, self-efficacy, the ability to manage emotions and performance in a back-court task with a ball-thrower and in an official match in competitive tennis players at a regional level.

METHOD

Sixteen male players (M = 22.4 years), ranked between 30/1 and 15/3 (French Tennis Federation) and who had been playing tennis for more than 6 years, volunteered to participate in this study. After signing a consent form, the participants were

randomly assigned (by drawing lots) to 2 experimental groups: Control (N = 8) or Mindfulness (N = 8). The players underwent 3 experimental phases: pre-test (30 forehands and backhands with a ball launcher + 1 tournament match), acquisition (6-week mindfulness training programme or listening to music), and post-test (30 forehands and backhands with a ball launcher + tournament match). This study, approved by the ethics committee of the ACTES laboratory (Urp5-4) at the University of the West Indies, was carried out following the Helsinki Declaration.

PROCEDURE

The experiment took place at the Amicale Tennis Club (Le Gosier, France), on outdoor hard courts. After the presentation of the study and the signature of the consent form, the participants carried out the 3 experimental phases.

The pre-test consisted of a back-court exercise with a ball launcher and a match in official competition (2 winning sets or a super tie break in the event of a tie at one set all). The test carried out with the ball launcher (Lobster Elite 2 type) consisted of returning 5 blocks of 6 balls from the baseline (the 30 balls were sent at high speed: 75 km/h and with an inter-ball delay of 2 seconds), with forehand and backhand shots. The instruction was to return the ball to the opposite side of the court. The accuracy of the returns (Figure 1), the speed of the balls (measured with a cordless R1000 radar gun), and the fouls committed (recorded with Swingvision software installed on an iPad pro) were recorded by the experimenters. Before carrying out the 30 strikes in the test, the players were asked to complete a self-efficacy questionnaire on their success in the ball-throwing exercise: "I think I can make at least x returns in the target zone out of the 30 balls", "yes or no", using six increasingly difficult statements ranging from 5 to 30. Finally, before the competitive match against a player of a similar ranking, the participants completed a questionnaire measuring their state of anxiety (Saviola et al., 2020 scale comprising 20 items, covering feelings and emotions experienced, assessed using a Lickert scale ranging from 1 'almost never' to 4 'almost always').

The number of gestures and speeches (positive, such as encouragement or closing the point, and negative, such as lowering the head or shoulders, huffing or cursing after a foul) during the match were also recorded by 2 experts, coaches, and referees, in a double-blind test.

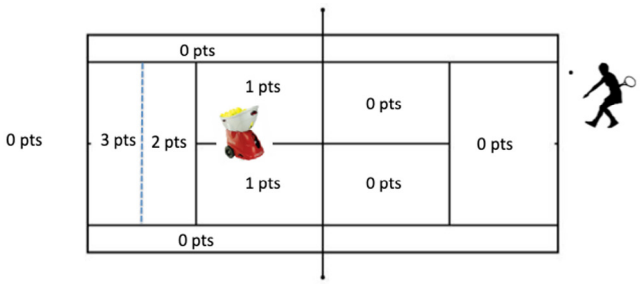

Figure 1: *Accuracy score in the ball-throwing test.*

The acquisition phase, which took place over 6 weeks, consisted of listening to an audio recording (background music without words) for the Control group or carrying out the "Mindfulness for Performance" programme (MFP, Fournier & Bernier., 2023) for the Mindfulness group. The MFP includes a daily meditative practice of about 10 minutes for the duration of the programme, administered with audio recordings sent to the mobile phones of the players in the Mindfulness group. In the first stage of the MFP, the players were asked to identify and use a personalised focus of attention (e.g. their breathing), after which mindfulness was introduced and practised with brief exercises (see Table 1). In 2ème time, acceptance was developed to help participants in the Mindfulness group to manage their negative sensations or feelings rather than blocking them. In a 3ème time, the skills of mindfulness and acceptance were integrated into the practice: the players had to become aware of the physical and psychological distractions occurring in the present moment, accept them, and refocus on their point of attention (see Fournier & Bernier, 2023 for a similar procedure).

DESCRIPTION OF THE MFP PROGRAMME

Table 1

Description of the 6-week "Mindfulness For Performance" programme (MFP, Fournier & Bernier., 2023).

Description of the MFP programme	
Week 1	Long scan (once a day for 7 days) and long sitting breathing concentration session (once a day for 7 days)
Week 2	Short scan (once a day for 7 days) and alternating between a long session of concentration on breathing in a seated position (once a day for 4 days) and a long session of concentration on breathing in a standing position (once a day for 3 days).
Week 3	Short scan (2 times a day for 7 days) and alternating between a long session of concentration on breathing in a seated position (1 time a day for 4 days) and an intermittent session of 1 minute of mindfulness / 1 minute of free activity (1 time a day for 3 days).
Week 4	Short scan (3 times a day for 7 days) and alternating between a concentration session on emotions and thoughts (1 time a day for 3 days), a long concentration session on breathing in a seated position (1 time a day for 2 days), and an intermittent session of 1 minute of mindfulness / 1 minute of free activity (1 time a day for 2 days).
Week 5	Short scan (3 times a day for 7 days) and alternating between a concentration session on emotions and thoughts (1 time a day for 3 days), a long concentration session on breathing in a seated position (1 time a day for 2 days), and an intermittent session of 1 minute of mindfulness / 1 minute of free activity (1 time a day for 2 days).
Week 6	Short scan (3 times a day for 7 days) and alternating sessions of concentration on emotions and thoughts (1 time a day for 3 days), a long session of concentration on breathing in a seated position (1 time a day for 2 days), and an intermittent session of 30 seconds of mindfulness / 30 seconds of free activity (1 time a day for 2 days).

The post-test was identical to the pre-test.

During these tests and matches, new balls (Head pro) were used. In addition, scores for self-efficacy, pre-competitive anxiety and return accuracy, ball speed, number of faults, positive and negative speeches, and positive and negative gestures were measured or recorded. Normally distributed dependent variables (Kolmogorov-Smirnov tests) were subjected to repeated-measures ANOVAS (pre-test vs. post-test) with independent groups (control vs. mindfulness). Post-hoc analyses (Newman-Keuls test) and an alpha threshold of .05 were used.

RESULTS WITH THE PITCHING MACHINE

Statistical analysis revealed that the players in the Mindfulness group improved their self-efficacy score (+30%) between the pre-test and post-test ($p < .05$), whereas that of the Control group remained stable (-5%) between tests (see Figure 2 A).

The ANOVA on the speeds of the returns to the back-court exercise performed with the ball-thrower showed no significant difference between the groups (Mindfulness and Control) or between the tests (ps > .05).

The ANOVA on the ball-throwing accuracy scores showed that all the players improved their performance (+10% for the Control group and +46% for the Mindfulness group) between pre-and post-test ($p < .01$), but also that the Mindfulness group outperformed the Control group at post-test ($p < .05$), as shown in Figure 2 B.

The ANOVA on the number of fouls (-15% for the Control group and -45% for the Mindfulness group) committed during the ball-throwing exercise showed that the players in the 2 experimental groups reduced the number of fouls between the pre-and post-test ($p < .05$), and that the players who benefited from the mindfulness programme made fewer fouls in the post-test than those in the Control group ($p < .05$), see Figure 2 C.

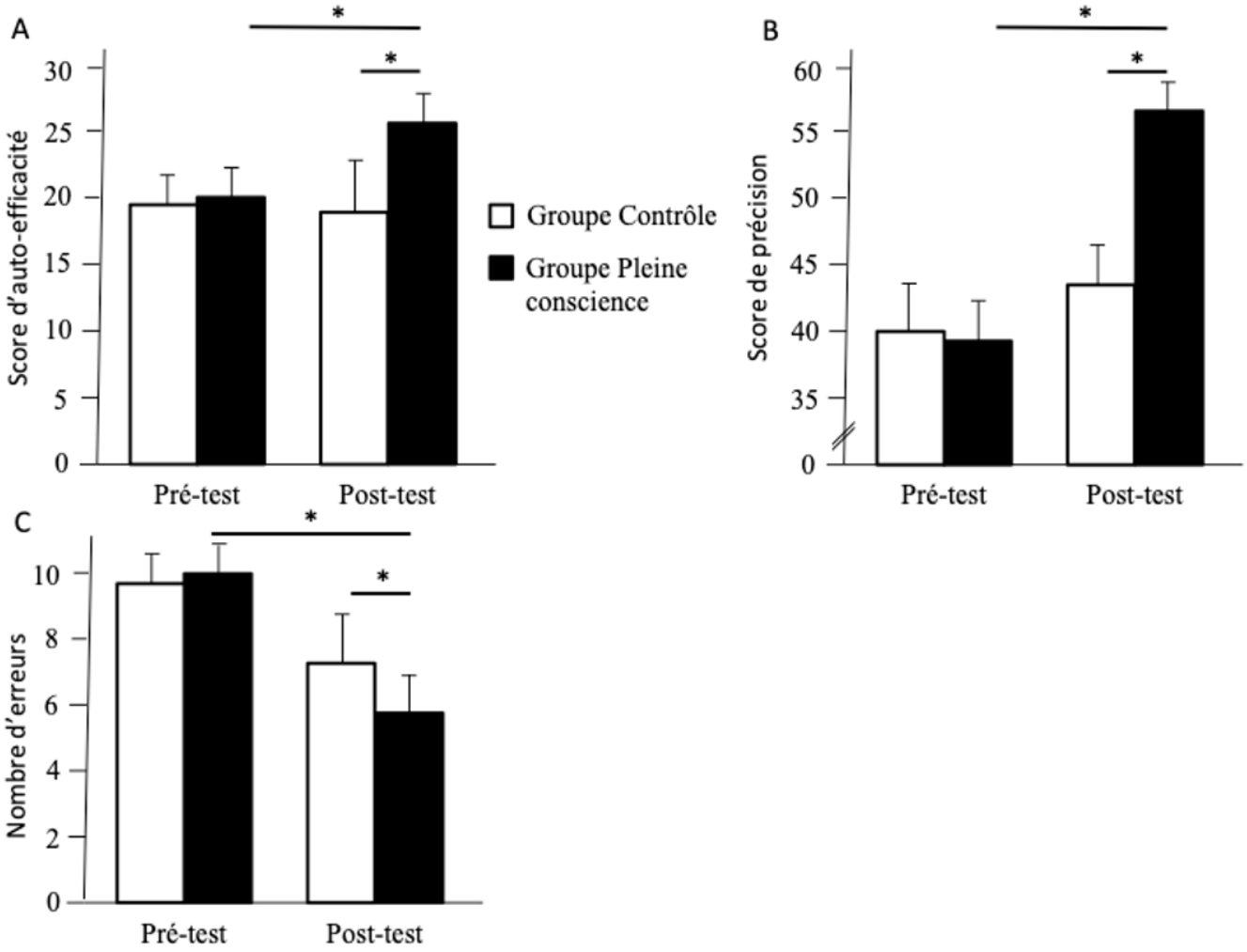

Figure 2: *Scores for self-efficacy (A), performance (B) and number of errors (C) in the ball-throwing exercise for participants in the Control (white) and Mindfulness (black) groups, in the pre- and post-tests (* p < .05).*

COMPETITION RESULTS

Statistical analysis of the pre-competitive anxiety score did not reveal any significant difference between groups or between tests (ps > .05), but did reveal a trend (p = .06) of a decrease in the pre-competitive anxiety score between the pre-test and the post-test (-12%) for participants in the Mindfulness group.

Similarly, the statistical analyses carried out on the number of positive gestures and the number of positive speeches, in matches, did not reveal any difference between the groups (ps > .05) or between the tests (ps > .05).

On the other hand, the ANOVA on the number of negative gestures and speeches recorded during the match showed that the players in the Mindfulness group reduced the number of negative gestures (p < .05; see Figure 3 A) by 42% and the number of negative speeches (p < .05) by 33% between the pre-test and the post-test, and made fewer negative speeches in the post-test (p < .05) than the players in the Control group (see Figure 3 B).

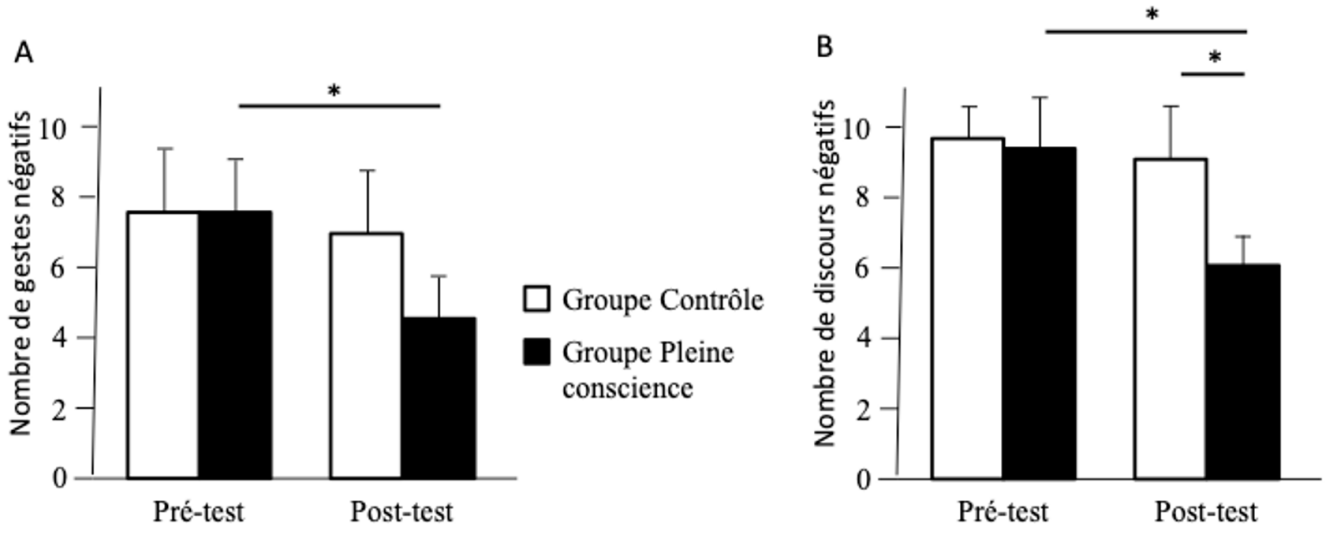

Figure 3: *Averages of the number of negative gestures (A) and negative speeches (B) observed in a match for participants in the Control (white) and Mindfulness (black) groups, during the pre- and post-tests (* p < .05).*

DISCUSSION

The aim of this experiment was to evaluate the effects of a 6-week mindfulness training programme on pre-competitive anxiety, feelings of self-efficacy, the ability to manage emotions and performance in regional-level competitive tennis players.

Firstly, the results of this study show the beneficial effects of the MFP mindfulness programme on performance in the ball-throwing exercise. Indeed, the players who developed their mindfulness skills using the MFP programme obtained better scores and made fewer errors than the participants in the Control group. These results confirm those of previous research studies showing the beneficial effects of mindfulness in sport (Baltzell, 2016) and particularly in tennis (Hoja & Jansen, 2019). The latter authors have, for example, observed positive effects of mindfulness on players' concentration and accuracy when serving, confirming the beneficial effects of this mental technique on motor performance (e.g., Gooding & Gardner, 2009; Nien et al., 2020; Tebourski et al., 2022). In addition, the results of our study showed an increase in the self-efficacy score in participants who had benefited from the MFP programme, confirming the results of a recent study showing a positive effect of mindfulness on the feeling of self-efficacy (Chandna et al., 2022).

In addition, this mental technique can also be used for stress management (Chang et al., 2004), for example by reducing the number of negative gestures and speeches, as observed in this study, which can be a source of stress during a match. In addition, although not significant, the results of this study also showed a trend towards a reduction in pre-competitive anxiety in players who had followed the MFP mindfulness programme, indicating that this technique could help to better manage pre-match stress. The effects of the MFP programme on reducing anxiety, observed in participants in the Mindfulness group, are in line with previous work in the literature which has shown that mindfulness has a positive influence on reducing anxiety (e.g., Dheghani et al., 2018; Wolsh et al., 2021).

Finally, in addition to a reduction in the number of negative speeches and gestures during matches, we also observed an improvement in accuracy and a reduction in errors when throwing the ball. It is highly likely that the development of lucidity, acceptance, and 'refocusing' skills during the MFP programme helped the players in the Mindfulness group to improve their concentration, particularly during the ball-throwing accuracy exercise, and to better manage their emotions felt during the competition (Baltzell, 2016), resulting in a reduction in negative verbalized aloud internal gestures and speech that can have deleterious effects on sports performance (Boudreault et al., 2016; Martínez-Gallego & Molina, 2019). For this reason, we recommend that players, trainers, and coaches use exercises to develop and then maintain the skill of mindfulness, which can have positive effects on tennis performance (Van de Braam & Aherne, 2016).

This experiment is not without its limitations. Indeed, this exploratory study involved a limited number of participants (N=16). Although the sample size is like that of other studies in the field (e.g., Hoja et al., 2019), further research with larger samples seems necessary before any generalisation. In addition, the measures of speech and gestures (positive and negative) only covered one match. In future research, it would be interesting to measure these variables over a larger number of matches (both pre-tests and post-tests), while trying to control the duration of the matches with, for example, multi-chance tournament-type competitions (MCT with 4 games per set and no advantages) for the pre-and post-tests. Finally, as this study was only carried out with men, it would be interesting to see whether similar results could be observed with a female population.

CONCLUSION

The results of this experiment show that developing the capacity for mindfulness, through the MFP programme, increased tennis players' sense of self-efficacy and their performance in a cross-court exercise using a ball thrower. In addition, the development of mindfulness skills enabled regional-level competitors to reduce the number of negative external gestures and self-talk during competition. These results lead us to suggest that tennis players and coaches develop and maintain mindfulness skills, using the Mindfulness For Performance (MFP) programme for example.

CONFLICT OF INTEREST AND FINANCING

No conflicts of interest are to be declared for this study, which received no funding.

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Elite player development through the lens of Bronfenbrenner's bioecological model

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ABSTRACT

This article aims to highlight the inherent complexities of elite player development, unravelling the entanglements that could enable coaches and national organisations to move beyond a focus on early-age specialisation and domestic-level results. Bronfenbrenner's bioecological model of human development was originally proposed to explain how human development occurs, focusing largely on the impact of context and remains an evolving theoretical system for the scientific study of human development over time. Drawing extensively on Bronfenbrenner this article explores the interplay of processes across nested levels (e.g., microsystem, mesosystem, exosystem, macrosystem), that can potentially shape tennis development at an international level. The article first outlines the application of a social-ecological framework, which is useful for conceptualising how individual, social and environmental factors, and their interactions over time, may relate to consistent behaviours (e.g., application to training) and subsequent longer-term developmental outcomes (e.g., junior to senior transition). From a coach education perspective, the article then aims to provide practical suggestions to consider for healthy and successful international player development.

Key words: player development, coach education, long-term development, socio-ecological development model.

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INTRODUCTION

Inspired by Lewin's (1936) renowned theory of behaviour, Bronfenbrenner's (1979) framework for the ecology of human development examines individual behaviours within social and physical contexts. Bronfenbrenner's ecological theory can be applied to consider dynamic relationships with the player, interacting within an environment structured as a series of nested systems. He posits that complex individual behaviours (e.g., short and long-term player development) can be understood by exploring four neighbouring systems: the micro-, meso-, exo- and macrosystems (Bronfenbrenner, 1988). Bronfenbrenner explains how positive (e.g., healthy player development), or negative (e.g., burnout/dropout) outcomes arise through frequent and sustained social exchanges within microsystem contexts. Bronfenbrenner (2005) emphasises the importance of social exchanges concerning individuals (e.g., between players, players/coaches), within microsystems consisting of interactional relationships where the individual operates. Over time, ongoing interactions are proposed to bi-directionally influence the individual's psychosocial functioning, determining potential directional development (e.g., elite player development or dropout). Consequently, Bronfenbrenner's theory can be applied to explain how coaching strategies, practice and associated environmental features, all convey information and meaning to individual participants (Moulds et al., 2020). Players and significant others (e.g., parents, carers, other coaching staff), experiencing the microsystem will often (sub)consciously interpret and evaluate this information, affecting psychological perceptions.

The mesosystem represents the second layer of interactions, which may influence the microsystem. According to Bronfenbrenner's (1979) theory, the mesosystem consists of interactions between two or more microsystems, which can directly influence the developing player. Key mesosystem interactions can include parent–coach relationships and school –club/academy relationships.

Meanwhile, the exosystem involves relationships and processes between factors (e.g., governing body policies, sporting culture and community size) in which individuals are not active participants. In the exosystem, external people, places and events may influence development, even if the player does not directly interact with them. For example, considering parental employment, the player is not directly involved in the employer-parent relationship but the player benefits if the parent provides consistent financial support. Finally, the outermost layer (macrosystem) pertains to the overarching sociocultural patterns and belief systems of societies, including national socioeconomic, cultural and geographical conditions (e.g., societal views on sport and climatic location), which can potentially affect player behaviour. For a diagrammatic summary of the neighbouring systems, see Figure 1a.

Implementing an evidence-based coach education tool to explicitly consider the granular associations at each level of Bronfenbrenner's framework, could be valuable for functional longer-term player development at international level. Coaches and organisations should aim to increase

awareness through continued reviews and evaluations of player behaviours and outcomes within the four neighbouring systems. Previous findings from a coach education intervention in Australian national level youth swimming (Moulds, 2023) suggests equivalent coach education could be valuable to positively influence player psychosocial functioning. Potentially reducing dropout and/or burnout rates within early development stages and increasing the likelihood of attaining functional longer-term international developmental benefits.

Practical implications for coaches to contemplate at each level of the bioecological model are suggested below and presented in the form of a checklist and template (refer to Table 1 and 2). Here coaches are encouraged to carefully plan their player development strategies by considering and answering multiple questions at each level. When preparing players for international-level development, coaches should avoid addressing each level of the framework in isolation. Instead reflecting from a holistic perspective, which may evolve through a player's establishment in an environment that, consequently, affects his or her development (Larsen, Alfermann, Henriksen, & Christensen, 2013).

MICROSYSTEM CONSIDERATIONS FOR INTERNATIONAL DEVELOPMENT

The microsystem level highlights the significance of coaches as central agents who lead and structure their environments and training practices to create optimal conditions maximising international development (See Figure 1b). Given their frequent interactions with players, coaches should consider how coach-led environments can influence vital factors for long-term development. What coaches do and how they do it from experience and knowledge can shape a player's interpretation and subsequent behaviour (e.g., development or dropout; Moulds et al., 2023). A coach-led environment combining task-involving, autonomy-supportive, and socially supportive exchanges between players and coaches may increase the likelihood of international developmental outcomes from healthy and sustained involvement (Appleton & Duda, 2016; Moulds, 2023). Coaches should aim to increase self-awareness through consistent self-reflection and evaluation of coaching behaviours. Embracing multiple analyses (e.g., application of a bioecological checklist, see Table 1) and investing in continued learning and development could advance the coach-led microsystem. Engaging an effective coach developer can expand coach self-awareness, encouraging a coach to take responsibility for their ongoing development to become even more effective at an international level (ICCE, 2024).

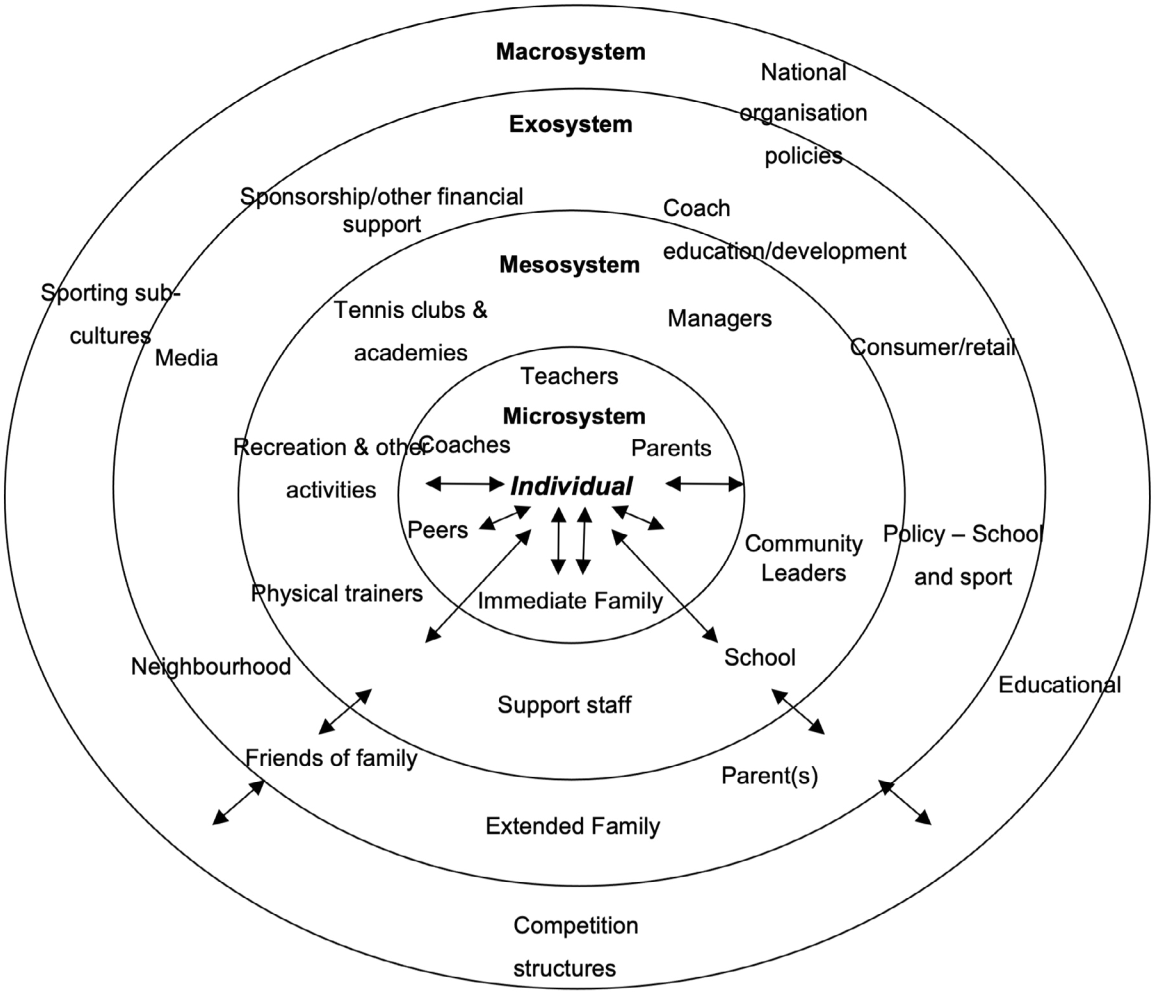

Figure 1a: *Bronfenbrenner's bioecological theory applied to international-level player development.*

Increasing parental knowledge of factors shaping a player's microsystem could assist young developing players to (sub-) consciously interpret and evaluate information. A lack of positive emotional support from parents has previously been associated with a higher likelihood of dropout (Moulds, 2023). Emphasising interpersonal relationships with significant others (e.g., coaches and peers), parents may find monitoring the young player's experience towards training and competition more conducive to their long-term development. Improved parent knowledge could help generate better understanding to help inform parent decision-making and support. To aid such understanding, online and in-person educational resources (e.g., videos, self-paced modules) may help parents identify influential microsystem climate factors. As the complexities of player development evolve, interactions between players and their environments cannot be devalued with a focus on long-term international development.

MESOSYSTEM CONSIDERATIONS FOR INTERNATIONAL DEVELOPMENT

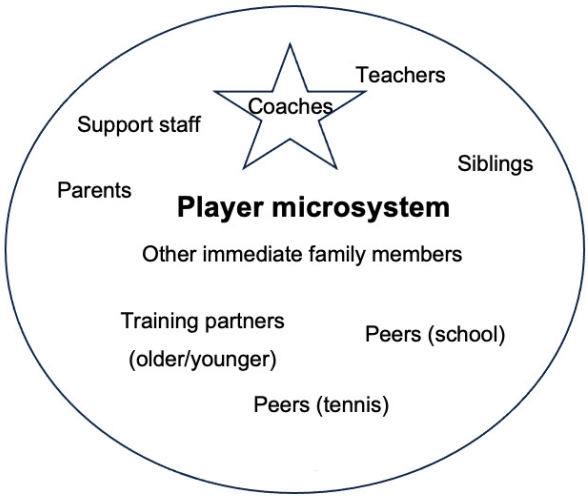

Figure 1b: Key relational social exchanges between individuals in the player microsystem.

This level features organisations (e.g., tennis clubs and academies) and their managers as essential facilitators for player development. There is an opportunity for organisational leaders to influence coaches, parents and players with systematic tracking and reporting of player development data. Such tracking could generate more informed decision-making concerning selection, training, and overall development interventions. Aligning financial and educational resources from organisations to assist with data reporting and adopting club and academy-led coach education programs to promote bioecological approaches could be beneficial. More broadly, there is an opportunity for clubs and academies, in conjunction with their coaches, to educate other microsystem influencers (e.g., parents, significant others). Increasing knowledge regarding micro and mesosystems could also assist key personnel in understanding and identifying the factors which may potentially expose players to suboptimal environments. Clubs and academies could assist microsystem influencers in educating and raising awareness, potentially identifying 'when' and 'where' to change/address current practice and provide an evidence base to help shift an organisation's cultural mindset which has historically prioritised early-age intensive training and investment.

The interchange of microsystem and mesosystem levels, between training, coaching approaches, and competition strategies, is another consideration for organisations as they attempt to connect with their players and coaches.

EXOSYSTEM CONSIDERATIONS FOR INTERNATIONAL DEVELOPMENT

The third level focuses on interactions that occur between several parts of the environment (e.g., coaches, facilities, and sport policies) that can indirectly influence long-term player development (Balish and Côté, 2014). The exosystem not only comprises the settings in which the player participates, but at least one more system that does not directly involve the player, and in which events occur that can influence processes within other settings not containing the player. For example, local court maintenance personnel, who maintain the courts, repairs lines, and clean the court playing area would be part of the exosystem, as the interaction between maintenance personnel and the facility would have an indirect effect on player long-term development. The exosystem highlights the distal processes that can influence more proximal processes (i.e., microsystems). Predominantly, an exosystemic level of analysis is usually employed when researchers/practitioners are attempting to understand how microsystem level influencers are enabled by outer layer processes, that are part of an organisation.

MACROSYSTEM CONSIDERATIONS FOR INTERNATIONAL DEVELOPMENT

Although an indirect influencer, national organisations and member associations often impact the macrosystem with their structures, rules, competitions, expectations, and ranking systems. An enduring area of concern is the early-age specialisation of youth sport, where injury, mental health concerns, the rigorous pursuit of ranking points, and elite academy programs for very young children are common (Malina, 2010; Jayanthi et al., 2019). Despite recent evidence suggesting few junior players go on to achieve an equivalent competition level at senior level, most national organisations are still operating in systems that award ranking points for each match, and reward quantity of matches regardless of developmental age (Güllich et al., 2023). Suggesting change at this level, to align with the developmental needs of youth players is not as simple as removing competitions or ranking points as this can disrupt the other, entangled levels. To reach a point where long-term international development is echoed in the macrosystem, stakeholders need to consider how to shift not only the competitions and legacy of a ranking system, but also the cultural narrative of sport in society. National organisations may need to integrate early developmental needs by deemphasising performance-driven outcomes, with a greater emphasis on fun, cooperation, and more team-orientated activities with a lesser focus on inter-individual competition. Reassessing environments designed around early-age rankings and performance, where coaches are only evaluated on performance-associated metrics, could assist. Connecting research and coach education by changing incentives, rewards, and recognition of coaches through a long-term 'healthy' international pathway based on age and stage of development rather than performance could benefit. Referring to Table 1 and 2 could help coaches and organisations identify individual player behaviours and dynamic relationships interacting within various levels of the bioecological system.

Table 1
Bioecological checklist for coaches when considering elite and sustainable player development planning.

Instructions	*The following questions can help identify areas at each level of the bioecological system useful for sustainable elite player development. Addressing these items aims to assist coaches structure their environments and coaching practices to create optimal player development conditions.*	
Checklist Item	Question(s) to Answer	Tick when addressed
Bioecological level		
1. Definition(s)	What level of the bioecological systems framework are you focusing on? Key features and/or interactions to consider at this level specific to a players age and stage of development. For example: Microsystem level considerations for a 14-year-old female player based in Sydney, Australia with an ITF junior ranking of 300. Her ranking has currently plateaued due to recent inconsistent performances, player currently shows signs of low self-confidence.	☐
2. Participants	Who/what are the key relationships for coaches to consider in this scenario For example: Parents, other coaches/support staff – physical trainers, teachers, peers, training partners (see Figure 1b) Key considerations/questions to explore? For example: Parents – Changes in home life that could be influencing on-court behaviour? Other coaches/trainers – Changes in training loads, application to off-court training? Teachers – Any upcoming milestones, assessment tasks required, how is the player balancing schooling and training/competition? Training environment – have there been any changes to training partners, peer environment etc?	☐
3. Variables	What other variables does the coach need to consider? Could be features from other bioecological levels. For example: Macrosystem level considerations – what does the scheduling and duration of competition and/or practice times) look like? How does this impact schooling and other family requirements? Exosystem level considerations – are there any chances in parent/socio-economic status, proximity to a training facility?	☐
4. Data Collection/ measurement	How will the coach collect the required data/information to assess the outcome and provide feedback? For example: Template to apply with player and/or parents/significant others on a regular basis (See Table 2) Comparing coach observations with player development matrix (e.g., Tennis Australia, 2024).	☐
Findings	Based on the information above, how will the coach include this information in future coaching practice? For example: Schedule regular debriefs/check-ins with parents and support staff. Invite coach developer (or mentor, another coach) to observe training sessions and provide feedback to the coach. Emphasise the importance of school participation for social development.	☐

Table 2

Template for coaches to use in conjunction with the bioecological checklist

Example Questions			
Level of Investigation – e.g., Microsystem Coach to provide an overview and purpose of the activity Emphasise confidentiality. Emphasise the importance of players thoughts, perspectives and insight. There are no right or wrong answers; their personal insight, understanding, perspective and explanations are important. Overall accuracy and detail will help with the coach-player relationship.	**Main question/s** How are you feeling/where do see your game is currently at?	**Probes** What were your goals/ motivations for this month/ year? Were your expectations met?	**Prompts** Can you tell me more about that?
Competition	What can you remember most about your recent tournament? To what extent has your training environment influenced your recent results?	What did you learn about the environment around you at the tournament? (Duda 2005) What did you learn most from the video analysis and feedback from the coach/ support staff? How did you feel during your matches? In terms of how you interact with others in your microsystem during training? Do you think this has had an impact on your overall levels of self-confidence?	Can you tell me more about any of these key areas? Can you provide specific examples? What impact has it had on you throughout this year/month? How did you feel when you tried to discuss these areas within your microsystem?
Training sessions	What can you remember most about your recent training sessions?	Did you feel like those in your microsystem have assisted you to explore areas of development throughout the last year/month? Did you feel supported and encouraged to explore how things were progressing relative to your goals, expectations, concerns, or questions? (Muir & North, 2023) What did you learn most from the video analysis and feedback from the coach/ support staff? How did you feel about the change in relationship dynamics with those in your microsystem?	Can you tell me more about any of these key areas?
Summary	Thinking of competition and training combined, what did you like/dislike most about you the last year/month? Of all the areas we have discussed, which one is the most important to you? Is there anything else you would like to add?	To what extent has your involvement in this program changed your development pathway? Specifically consider the environment.	

CONCLUSION

Key recommendations from this article are for coaches and organisations to specifically implement behaviours, communication strategies, values and conduct aligned to a bioecological approach. Emphasising the importance of coach relational skills, based on the 'nested-level' environment can shape player behavioural responses and outcomes. Developing a robust understanding of potential bioecological disruptors throughout various levels of the player development process is important, for example:

Microsystem level

- Coaches to invest in coach developers to assist with self-reflection and further assessment of bioecological environments.
- Coaches to invest in player/parent relationship building sessions.
- Coaches to be aware of distal processes that can influence an individual player's microsystem.
- Coaches should also consider the value of including (or not) other critical stakeholders (e.g., support staff and practitioners, significant others) in the direct micro-climate immediately surrounding the developing player.

Mesosystem level

- Clubs and academies to facilitate/regulate coach education and development.

Exosystem level

- Clubs, academies, national organisations to consider embedding social science researchers to understand how microsystem level influencers are enabled by outer layer processes.

Macrosystem level

- National organisations to align researchers, coach education and coach developers by changing incentives, rewards and recognition of coaches through sustained player outcomes rather than early-age performance.
- Consider differences in cultural and socioeconomic characteristics between countries which can be expressed in terms national events, training facilities/surfaces, providing unique environments and conditions for player and coach development.

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Skill acquisition and representative design: recommendations for tennis practice

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ABSTRACT

This article discusses the concept of representative practice design and the supporting skill acquisition theoretical framework. Implications for tennis coaching will be presented including a model for tennis task design. The goal of this paper is to introduce coaches to the concept of representative practice design, explain the rationale and supporting theoretical evidence and provide tools for coaches to design their own practice tasks to maximize skill development.

Key words: ecological dynamics, skill learning, practice design.

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INTRODUCTION

Traditional, linear views of skill learning are prevalent in coaching due to an information processing view being the leading theoretical framework at coaching conferences and on licensure courses. However, the influence of information processing as the predominant explanation of skill learning has waned in the academic literature with the advent of more contemporary theories (Reid et al., 2007; Anderson et al., 2021), such as ecological dynamics (Araujo & Davids, 2011). Furley (2016) suggests the drop in popularity may be due to information processing accounts of skilled behavior not adequately accounting for the complex dynamic nature of sport. This would indicate that commonly held coaching beliefs grounded in an information processing view of skill learning need to be updated (Parry & O'Rourke, 2023; Renshaw & Chow, 2019). Experiential knowledge gained through coaching experience must be complemented by knowledge from empirical, motor skill learning research, so that unsubstantiated opinions of historical precedence, even if successful for the coach as a player, do not bias learning designs in sport (Chow et al., 2022). It is without a doubt that a coach's beliefs and assumptions about skill acquisition play an integral role in how they design activities, the focus of their instruction and provision of feedback. Traditionally this may look like the demonstration of "correct" technique, isolated practice drills and extensive verbal feedback all grounded in an information processing view of skill (Davids et al., 2008; Anderson et al., 2021). Unfortunately, although these coaching practices are common, they do not have extensive support from the skill acquisition literature. In fact, many are often counter to what we know about how people develop and control skilled action. Whether articulated or not, all coaching methods are driven by our underlying beliefs about skill learning [See Figure 1] (Parry & O'Rourke, 2023). If a coach's assumptions about skill learning are not grounded in sound skill acquisition theory, all coaching methods used as a function of those assumptions are somewhat flawed. A common approach of repetitively practicing so-called "correct technique" in sterile environments, could be attributed to the belief in "muscle memory", that players must first ingrain the correct technique prior to game application (Smith, 2018). What is problematic is that from a skill acquisition perspective, the concept of muscle memory has zero evidence to support its existence (Parry & O'Rourke, 2023; Roetert et al, 2018; Ivancevic et al., 2012). Many coaches solely depend on their playing and coaching experiences to guide their beliefs and therefore are susceptible to myths such as muscle memory which perpetuates traditional practices (Figure 1). This underlines the importance for coaches to have a strong grasp of skill acquisition theories to support their coaching and ultimately athlete performance. Therefore, as noted in Figure 1, prior experiences of learning to play becomes the foundation of coaching that then feeds into the coach's unquestioned assumptions and beliefs about learning, that in turn perpetuates traditional methods of instruction.

Figure 1. *Relationship between assumptions and beliefs about learning and chosen practice methods. Adapted from Parry & O'Rourke (2023).*

DEFINING SKILLED PERFORMANCE

Skill can be described in numerous ways depending on the theoretical lens one uses; the two main ones being information processing and ecological dynamics. Information processing is aligned with schema theory, where the development of mental representations of skilled action is established through repeated practice of the correct action (Schmidt, 1975, Renshaw & Chow, 2019). Ecological dynamics on the other hand views skill as an adaptive, functional relationship between the individual and performance environment (Araujo & Davids, 2011). In this vein, skill learning is not the acquisition of mental representations, but the process of adapting and attuning to the information present in the performance environment (Renshaw & Chow, 2019).

One thing they do seem to agree on is that skill is goal-directed, meaning it is performed to achieve some objective, it has a purpose (Coker, 2021). Although both theories appear to agree that achieving a task goal is a key descriptor of skilled behavior, many coaches appear to be enamored with movement production, such as specific techniques, without enough attention on the movement outcome, or achievement of the task goal. The assumption is that if a player can develop correct technique, it will somehow seamlessly transfer effectively to the game environment, a large assumption with little supporting evidence (Weigelt et al., 2000). The concept of fundamental techniques is still a common belief that is widespread across the coaching community (Rudd et al., 2021). This often results in methods that isolate or break down skills, focus on mechanical forms, and use repetitive practice void of game-based contextual information, such as scoring, which takes precedence over a more representative, game-like framework (Krause, Farrow, Pinder, et al., 2019).

A key question for coaches is whether "correct" technique is a requirement for successful performance?

Technique training is often undertaken via isolated drills, with the aim of feedback to reduce the gap between what the movement looks like and the putative "ideal" technical model (Renshaw, Davids & O'Sullivan, 2022). What is interesting is that many professional athletes do not perform with this so-called ideal technique. In fact, many high-level tennis players appear to adapt to what the competitive context offers them (Renshaw, Davids & O'Sullivan, 2022). It is suggested that coaches move away from "correct techniques" in terms of movement postures, and towards an optimal technique using a framework such as BIOMEC presented by the ITF Academy coach education courses (Martinez-Gallego, 2024). This helps coaches to avoid focusing on idiosyncratic and cosmetically displeasing features of a stroke (i.e. the look of the stroke) but instead will help them focus on the effectiveness of the stroke (ITF-Academy, 2024).

Defining skill as being goal-directed and focusing on effectiveness, actually reduces the requirement of a particular technique, as technique is just one of many coordination patterns we can use to achieve a task goal (Bennett & Fransen, 2023). As Martens (2012 p.151) suggests, "technique and skill are different". What coaching "correct" techniques doesn't take into consideration is that individual, environmental and task constraints act as boundaries which guide the emergence of skilled movement behavior (Fitzpatrick, Davids, & Stone, 2017, Regan, 2021). The interaction of these constraints can have a dramatic influence on performance, as noted by Fitzpatrick, Davids & Stone (2018) showing developmentally appropriate smaller courts and lower compression balls resulted in longer rally lengths in comparison to a traditional set up for 7-14 year olds. Instructions can also act as a task constraint (Gray, 2021), so coaches need to be aware how their instructions may be over-constraining their players search for functional solutions. Coaches are encouraged to instruct the goal of the practice task and utilize questioning to guide players away from non-functional techniques and toward effective ones without prescribing solutions. Coaches can also use feedback top guide players to functional solutions. Traditionally, this post-performance information has been focused on correcting errors from a prior movement attempt. However, the literature suggests a focus on feedback that helps players transition to a new pattern of coordination, by focusing on key information sources in the environment (Otte et al., 2020). Coaches may direct players attention to ball flight, position of opponent, or even opponent tendencies to facilitate the search for functional movement solutions.

The performance environment created in practice is a key factor in the development of skill and dictates how effectively these skills transfer to the competition environment. As Araújo & Davids (2009 p.6) put it, "to do, is always to do something, somewhere", illustrating that skill is in the relationship between a performer and their environment. This relationship is termed individual-environment mutuality (Gibson, 1979; Araújo & Davids, 2011) and is central to ecological dynamics theory.

ECOLOGICAL DYNAMICS - A NEW THEORETICAL LENS

Ecological dynamics is a contemporary theory of skill development that combines ideas from ecological psychology, dynamical systems, and complexity sciences (Davids et al., 2013). In this view, skill does not refer to the acquisition of an entity, such as a mental representation, as suggested by traditional, information processing-based theories of skill learning. From an ecological dynamics perspective, skilled performance derives from the increasingly improved function fit between an individual and an environment (Araújo & Davids, 2011; Chow et al., 2022). This individual-environment mutuality is a key concept in ecological dynamics focusing on the importance of the performance environment in the development of skill. This suggests the specific environment the coach designs and the instructions they provide will shape the skills that they develop (Araújo et al., 2004). Ultimately, context is key in the development of skilled behavior (Otte et al., 2021).

Another key element of this theory is the concept of perception-action coupling and the production of functional movement behavior under constraints. As Gibson (1979 p.223) put it, "we must perceive in order to move, and we also move in order to perceive". What we perceive guides our actions, and our actions guide our perception, they are functionally coupled in a reciprocal relationship. What we are perceiving are opportunities to act, or affordances (Gibson, 1979) scaled to our own action capabilities. For example, a short player (organismic constraint) may not perceive approaching the net as an affordance as they could easily get lobbed, whereas a tall player may see it as a strong affordance (Parry & O'Rourke, 2023). When using ecological dynamics as a theoretical framework, coaches should be aware of how individual, environmental and task constraints interact to influence the perception of affordances, the perception-

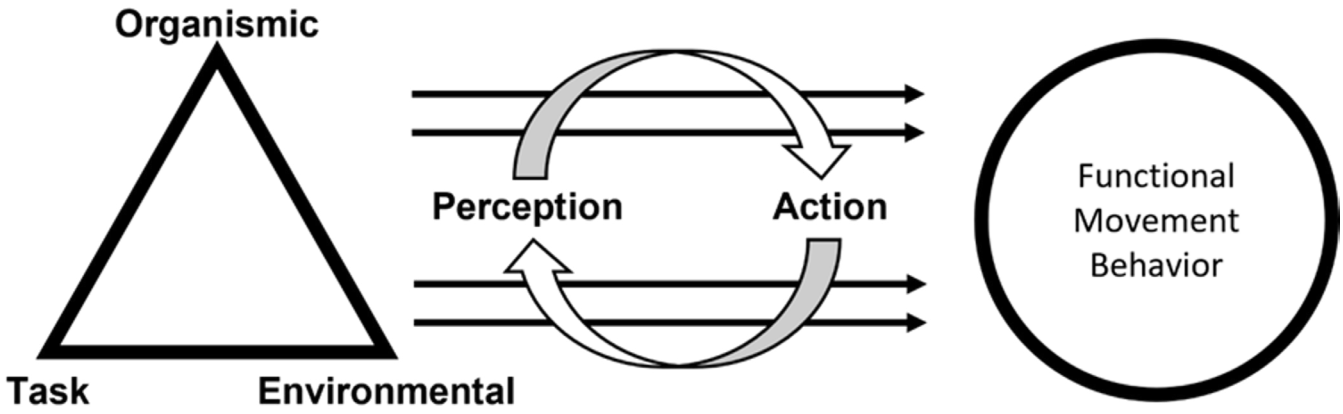

Figure 2. *The Constraints Model (Newell, 1986).*

action cycle, and the production of functional movement behavior (Figure 2). Therefore, the design of representative practice tasks that maintain the information-movement couplings experienced in competition should be a large portion of practice. Every time a player performs a task in a performance environment they are acting under the influence of constraints. Constraints can be identified as boundaries or features that eliminate certain possibilities or options for action, but

may present others (Newell, 1986; Gray 2021). For example, if a coach creates an activity where the court is halved in width, a long and thin court, this acts as a task constraint and will limit certain actions but encourage others. It is important to note that constraints do not prescribe a certain action, they simply limit options to act, there should still be multiple options, or affordances, available to the player. Creating practice activities that present multiple emerging and decaying affordances can be a valuable tool for coaches to facilitate the development of skilled movement behavior. Quality practice task design, using representative design principles, is where coaches can have the most influence on player development. The goal is to present game-like problems and guide the player, mainly through questioning, to their own functional solutions. Coaches should refrain from over-constraining practice activities, such as "you must" or "you can only" as it does not allow the performer to find their own, unique, functional movement solution and become an active problem solver. Coaches should facilitate athlete-environment interactions which encourage players to adapt their movements under constraints that are representative of those experienced in competition (Yearby et al., 2022). For example, when working with two players, one could be incentivized through more points to volley, whereas the other could be incentivized to lob. Each task constraint presents opportunities to the other player, and each must actively pick up information from their environment to be successful. The goal of representative practice design is to help athletes to attune their attention to the relevant sources of information in the environment, e.g., ball flight, opponent movement, that will help guide their choices and actions.

REPRESENTATIVE LEARNING DESIGN (RLD)

Brunswik (1956) first coined the phrase representative design when discussing the need for ecological validity in behavioral research. This idea has since been adopted eagerly by sport performance researchers interested in the adaptive movement behaviors exhibited by athletes in competitive environments (Pinder et al., 2011). Due to perception-action coupling and the mutuality that exists between the performer and the environment, the design of practice tasks must ensure that the constraints, specifying perceptual information and actions present in the competitive performance have been adequately sampled (Button et al., 2020; Vilar et al., 2012). RLD is underpinned by two key elements, action fidelity and functionality. Action fidelity refers to how the movement behavior performed during practice replicates that of competition (Travassos et al., 2012; Krause, Farrow, Buszard, et al., 2019). Functionality refers to the degree to which an athlete can use the same information sources (e.g., ball flights, speed and spin rate) present during competition to contextualize their decisions and movement to achieve a similar level of success in practice (Pinder et al., 2011). Notice in both definitions that the similarity of actions and information sources between practice and competition is key. Ultimately, coaches should be looking to simulate the competitive environment in most practice tasks so that performance is representative, increasing the chances of positive transfer. Passos, Araújo and Davids (2013) suggest that without appropriate representative design, movement behaviors that emerge may not be functional and realistic in dynamic sports performance environments. This is based on compelling evidence that shows when the informational constraints of a task are altered, different movement behaviors emerge (Araújo, Davids, & Hristovski, 2006; Dicks, Button & Davids, 2010; Pinder et al, 2011).

Through an ecological dynamics lens, decontextualized, repetitive, technical practice tasks that remove important perceptual information, such as an opponent and varied ball flight, would not elicit positive skill transfer and thus should be used sparingly. With novice learners, coaches do not need to use task decomposition, by breaking the skill down to its component parts. Instead, RLD principles such as task simplification, allow coaches to simplify the practice task, whilst maintaining the perception-action coupling between their movements and information in the environment. Game and equipment scaling is a good example of task simplification, where smaller courts, lower nets, lower compression balls and developmentally appropriate racquets can have a dramatic effect on the movement behavior of young players. Decision-making is predicated on the perceptual information a player is attuned to in the competitive environment (Krause,

Farrow, Buszard et al., 2019). Therefore, the removal of key information sources from practice tasks would appear to be a waste of time if the goal is positive skill transfer to competition. The main key information sources in tennis are the movement of the ball, movement of opponent, and court boundaries. This does not, however, mean that all practice tasks must be a full competitive match, a common misconception. Coaches can manipulate court size and dimensions; the type of ball and racquet used and constrain the opponent in some way to present opportunities to solve the game problem. Methods such as the Constraints-Led Approach (CLA) can be used to scale practice tasks appropriate for the level of their participants by manipulating key individual, environmental and tasks constraints to facilitate the emergence of goal-directed functional movements (Chow et al., 2022; Hopper & Rhoades, 2022; Regan, 2021; Renshaw et al, 2019). Allowing a novice player to volley the ball to themselves before attempting to hit over the net is an example where task constraints can be altered to facilitate learning. A representative task does not equal just playing games either, although modified games do have many of the key characteristics of a representative task. For example, practice games often look somewhat like actual competition, often involve an opponent, have consequences tied to actions and involve key characteristics of the competition environment such as a net, boundaries, and scoring. Manipulating key constraints, scaling equipment and boundaries to create a more representative practice task has been shown to improve tennis performance of varying levels of performers in a number of studies (Krause, Farrow, Pinder et al., 2019; Krause, Farrow, Buszard et al., 2019; Fitzpatrick, Davids & Stone, 2018; Fitzpatrick, Davids & Stone, 2017). Therefore, traditional approaches will continue to be challenged until key movement and informational performance characteristics experienced in competition are more effectively represented in practice tasks (Pinder et al., 2011; Davids, Araujo, Vilar et al., 2013; Krause, Farrow, Buszard et al., 2019).

RLD IMPLICATIONS FOR TENNIS COACHING

Applying these ideas in practice requires a shift in mindset for tennis coaches. Coaches need to see themselves as learning environment designers who work with athletes to manipulate key constraints (Woods et al., 2020a). This shift in mindset can be difficult as coaches need to let go of some of their control which can be one of the hardest things to do for many (Chow et al., 2023). Another barrier that coaches will need to overcome is the influence of the tennis form of life on their coaching practices. In the context of player development, a form of life refers to the cultural aspects that shape an individual's attitudes and behaviors towards developing expertise and includes values, beliefs, traditions, and customs that influence a coach's approach to skill acquisition (Rothwell et al., 2019). Tennis coaching is heavily influenced by traditional coaching pedagogies where repetitive drills to build consistency are at the fore (Reid et al.,2007). As 'traditional practice' is so ingrained in the tennis practice culture, it can be very difficult for coaches to move away from these ideas (Anderson et al., 2021). Coaches utilizing an Ecological Dynamics approach must appreciate that the players must 'learn to learn to move' in specific performance contexts, recognizing the inseparable connection between the individual and their environment (Otte et al.,2021).

The design of representative tasks needs to be based on a detailed sampling of informational variables that are present in specific performance environments (Button et al., 2020). These informational variables are also referred to as affordances which are invitations and opportunities for action that an athlete can use in a performance environment (Otte et al., 2021). A key part of the coach's role as a learning designer is to identify these key affordances that are going to influence a player's behavior (Woods et al., 2020a). Information from ball flight and the position of opponents have been identified as key affordances for tennis players (Krause, Farrow, Buszard et al., 2019). Therefore, a representative task in tennis would have to include both key affordances as they provide valuable information for the control of action. Designing practice using representative learning design would better prepare athletes for competition and allow coaches to test the effectiveness of their coaching (Renshaw et al., 2022).

An important aspect to RLD is that a representative task doesn't need to fully replicate the performance environment (Oppici et al., 2019). Fully representative tasks can often be too complex for learning and don't present the learner with enough opportunities to engage with specific areas they are focusing on. However, reverting to isolated, repetitive, drilling of technique is not the answer either as it is missing key information used in competition. A key concept to implement RLD effectively is Task Simplification. This involves making movement skills easier to perform while maintaining the connection between perception and action (Chow et al., 2021). These simplified constraint-led games are going to be less representative but still contain some of the key important information needed in the performance environment. As players progress, we can gradually increase the levels of representativeness by designing more specific constraint led games. Coaches could think of 'turning up' or 'turning down' the levels of representativeness depending on the needs of the player. For example, coaches could incentivize the search for solutions by increasing or decreasing space after players reach a certain point total. As the task constraints change, so must the solutions. Figure 3 illustrates levels of representativeness and associated practice activities, with most practice time being devoted to the green zone (Adapted from Renshaw et al., 2019).

Lastly, it is crucial for coaches to understand that decision-making and problem solving are key elements of RLD. Tasks with unpredictable outcomes and strategies should be utilized as these "alive" tasks help athletes adapt to changing conditions and develop essential problem-solving skills (Myszka et al., 2023). Coaches could think of creating slices of the game that focus on specific situations while maintaining elements of the competition environment. The players problem-solving skills can be enhanced by experiencing the game in "slices" where rapid invitations for action emerge and decay, challenging them to adapt (Yearby et al., 2022). As the players progress, we can then challenge them by designing more complex, dynamic representative tasks to further enhance their decision making (Otte et al., 2021).

DESIGNING TENNIS SPECIFIC LEARNING ENVIRONMENTS

Figure 4 is proposed as a guide for coaches to create tennis specific learning environments that maximize transfer to competition. Including these key elements in practice tasks will increase their representativeness creating effective, adaptable players.

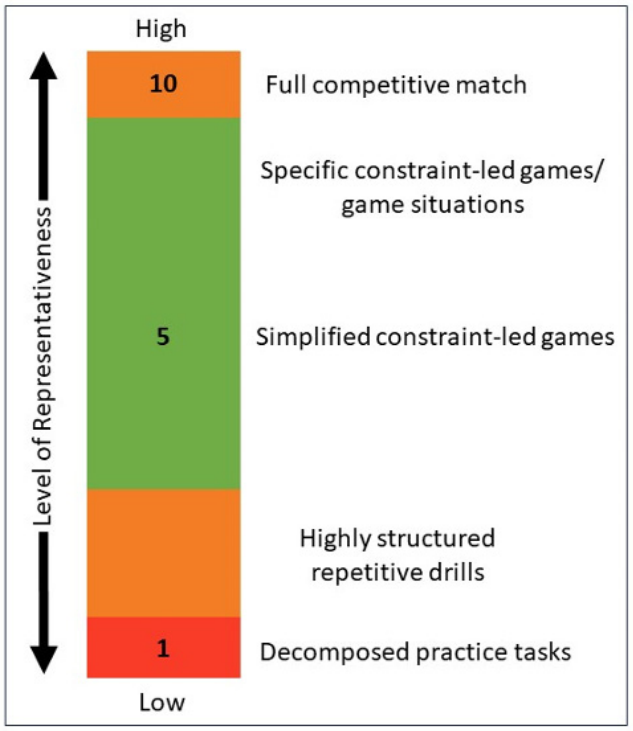

Figure 3. *Levels of Representativeness in Tennis Practice*

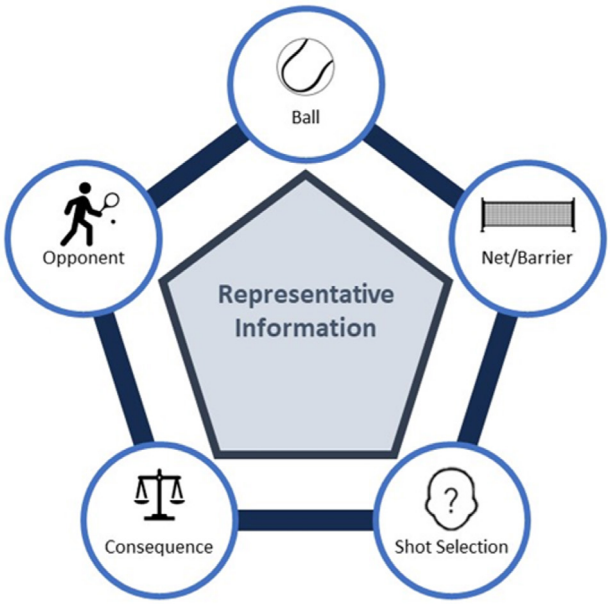

Figure 4. *Foundations for Tennis Task Design (Adapted from O'Sullivan et al., 2021 Foundations for Task Design Model).*

Representative Information

At the heart of the practice design is representative information. As discussed above, key information such as ball flight information and information from opponents needs to be present during practice tasks. The players will need to learn to attune to this representative information to help develop their decision-making skills (Araujo & Davids, 2009).

Ball

Coaches need to make sure that there is a ball present and that the players have a chance to learn to attune to the key information from its flight. The type of tennis ball used will change depending on the needs, action capabilities and skill level of the player, from sponge, red, orange and green transition balls up to a regulation ball.

Over a Net/Barrier

Tennis is a divided court game. The objective is to hit the ball over a net/barrier to achieve a winner, make the opponent miss, or force a mistake. Adjusting net height can be a useful way to extend rallies or help more advanced players search ways to produce more topspin (Hopper & Rhoades, 2022).

Shot Selection

Giving players the choice to decide how they hit the ball and in which direction is crucial. Coaches sometimes use drills like 'cross courts' that limit players to hitting the ball in a specific direction. However, this approach restricts decision-making and can result in less representative behaviors in comparison to competition. Representative tasks should encourage both variation between and variation within shots (Krause, Farrow. Buszard et al., 2019).

Consequences

By incorporating consequences, learners can improve their ability to perceive and respond to relevant information in the performance environment. For example, in a match, when a player hits the ball over the net, there will be an opponent aiming to return the ball and potentially win the point. Depending on the practice task intention, different scoring systems can be created to incentivize certain behavior for each player. For example, players may receive 3 points winning using a volley, and only one point for other winners (Hopper & Rhoades, 2022b). This would incentivize volleying and discourage playing the ball high and short as that would present an opportunity for the opponent to volley.

Opponent

Opponents play a crucial role as sources of information for players, providing them with valuable insights that they can use to adapt their movement strategies. Players need to learn to 'attune' to the information provided by their opponents' behaviors, such as their favored side or reluctance to approach the net. By attuning to this information, players can better exploit gaps and spaces to either hit a winning shot, force their opponent to make a mistake, or force them to miss.

HELPING COACHES "G.R.A.S.P" REPRESENTATIVE LEARNING DESIGN

Providing examples can help support coaches looking to move away from traditional methods which focus on technical performance templates prescribed in coaching manuals (Woods et al., 2020b). It is very important for coaches to understand why learning tasks are designed in a specific way as it will enable them to more effectively adapt practice tasks to meet the needs of their own players (Chow et al., 2023). When using representative learning design, the goal is to simulate the key aspects of a specific performance environment in training (Krause et al., 2018). One of reasons we do this is to

help learners to develop the skills that will help them to thrive in the dynamic performance environment (Chow et al., 2021).

The 'Foundations for Tennis Task Design' diagram provides a framework for coaches to design practice tasks that are representative of the game and appropriate for their players. To build on this idea, coaches can use the acronym G.R.A.S.P, explained below, to help them identify key components of their role and the design of practice tasks:

Guiding role of the coach

The coach takes on the role of a 'Learning Environment Designer' where there is a focus on manipulating constraints to create learning experiences with the players (Woods et al., 2020b). The goal is for players to find functional movement solutions that work for them, not an idealized technique. Therefore, the coach, instead of being a director of the experience, providing detailed instructions and feedback, design practice environments that allow them to explore effective solutions.

Representative information

Ensuring the key representative information is present during the practice task must be a major focus for the coach. In tennis, the most important key information is from ball flight and the movements of their opponents. (Krause et. al., 2019). This has a dramatic effect on how we design activities as it provides a framework to make sure important elements that guide performance are included.

Alive Tasks

The major question for coaches is how a movement practiced in isolation positively transfers to the dynamic, unpredictable nature of the game. It would therefore make sense for coaches to include appropriately scaled levels of unpredictability, or aliveness, so players are not simply reproducing a set of prescribed actions. Perception and action are coupled and therefore should not be separated in practice tasks by only practicing the action component of the movement separated from the perception and decision-making components. These 'slices' of the game should include lots of problems for players to solve, so they are learning in context (Myszka et al., 2023; Yearby et al., 2022).

Simplification

Task decomposition, where skills are broken down into component parts, is common in tennis coaching. The contentious assumption is that these pieces can be effectively put back together later in a game-like context. Task simplification, on the other hand, reduces task difficulty while maintaining the connection between perception and action (Chow et al., 2022).

Progress

It is important to scale practice appropriately using concepts such as task simplification, whilst considering the skill level of the performer. But, the practice tasks also need to progress appropriately to be challenging for each learner. To address this issue Guadagnoli & Lee (2004) presented the Challenge-Point framework and noted that the conditions of practice contribute to the functional difficulty of the task. Therefore, coaches need to find the appropriate challenge point for each player and progress their practice tasks from there. This demonstrates the importance of finding the 'Goldilocks Zone', not too hard, not too easy, for each individual (Robertson & Woods, 2021).

PUTTING IT INTO PRACTICE

A good starting point for coaches looking to put these ideas into practice is to start by creating practice tasks where the key information sources are designed into tasks to simulate the perception-action demands during matches (Krause et al., 2019). This is important because if the key information sources are removed from the practice task, then players lose the opportunity to learn to regulate their action to this key information (Renshaw et al., 2022). The coaching competency required here is the art of constraint manipulation. Constraint manipulation is the cornerstone of all practice using a Constraint-Led Approach. Adopting a constraints-led approach gives coaches a framework for understanding how the interaction of 'performer, task and environmental constraints shape each individual's performance (Renshaw et al., 2010). While constraints are often viewed as barriers, Newell (1986) suggests a constraint refers to any factor related to the task, environment, or individual that affects or shapes the observed outcome of movement. Some great examples of constraint manipulations for various levels of performer can be found in Regan (2021).

EXEMPLAR OF REPRESENTATIVE PRACTICE DESIGN

For this example, coaches would look to create a 'slice' of the game for a player that is struggling with their 1st volley when approaching the net. This is often an area that beginner and intermediate players are initially uncomfortable with, so would be an ideal scenario to use a constraints-led approach. Using Figure 4. Foundations for Tennis Task Design, coaches can design appropriate learning environments to provide the appropriate level of challenge by manipulating certain constraints. The practice task examples below (Figures 5 & 6) show how the principles of task simplification can be used to design developmentally appropriate activities for a variety of learners.

These practice tasks would fall under the category of 'Simplified Constraint Led-Game' as shown in Figure 3. Where these tasks fall on the level of representativeness would depend on the constraints implemented, but can be progressively adjusted to increase the representativeness of the full game.

Representative Information

While the game is 'simplified', the key regulatory information is maintained, specifically the movement of the opponent and ball flight. To ensure a developmentally appropriate delivery, the coach can feed the initial ball into play.

Ball

In the first task, a sponge ball can be used to simplify the task, then to maintain an appropriate challenge point, can transition into red, orange and green lower compression balls. There is always a ball present at this is important representative information for the player.

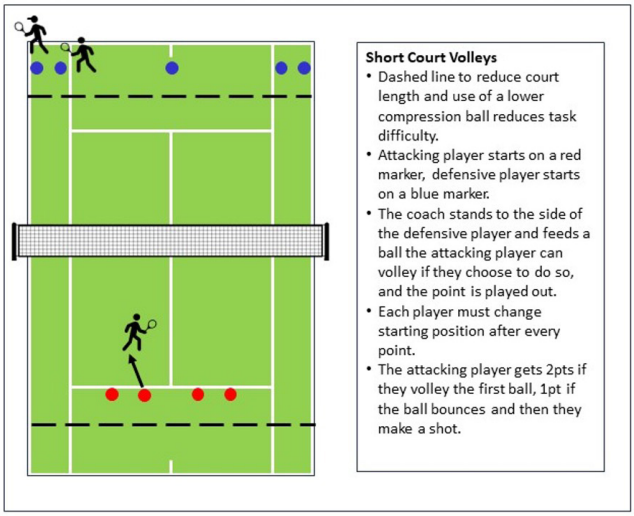

Figure 5. *Short court volley task.*

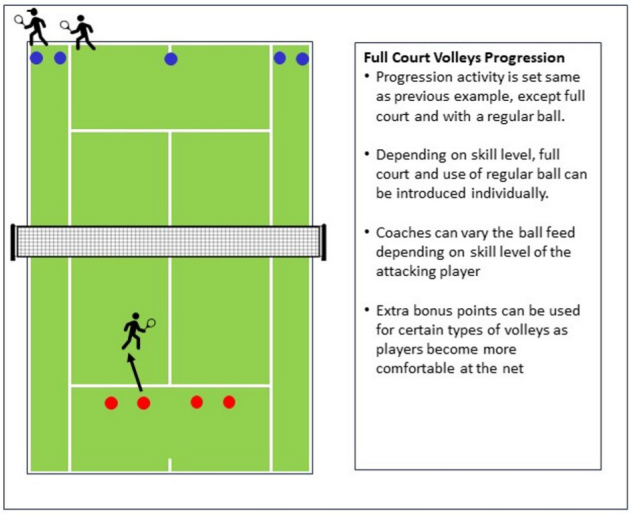

Figure 6. *Volley task progression*

Opponent

By including an opponent in these simplified tasks, perception-action coupling is maintained, and key representative information is present. By varying the starting position of both players, the attacking player will get the opportunity to learn make decisions on where to volley based on their opponent's movements. As the point is played out, they will get further chances to couple their decisions and actions during the point to hit shots at the net.

Consequence

In these tasks, the involvement of an opponent creates a consequence that is representative of gameplay. Coaches can utilize scoring as a constraint to afford opportunities for certain behaviors. For example, using a 3,2,1 points scale for winning the point on the first volley, second volley, or any time after, encourages players to find solutions to end the point quickly.

Shot Selection

The focus in these tasks is to emphasize repetition without repetition, where players are presented with different problems and thus must find different solutions. In these tasks, varying the start positions of the attacking and defending players will present different opportunities to select appropriate shots to maintain the rally or win the point. Coaches should avoid prescribing solutions and instead allow players to explore solutions to achieve the task goal.

Over a net/barrier

In these tasks the net is a standard net, but to identify an appropriate challenge point for each player, the net could be adjusted lower or higher.

CONCLUSIONS

A major goal of coaching is for skills to transfer from practice to the competitive environment, a key product of effective representative practice design. Using the foundations for tennis task design model (Figure 4), coaches can effectively design practice tasks that have an appropriate level of representativeness, scaled to the needs of their athletes. Coaches should aim to spend most of their time in the green zone (See Figure 3) by using simplified and specific constraint-led games plus some specific game situations. This will help their athletes attune to key sources of information that will guide their choices and actions in competition, creating functional, adaptable, effective tennis players.

CONFLICT OF INTEREST AND FUNDING DECLARATION

The authors declare that they do not have any conflict of interest and that they did not receive any funding to conduct the research.

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From early exit to revitalized — navigating and documenting my growth as a young coach

William O'Connell

Fiji

ABSTRACT

This article delves into the crucial role of coach education in enhancing coaching effectiveness and professional development. Drawing from personal experience and scholarly insights, it emphasizes the transformative impact of coach education programs—such as the Olympic Solidarity/International Tennis Federation Coaching Advanced Players (OS/ITF CAP) course—in broadening perspectives and improving coaching quality. Key themes include confronting ignorance through continuous learning, clarifying coaching philosophies to drive meaningful impact, integrating ecological dynamics in coach education, and the reflecting on and sharing of one's work to enhance your coaching practice.

Key words: coach education, coach development, coaching course, reflection.

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INTRODUCTION

Most coaches enter the profession because they wish to share a love for the sport they developed as a player with their students (McLean & Mallett, 2012). These former players enter the profession naive and optimistic, and if unsupported, often become disillusioned and leave coaching within a few years (Gowling, 2019). What's worse, as unprepared coaches stay in the profession, their resentment toward the sport can build, creating a poor experience for their clients (Gowling, 2019). While little data exists on tennis coach retention, reports have evidenced that NCAA athletic departments in general have a much lower employee retention rate compared to similar industries in America, with 43.7-58.1% attrition rates across its different divisions compared to 27.75%, respectively (Huml & Taylor, 2022).

There are numerous reasons a young tennis coach may become disgruntled. The coach must possess a wide array of hard and human skills to delight all the stakeholders (players, parents, other coaches, club, etc.). Tennis coaching can be a challenging way to make a living: players' tournament schedules and/or injuries, competition from other coaches/industries, and recurring resource costs are some of the many aspects of the occupation that get in the way of a stable and sustainable income. Additionally, the profession takes a physical toll as it is one of the few professions in sport where the pro is expected to spar with their players (Crespo & Miley, 2007). Unlike team sports, the player/parent picks the coach/club; the evaluation of relational fit often does not go the other way around. As a result, there is a heavy reliance on the coach for the ongoing happiness of the sometimes-unappreciative clients (Gowling, 2019).

Despite the reports that coach education improves coaching efficacy and leads to positive athlete outcomes (Li et al., 2024), regard for certification does not seem to match the goal to grow our global sport through better coaching (Santos et al., 2010; Crespo et al., 2006). From a coach's perspective, the financial burden of certifications can deter formal coach education, both in terms of the course fee as well as the opportunity cost in lost wages (Hannays, 2020). National associations and employers also appear to undervalue coaches' education. As of 8 March 2024 (International Tennis Federation), the ITF only recognizes 74 national federations' coach education programmes with varying levels of self-sufficiency (18 Gold, 11 Silver, 23 Bronze, and 22 White Level Certification). This is a little over a third of the ITF's 213 member associations. Certification is not required to coach in many nations (including where I coach, the United States of America [Allen et al., 2021]) and even fewer national associations mandate formal continuous professional development. The preponderance of recent college tennis graduates in America who immediately slide into highly sought after college coaching jobs (Fehr, 2013) indicates that playing ability might be incorrectly considered more important than actual coaching education and experience (Crespo et al., 2006; Cushion & Rynne, 2017; Pill, Hewitt, & Edwards, 2016). Out of 181 college coaches surveyed, 34.8% had 0-4 years coaching experience and 50.3% did not possess certification (Fehr, 2013).

When a coach tries to find quick and convenient solutions to their coaching challenges, knowledge is hard to come by in this age of misinformation (Fisher, 2021). Quality information is nuanced, and so it is superseded by polarizing opinions which garner attention on social media and other prominent modes of communication. In this context, an inexperienced coach may not know who, where, and/or how to look for reliable help. Moreover, does the inexperienced coach have the discernment to recognize helpful versus harmful content?

Conversely, social media and other forms of online interaction generate awareness and inspiration; new individuals are impelled to pick up a racquet and previously inaccessible insights are provided to coaches, players, and fans. Shows like Netflix's Break Point magnify the profile of professional players and their coaches, increasing the awareness of the sport (Gough, 2023). The heightened sense of community and the substantial insight the average tennis enthusiast possesses is largely attributable to the internet and media.

To this point, the tennis industry is experiencing a bit of a renaissance, with many opportunities for coaches to capitalize upon: participation has been increasing significantly. In 2021, the global player count reached 87 million, reflecting a 4.5% growth from 2018. This growth means that on average, there are 585 players for every coach worldwide. Moreover, the global count of courts has risen by 28.2% since 2018, reaching a total of 578,681 (International Tennis Federation, 2021). With an abundance of players to work with, and an increasing number of courts to work on, coaches have ample opportunities to succeed. Furthermore, with the decreasing availability of third spaces—places other than home and school/work for people to meet and interact (malls, bars, parks, etc.)—, tennis clubs have the opportunity to serve as this vital social space for the community (Roberts-Ganim, 2023).

The opportunities and challenges of coaching tennis are immense. The following sections reflect on my own coaching journey in an attempt to offer encouragement and guidance to young/dissatisfied coaches seeking to enrich their practice. Whether drawn to coaching for altruistic or self-centered reasons, there is an imperative to get better. So, how should a coach go about improving their skills, so that they can better develop their players, and stand out in a competitive yet growing industry? Education and experience are vital in this pursuit. This article is a critical reflection on my experience at the Olympic Solidarity/International Tennis Federation Coaching Advanced Players course in 2019.

MY STORY

In 2016, I was a 24-year-old Junior College Head Tennis Coach in America, ready to make my exit from coaching. I was arrogant, unfulfilled, and resentful towards coaching for stripping my passion for playing tennis. My exit strategy from coaching was to become a student-athlete again: earn a master's degree that would allow me to leave coaching, and simultaneously pursue my passion for playing tennis through the UK university system.

Fast forward three years, and a master's degree attained, I returned to coaching as a source of income and means of preparing for what I thought was the culmination of my player journey at the 2019 Pacific Games. During this time, Fiji Tennis invited me to apply for the Olympic Solidarity/International Tennis Federation Coaching Advanced Players (OS/ITF CAP) course. Despite my disinterest in continuing to coach, I attended out of curiosity and lack of a better opportunity. This decision changed the course of my life and career.

This immersive experience in Valencia, Spain with other international coaches looking to improve their craft challenged my view of our game. A more thoughtful and sophisticated view of tennis challenged the assumptions and unsubstantiated opinions I had collected as a player and a naive young coach. From teaching methodology, to biomechanics, business, and psychology, the course highlighted just how ignorant I was about a game I had played and been around my entire life.

The daily classroom and on-court sessions during my OS/ITF CAP course produced stimulating discussions. Our tutors shared evidence and experience-backed frameworks, and when best practices were inconclusive, options were discussed so the coach attendee could choose their approach. We also worked within the host academy during the coaching course. Pancho Alvarino and his team have a rich history of producing international caliber players; coaching and interacting with this coaching staff and their players accelerated our growth. Regular visits to dissimilar academies and meetings with renowned coaches gave me a glimpse into varying philosophies in action. Seeing so many coaches pursuing excellence was inspiring.

While the discussions with my classmates were invigorating, it was the moments of quiet contemplation and journaling that were the most profound. The guilt and sense of overwhelm I initially felt in realizing my ignorance was replaced by a desire to better understand my sport. I was enjoying the challenge of being back on court in a supporting role. Through reflection, my apprehensions about the coaching profession slowly eroded. As the course progressed, I thought more and more about how tennis has shaped me as a person and the opportunities it has granted me throughout my life. I remembered that the most impactful people in my life beyond my family were my coaches. The prospect of trying to inspire and improve my future players' next point became exciting. Equipped with frameworks, principles, and a means to understand problems and find solutions (scientific literature), I found the courage to make my return to coaching tennis.

REFLECTION

Since the completion of the OS/ITF CAP course in 2019, I have had time to reflect on and better understand this transformational experience. This section substantiates the anecdotes from my 2019 OS/ITF CAP course with academic research and some suggestions. Moreover, this section hopes to prepare a young coach for important aspects of their journey to improving their coaching practice; that is, opening oneself to collective knowledge and challenging preconceptions, establishing the foundations and guiding principles of their coaching practice, selecting the best possible learning environment, and the power of publishing your work.

Overcoming the Ignorance of One's Ignorance: The Dunning-Kruger Effect

The realization that I had fallen victim to the Dunning-Kruger Effect most closely describes my initial feelings of inadequacy when participating in the OS/ITF CAP course. The Dunning-Kruger Effect is a psychological phenomenon where those who possess little wisdom tend to overestimate their competence in a given domain (Kruger & Dunning, 1999). Like many former players, I thought my playing experience taught me everything I needed to know about coaching. The course made me realize there was a whole world of more advanced and unexplored coaching knowledge. While confronting the ignorance of one's ignorance is extremely uncomfortable, it is necessary if you want to progress as a coach. Sometimes, a person's inadequacy is only made apparent when they are confronted by someone far more competent in their field or with information that challenges previously held beliefs.

As a further example, consider a young coach that believes a traditional approach to coaching—which is heavy in technical training and internal instruction—is the best way to coach because it was the way they were taught as a player, and it is reinforced by the coaches around them. While attending a coaching conference, this coach learns of the constraints-led approach (CLA) and the research supporting its efficacy. The CLA highlights how external cues are more effective methods of teaching than internal cues the coach predominantly uses (Gray, 2021). In the on-court presentation at this coaching conference, the young coach sees the fun the players are having and suspects his coaching may have something to do with his/her poor player retention. They realize their methods may not have properly prepared their players for the pressure and problem-solving required on a match court. This young coach then begins to question other assumptions they have.

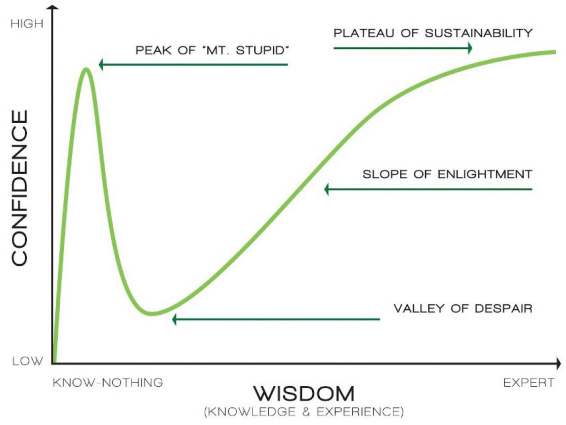

Figure 1. *The Dunning-Kruger Effect*

To combat the Dunning-Kruger Effect, one of the most impactful aspects of the OS/ITF CAP course was being introduced to the scientific literature on tennis and its adjacent fields. Receiving a means to better understand problems and discover solutions is daunting, but also intriguing and encouraging. In my case, the awareness of my nescience has cultivated humility and curiosity in me that I hope will remain perpetually.

A question I ask myself periodically is "are my players succeeding because of or in spite of my training?" This challenging question has helped to open up my curiosity and keep my arrogance in check. A response to this penetrating question and other questions I lack a strong understanding of is, "I don't know, but I will find out." When I feel that I have made an effort to resolve knowledge gaps in my coaching, I work with greater conviction. If you wish to have the greatest impact on your players, you need to be equipped with both knowledge and experience and this starts with an awareness of what you know while recognizing there is a boundless amount of information you don't know.

Finding Clarity on the Change you Seek to Make Through your Coaching

At the heart of the coaching practice are the values, philosophy, and goals of the coach. Experienced coaches assert that developing a coaching philosophy helped to sustain them in their career (Gowling, 2020). In attending the OS/ITF CAP course I learned that there are numerous ways to

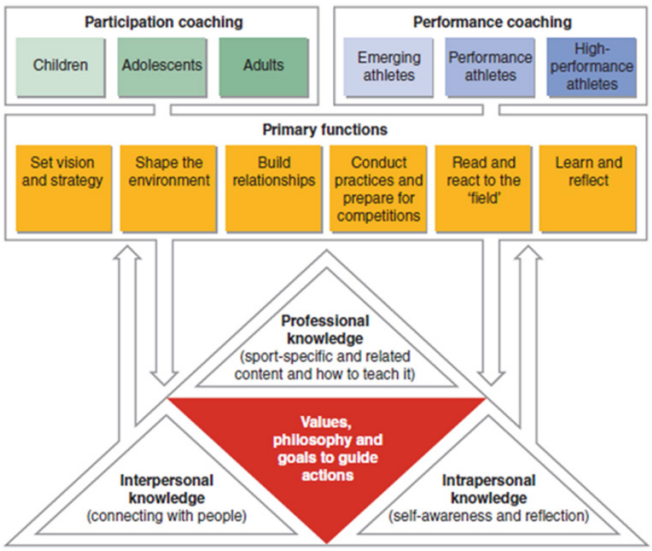

Figure 2. *(Lara-Bercial, Duffy, & Harrington, 2013)*

coach other than a composite of how I was taught or observed as a player. While I am extremely grateful for the role each of my coaches played in my life and what they taught me, I recognized a lack of genuineness and conviction in my own coaching. Experiencing such diverse approaches to coaching in a short amount of time at the OS/ITF CAP course prompted an exploration into what impact I wanted to have with my work. If you haven't been teaching for a long time, coaching courses provide an opportunity to connect with others in the industry that can expedite the formation of your coaching values, philosophies, and goals. If coaches can be clear on how they want to work, and who they wish to serve, they will have an easier job acquiring the knowledge required to improve their craft.

The Power of a Representative Learning Design: An Ecological Dynamics Perspective on Enskilling Coaches

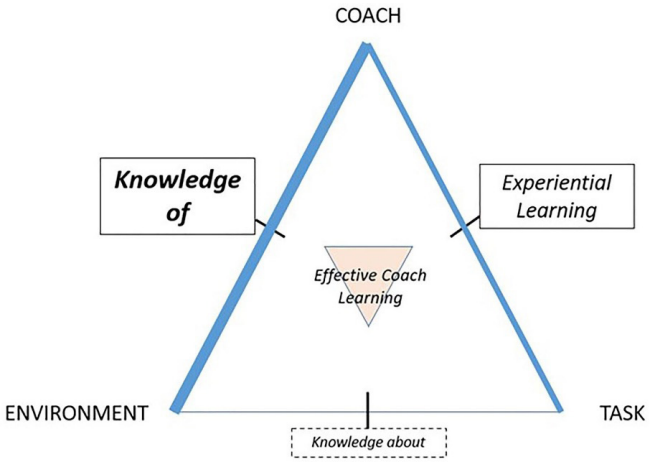

Figure 2. *How interacting categories of constraints influences coach learning and development. Extensive experiential learning and understanding provides knowledge of the environment, combined with just enough knowledge about the coaching process, to create a most effective coach learning environment. Developing coaches who emerge from the simultaneous interaction of these sources of constraints have the potential to continually inform and reshape their behaviors, in a dynamic process of co-adaptation with the environment (Wood et al., 2023).*

How you go about attaining your professional knowledge is important. Looking at coach education through an ecological dynamics (ED) lens, most coaching courses overlook or minimize the importance of representative learning design in enskilling coaches. Representativeness measures the degree to which the learning environment simulates the demands of the actual environment (Wood et al., 2023). Due to the rise in e-learning and the limited consideration for representative learning environments, developing coaches are predominantly offered a knowledge about coaching. "Knowledge about an environment can be considered as an indirect description of a phenomena created by a mediator as a way of having access to facts about an environment" (Wood et al., 2023). Facts such as the players average rally tempo can be important to know, but will not account for or assist a coach in helping a player find the appropriate tempo based on their constraints and those imposed by the score, environment, opponent, etc.. Charts, statistics, frameworks, etc. are useful in planning practice or describing what is being perceived, yet limited in helping a coach solicit the outcomes they desire within practice.

The ED view of educating coaches emphasizes that skill is expressed in the coaches' interaction with the constraints of a representative environment. This "[k]nowledge of the performance environment supports individuals in their continuous direct interactions with their task and environmental constraints. This type of knowledge is useful in different types of performance: organizing actions, making decisions, detecting relevant information to regulate behavior and solving problems directly" (Wood et al., 2023). Knowledge of the performance environment can be facilitated by an experienced coach who attunes the developing coach's attention and intentions based on what is unfolding in the coaching environment. Once/while sufficient knowledge about the environment has been/is being established, an experienced other (Lascu et al., 2024) would share the court with the training coach. This knowledge of coaching developed with the help of a mentor is important as how one claims to teach tennis and how they actually teach can be very different. Pill, Hewitt, and Edwards (2016) found that in a study of thirteen coaches, "personally anticipated coaching behavior of the coach was not what they realized upon observation of their coaching."

An ED view on coaching cautions that an excessive knowledge about without sufficient knowledge of the coaching environment can contribute to adapted (Wood et al., 2023) coaches who feel a lack of agency. An example of an adapted coach is one who follows a lesson plan regardless of whether the player(s) are ready to move on to another task or fails to realize the task needs modification. They may not recognize that a task designed for a morning group when the weather is cooler might need to be adjusted for the afternoon group when it is warmer. Coaches who possess sufficient knowledge of the coaching environment are adaptive (Wood et al., 2023) and able to calibrate their behavior to their environment and objectives. An adaptive coach may recognize that the players' parents hanging out on the back fence are affecting the practice, or the windy conditions might require a modification to the task. Prioritize educational courses or conferences that will allow you to interact directly with experienced others or atleast offer on-court presentations that simulate the coaching environment.

The Benefits of Documenting and Sharing your Journey

While preparing for the 2019 Pacific Games, I began filming aspects of my training and shared clips on Instagram under the handle @tennisrecon. I was looking to develop some basic skills on social media that might lend themselves to my next profession. This documentation of my tennis journey continued at the OS/ITF CAP course (O'Connell, 2019). I not only recorded the eye-opening occurrences that were happening around me, but also captured my reflections on these events in the form of notes. I have since realized the numerous benefits of continuing to post on Instagram for my coaching career.

Depending on the nature of the post, the process of documenting one's work and sharing it on social media can be a form of reflective practice. Reflective practice is the deliberate evaluation of past actions and experiences for learning and improving future actions (Roy, Gavrila, & Sercia, 2021). This process is commended in particular for its ability to develop a coach's intrapersonal knowledge: the awareness and introspection to transform ideas and experiences into learning and growth (Roy, Gavrila, & Sercia, 2021). Regardless of when (prior to, during, or following a coaching event), how (journal, reflective cards, video, audio recording), or why (technical, practical, or critical) reflective practice is incorporated by the coach, evidence reflects a positive influence on coaching effectiveness (Roy, Gavrila, & Sercia, 2021), and hardiness (Cropley et al., 2020).

Since committing to coaching, posting on Instagram has been a means of improving my professional knowledge. In researching different pain points of my coaching, I have been able to use social media to improve my knowledge about tennis. Taking complicated scientific articles and condensing them so that they might be shared on Instagram has been extremely helpful to my learning. Seizing opportunities to grow your knowledge is important, but retaining what we have learned can be even more difficult. Ebbinghaus noted the challenge to memory in the late 1800s in that half of forgetting occurs within the first hour of learning (Ebbinghaus, 1913; Murre & Drose, 2015). Not to leave his own problem unsolved, Ebbinghaus found that if he reviewed the material, he learnt intermittently he was able to stave off forgetting, and as time went on, he spent less time reviewing (Ebbinghaus, 1913). Periodically scanning through my posts or the saved posts from other accounts that I have curated for ideas has helped to make me a more knowledgeable coach for the next person I step on court with.

Moreover, publishing the work I do with my players on Instagram has opened up another avenue of communication with people interested in my work, and has improved my interpersonal knowledge. We live in a world where people are spending an increasing amount of time on screens. Players, parents, coaching peers, and other potential partners are creating and connecting on social media. Augmenting your educational posts with the media to commemorate important milestones and achievements for yourself, your players, and your business is endearing to others and motivating to you as the coach. The multiple modes of communication this medium offers (posts, polls, prompts, reels, live, comments, direct messages, etc.) has provided me insights on my clients and those interested in my coaching journey. Over time, my Instagram account has assisted me in building relationships with coaches and other individuals I respect.

From a business perspective, publishing my coaching journey on Instagram has been extremely beneficial. Instead of introducing myself and my values, philosophy, and goals to each individual, I have a digital persona that does this for me. These pre-qualified stakeholders have an understanding of how I work and choose me because they appreciate what I do. When the demand for what you do moves beyond the hours you are willing to work, you get to select your clients and can consider asking for greater compensation. Consider the resources spent on creating a digital profile an investment that can accelerate you and your business' growth.

With sufficient investment into your digital profile, opportunities may arise to connect with people you can help and vise versa. Other tennis content creators have orchestrated opportunities for growth and enjoyment (invitations to events, etc.), alternate revenue streams, (products, partnerships, etc.) and passive income (media, asset ownership, etc.). Ashley Neaves used the mandated time off-court during the COVID-19 pandemic to create tennis content under "The Tennis Mentor" brand for social media that has grown to a 190,000 and 79,400 follower count across Instagram and YouTube as of October of 2024 (Neaves, n.d. a). This has resulted in the creation of and collaborations on courses (Neaves, n.d. b), invitations to present at reputable coaching conferences (RDK Sports International, 2023), invitations to events or experiences (The Tennis Mentor, 2022), and partnerships (Neaves, n.d. c) with businesses.

For those apprehensive about sharing with the world, there are multiple platforms and means of sharing your tennis message. You can present on a platform in a way you are comfortable with, you just need to make sure your intended audience is on the platform. While Instagram and TikTok orient more towards short format visuals, X (Twitter) is primarily a text-based platform, and YouTube leans toward long format video. The geographics, demographics, behaviorgraphics, and psychographics are also different on each platform. Furthermore, one doesn't need to behave out of character or musn't feel pressured to overshare to take part in social media. As Daniel Priestly would say "Don't try to be in the spotlight, try to become the spotlight" (2011). That is, shine light on the internal and external happenings that pertain to your coaching niche. Be clear on how you want to present and show up consistently for your smallest viable audience (Godin, 2022).

CONCLUSION

The opportunity for coaches is immense in respect to the growth in popularity and investment in the infrastructure of tennis (International Tennis Federation, 2021). If tennis is to improve its reach, regard, and retention, it is incumbent on its coaches to view their profession with curiosity and approach their profession with a sense of craftsmanship. Unfortunately, regard for certification (Allen et al., 2021; Fehr, 2013; International Tennis Federation, 2024) does not seem to match the goal to grow our global sport through better coaching (Santos et al., 2010; Crespo et al., 2006).

My experience at the ITF/OS CAP course was transformative, and consistent with the positive outcomes experienced by other participants of this course (Martínez-Gallego, Nash, & Crespo, 2023). Finding the right coaching course can reinvigorate your coaching career. An important aspect of selecting your next course is enquiring into the knowledge of coaching offered in comparison with the knowledge about coaching provided. The distinction is important as knowledge of coaching will produce adaptive coaches, who can positively impact their coaching environment. Also, consider the exposure to other coaches your course will provide. The creation of values, philosophies, and goals is central to an effective coaching practice (Gowling, 2020) and can be accelerated by interactions with other coaches.

Despite the efficacy of reflective practice (Roy, Gavrila, & Sercia, 2021; Cropley et al., 2020), there may be a lack of appreciation for this means of coach development (Cortela et al., 2017). This heightened self-awareness developed through a reflective practice might help to avert common pitfalls for coaches like the Dunning-Kruger effect. Documenting your work can be a means to improve and retain your professional knowledge. Publishing your work can be another avenue to growing your interpersonal knowledge and your business. Addressing these foundational aspects of the coaching practice (Lara-Bercial, Duffy, & Harrington, 2013) can foster a sustainable and rewarding career.

CONFLICT OF INTEREST AND FUNDING

The author declares that he has no conflict of interest and that he did not receive any funding to produce the article.

FURTHER RESEARCH

There does not appear to be any quantitative data on the career span of tennis coaches. Further research into how factors such as personal motivations, job satisfaction, and the pressures associated with the coaching environment affect the career longevity of a coach may be fruitful.

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Initial evidence on the impact of the 2023 World Tennis Number algorithm change for predicting match outcomes

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ABSTRACT

The World Tennis Number (WTN) algorithm was changed in 2023. We examine 2,956 matches from the United States Tennis Association (USTA) Junior National Championships to ascertain whether this algorithm change improved the ability of WTN to accurately classify match winners. We assess improvement relative to two benchmarks: Universal Tennis Rating (UTR) values and WTN values prior to the algorithm change. Existing research establishes that UTR and WTN exhibit equivalent classification accuracy for match outcomes and we find no evidence in any tournament division that the algorithm change improves WTN relative to UTR. When we compare classification accuracy of WTN values under the new algorithm to WTN values prior to the algorithm change, we find a statistically significant improvement in only one of four tournament divisions. The overall evidence is most consistent with statements by the USTA that within a player's network, little accuracy improvement may be observed from the WTN algorithm change. Our findings update prior literature on the classification accuracy of UTR and WTN and provide a new reference point for evaluating future algorithm changes.

Key words: World Tennis Number (WTN), Universal Tennis Rating (UTR), Junior Tennis, Match Forecasting.

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INTRODUCTION

On July 26, 2023, the International Tennis Federation (ITF) implemented significant revisions to the algorithm responsible for computing a player's World Tennis Number (WTN). The intention behind the change was to increase WTN accuracy in competitive events, particularly with regard to age (ITF, 2023a). The United States Tennis Association (USTA) noted that the algorithm revision would result in minor WTN changes for adult players between 19 and 29 years of age. However, adult players over 30 and junior players 10 and under were expected to move down the quality scale, and players aged 17 and 18 were expected to move up the quality scale (USTA, 2023a). This change raised the question of whether the WTN prior to the algorithm change was inaccurate. In response, the USTA stated that the previous WTN was indeed accurate within a given player's network and would remain so after the algorithm change (USTA, 2023a).

Given that a WTN accuracy improvement should result in an improved ability of WTN to predict match outcomes, we empirically examine whether or not the 2023 algorithm change had any impact on WTN's ability to predict match outcomes at the USTA Junior National Championships. Ascertaining whether the WTN algorithm change leads to any improvement is important as organizations within the tennis community evaluate whether to adopt WTN or Universal Tennis Rating (UTR) as their preferred measure of player skill. For example, in the United States, the Intercollegiate Tennis Association (ITA) switched their official rating system from UTR to WTN in 2023 (ITA, 2023). Despite this change, UTR appears to nonetheless be preferred over WTN when college coaches engage in recruiting (Palmer, 2024). If the WTN algorithm change has improved WTN perhaps constituents like college coaches will change their view about which rating is superior.

We focus on the USTA Junior National Championships for three reasons. First, as a prestigious national tournament, players from across the country are represented. This differs from regional or sectional USTA tournaments that are more geographically bounded and reflect a less generalizable participant pool. Second, how well WTN predicts match outcomes has been reported for this particular tournament in recent prior research (Mayew and Mayew, 2023; Im and Lee, 2023). Finally, and most importantly, the participants compete in divisions based on both age (18u and 16u) and gender (boys and girls) bands that hold the player network relatively constant. Given the USTA comments, within a division, we would expect no match classification accuracy difference as a result of the WTN algorithm change. On the other hand, the 18u division of this tournament contains the 17 to 18-year-old demographic that the ITF stated would likely result in WTN changes. If this WTN change improves accuracy, we may see an improvement in the ability of WTN to predict match outcomes.

We test whether the 2023 algorithm change improved the ability of WTN to predict match outcomes in two complementary ways. First, we note that existing research

prior to the 2023 algorithm change shows that WTN values predict match outcomes at better than chance levels and at levels statistically equivalent to the UTR (Im and Lee, 2023; Mayew and Mayew, 2023). As such, our first test assesses whether WTN now outperforms UTR in terms of predicting match outcomes during the 2023 USTA Junior National Championship, which was one of the first tournaments occurring after the WTN algorithm change. This empirical strategy exploits the fact that no known changes to the UTR algorithm have occurred, allowing UTR to serve as a benchmark against which WTN derived under the new algorithm can be assessed. As our second test, we re-examine the 2022 USTA Junior National Championship matches. The original WTN values in place during the 2022 USTA Junior National Championships were prior to the algorithm change. We obtain retroactively restated WTN values that reflect the 2023 WTN algorithm change and compare their ability to predict match outcomes with the original WTN values in place at the time of the 2022 tournament. With this empirical strategy, we take the originally reported WTN values as the benchmark and ascertain whether the restated WTN values predict match outcomes better than the original WTN values.

METHODS

Sample

For our analysis of the 2023 USTA Junior Championships, we obtain match and player information by reviewing publicly displayed match draws on the USTA tournament website (USTA, 2023b; Tournament ID 23-04247 for boys starting August 5, 2023 and Tournament ID 23-60720 for girls starting August 4, 2023). The total number of potential matches is 2,028, which includes the main draw and consolation draw for both boys and girls in both 18u and 16u divisions. After removing 256 byes in both the main and consolation draws, 87 withdrawals prior to the match starting and 3 matches where players had identical WTN or UTR values, we are left with a final sample of 1,426 total matches, representing 768 unique players. Player WTN and UTR values were collected on August 3, 2023, prior to the start of play. UTR values for each player were obtained via a power subscription to the UTR Sports App (UTR, 2023). WTN values for each player were obtained from the WTN rating website (ITF, 2023b), and these WTN values reflect the WTN algorithm change.

For our analysis of the 2022 USTA Junior National Championship, we obtain the data analyzed in Mayew and Mayew (2023), which contained 1,532 matches and 870 unique players. The WTN values analyzed in Mayew and Mayew (2023) were the prior to the algorithm change. We append to this dataset restated WTN values for each of the 870 players which were provided to us by the ITF, delivered via a Google Sheet from the USTA Manager of Community Tennis Digital Services. We then removed two matches where competing players had identical restated WTN values, resulting in 1,530 matches.

Statistical Analysis

For each match played in the 2023 tournament, we follow Im and Lee (2023) and randomly choose one player from the match as the reference player. We then regress an indicator variable for whether the randomly chosen reference player won the match on the difference between the reference player's rating versus the rating of the other player. Separate bivariate logistic regressions are estimated for UTR and WTN ratings using STATA/SE 17.0 statistical software. From each logistic regression we obtain two measures of classification accuracy utilized in the tennis match forecasting literature: the area under the receiver operator characteristic curve (AUC) (Im and Lee 2023; Mayew and Mayew 2023), and the Brier score (Boulier and Stekler, 1999; del Corral and Prieto-Rodriguez, 2010; Mayew and Mayew 2023). An AUC (Brier score) value of 0.50 (0.25) represents random chance levels of classification accuracy, and an AUC (Brier score) of 1.00 (0.00) represents perfect classification accuracy. We compare the WTN AUC (AUC_{WTN}) to the UTR AUC (AUC_{UTR}) and the WTN Brier score (BRIERWTN) to the UTR Brier score (BRIERUTR). Observing statistical differences in AUC and Brier scores where $AUC_{WTN} > AUC_{UTR}$ and BRIERWTN < BRIERUTR would support the conclusion that the 2023 WTN algorithm change improved match outcome classification accuracy. If there is no statistical difference, it would support the USTA claim that within a player's network, WTN values would not exhibit a difference in accuracy. We consider p-values < 0.05 to be statistically significant.

For the 2022 Junior National Championships, we undertake the same analysis as 2023 except our ratings of interest are no longer WTN versus UTR, but rather the original WTN used during the 2022 tournament (WTNO) versus a retroactively restated WTN (WTNR). We would conclude that the WTN algorithm change improved match classification accuracy if $AUC_{WTNR} > AUCWTNO$ and $BRIER_{WTNR} < BRIER_{WTNO}$.

RESULTS

Panel A of Table 1 provides WTN and UTR values for players in the 2023 Junior National Championships by division. WTN values for these players reflect the 2023 algorithm change. Recall that lower (higher) WTN (UTR) values indicate higher skill. The Boys 18u division has the highest-skilled players with an average UTR and WTN of 11.37 and 13.48, respectively. The Girls 16u division has the lowest-skilled players with and average UTR and WTN of 8.48 and 19.07, respectively. Holding gender constant, older players have higher UTR values and lower WTN values in both the Boys and Girls divisions, reflecting natural development in skill as players age.

In Panel B we tabulate how often the favored player wins the match. Across divisions, the favored player based on WTN wins between 76.29% (Boys 16u division) and 72.45% (Girls 16u division) of the time. Based on UTR, the favored player wins between 76.33% (Girls 18u division) and 71.07% (Girls 16u division). In no division do the proportion of matches won by the favored player differ statistically between UTR and WTN. Considering all matches together, the favored player wins based on their rating in a head-to-head match 74.40% of the time for WTN and 74.33% for UTR. These proportions do not statistically differ (p-value = 0.94), are very similar to the 75% and 76% rates documented for this tournament in the prior year (Mayew and Mayew, 2023), and fall in between the ranges of 71.2% and 81.8% documented in professional tournaments (del Corral and Prieto-Rodriguez, 2010; Boulier and Stekler, 1999).

Assessing the proportion of matches won by the favored player only considers the sign of the difference in ratings but not the magnitude of the difference. The magnitude is considered in our logistic regression estimations from which we derive AUC and Brier scores to assess classification accuracy. In Panel C, across divisions we find AUC values

Table 1. *Analysis of 2023 USTA Junior National Championships.*

Panel A. Player Level Descriptive Statistics

	Boys 18u (n=192)		Boys 16u (n=192)		Girls 18u (n=192)		Girls 16u (n=192)		OVERALL (N=768)	
VARIABLE	**MEAN**	**STD**	**MEAN**	**STD**	**MEAN**	**STD**	**MEAN**	**STD**	**MEAN**	**STD**
WTN	13.48	3.19	16.83	2.65	15.93	2.78	19.07	2.36	16.33	3.41
UTR	11.37	0.86	10.54	0.89	9.26	0.73	8.48	0.67	9.91	1.37

Panel B. How Often Favored Players Win Matches

	Boys 18u (n=358)		Boys 16u (n=367)		Girls 18u (n=338)		Girls 16u (n=363)		OVERALL (N=1,426)	
	#	**%**	#	**%**	#	**%**	#	**%**	#	**%**
FAVORED PLAYER WINS$_{WTN}$	266	74.30%	280	76.29%	252	74.56%	263	72.45%	1,061	74.40%
FAVORED PLAYER WINS$_{UTR}$	264	73.74%	280	76.29%	258	76.33%	258	71.07%	1,060	74.33%
P-value of test of equal proportions^{+}		0.75		1.00		0.35		0.46		0.94

Panel C. Match Outcome Prediction Analysis Based on Logistic Regression Results

	Boys 18u (n=358)		Boys 16u (n=367)		Girls 18u (n=338)		Girls 16u (n=363)		OVERALL (N=1,426)	
VARIABLE	**EST**	**95% CI**	**EST**	**95% CI**	**EST**	**95% CI**	**EST**	**95% CI**	**EST**	**95% CI**
AUC$_{WTN}$	0.814	0.771-0.856	0.837	0.796 - 0.877	0.825	0.781-0.868	0.796	0.751-0.765	0.817	0.796 - 0.839
AUC$_{UTR}$	0.825	0.783-0.867	0.848	0.809 - 0.886	0.853	0.814-0.892	0.809	0.766-0.853	0.833	0.813 - 0.854
P-value of test^{++}*: AUC$_{WTN}$ =AUC$_{UTR}$*	0.33		0.33		0.01		0.17		<0.01	
BRIER$_{WTN}$	0.175	0.154-0.195	0.165	0.144-0.186	0.171	0.150-0.192	0.184	0.164-0.204	0.174	0.164-0.185
BRIER$_{UTR}$	0.171	0.151-0.191	0.159	0.138-0.180	0.157	0.135-0.179	0.178	0.158-0.198	0.167	0.156-0.177
P-value of test^{+++}*: BRIER$_{WTN}$=BRIER$_{UTR}$*	0.49		0.34		0.01		0.17		<0.01	

Table 1 presents data for 768 sample players in Panel A and 1,426 sample matches in Panels B and C from the 2023 USTA Junior National Championships. UTR is the UTR value as of the start of the tournament, which ranges from 1.00 (lowest skill) to 16.50 (highest skill). WTN is the WTN value as of the start of the tournament, which was after the 2023 algorithm change, and ranges from 40.00 (lowest skill) to 1.00 (highest skill). FAVORED PLAYER WINS$_{WTN}$(UTR) indicates the player with the lower (higher) WTN (UTR) won the match. AUC$_{WTN}$ and BRIER$_{WTN}$ represent the area under the receiver operator curve and Brier score, respectively, derived from a bivariate logistic regression where the dependent variable is an indicator for whether a randomly chosen reference player from the pair wins the match and the independent variable is the reference player WTN minus the WTN of the other player. AUC$_{UTR}$ *and BRIER$_{UTR}$ represent the area under the receiver operator curve and Brier score, respectively, derived from a bivariate logistic regression where the dependent variable is an indicator for whether a randomly chosen reference player from the pair wins the match and the independent variable is the reference player UTR minus the UTR of the other player. AUC (Brier score) values of 0.50 (0.25) represent chance levels of classification accuracy and 1.00 (0.00) represent perfect classification accuracy. EST is the derived estimate and 95% CI indicates the 95% confidence interval. All reported p-values are two tailed. +McNemar test of equal proportions; ++DeLong et al. (1998) test of equal areas called via the roccomp command in STATA; +++Paired t-test.*

ranging from 0.796 to 0.837 for WTN and from 0.809 to 0.853 for UTR. Comparing WTN to UTR, we find no statistical statistically significant differences between WTN and UTR classification accuracy in three of the four divisions, whether we consider AUC or Brier score differences. However, in the Girls 18u division we find UTR exhibits statistically better classification accuracy when considering AUC differences (AUC$_{UTR}$ = 0.853 versus *AUC$_{WTN}$*= 0.825, p-value = 0.01) and Brier score differences (BRIERUTR = 0.157 versus BRIER$_{WTN}$ = 0.171, p-value = 0.01). When considering all divisions collectively, both AUC differences (AUC$_{UTR}$ = 0.833 versus *AUC$_{WTN}$*= 0.817, p-value = 0.01) and Brier score differences (BRIER$_{UTR}$ = 0.167 versus BRIER$_{WTN}$ = 0.174, p-value = 0.01) suggest UTR statistically provides superior classification accuracy, but this finding is not independent of the divisional findings as the full collection of matches includes the Girls 18u division. We have no explanation why the Girls 18u division would exhibit a statistically significant difference in classification accuracy while other divisions do not. In terms of an overall inference, we note that prior research studying UTR and WTN classification accuracy at the USTA Junior National Championships prior to the 2023 WTN algorithm change concludes both ratings are equivalent predictors of match outcomes (Im and Lee 2023; Mayew and Mayew 2023).

Given we find no evidence that WTN derived under the new algorithm outperforms UTR, we conclude that the WTN 2023 algorithm change does not improve WTN classification accuracy when UTR is used as the benchmark.

Table 2 presents the re-examination of the 2022 tournament, where we consider the original WTN as the benchmark instead of UTR. Panel A compares the originally reported WTN against the WTN restated as if the 2023 algorithm change was hypothetically in place for the 2022 tournament. Viewing the differences by division, we see the effects of the 2023 WTN algorithm change vary by gender. The mean restated WTN is statistically higher than the original WTN in a paired t-test for the Boys 18u (12.32 versus 12.05; p-value < 0.01) and Boys 16u (15.66 versus 15.31; p-value < 0.01) divisions. Since higher WTN indicates lower skill, this implies the 2023 algorithm change shifted boys down the quality scale. The opposite is true for girls, where restated WTN values are statistically smaller than original WTN values for both the Girls 18u (16.52 versus 16.78; p-value < 0.01) and Girls 16u (17.89 versus 18.15; p-value < 0.01) divisions. This implies the 2023 algorithm change had the effect of moving girls up the quality scale. Why this is the case is unclear given the USTA suggested that shifts up the quality scale should more likely be observed by age (i.e. in the 18u divisions) rather than by gender. Considering all players overall, the restated WTN is not statistically different from the original WTN in a paired t-test (WTNR = 15.65 versus WTNO = 15.63; p-value 0.07). However, this overall finding is not independent of the division findings and observing no statistically significant difference overall is due to offsetting effects of the 2023 WTN algorithm change for boys versus girls.

In Panel B, we tabulate the proportion of matches won by the favored player where the favored player is assessed using original WTN and the restated WTN values. We find that the proportion of matches won by the favored player does not statistically differ between the original and restated WTN in any division or overall. The overall favored-player win proportion is 75.62% for the restated WTN, statistcially equivalent to the original WTN of 75.69%.

In terms of classification accuracy, in Panel C we find that in each division the restated WTN results in slightly higher (lower) AUC (Brier scores). However, these differences are not statistically significant in three out of the four divisions. Only in the Girls 18u division do we observe a statistically significant difference, where the restated WTN outperforms the original WTN, whether assessed with AUC (AUC_{WTNR} = 0.848 versus AUC_{WTNO} = 0.839; p-value = 0.01) or Brier scores ($BRIER_{WTNR}$ = 0.160 versus $BRIER_{WTNO}$ = 0.164; p-value = 0.01). Despite being statistcially different, the magnitude of the AUC and Brier score differences in the Girls 18u division are economically modest, at 0.009 and 0.004, respectively. Pooling all matches from all divisions reveals a statistically larger (smaller) AUC (Brier score) value for the restated WTN rating over the original, but again this overall result is not independent of the results observed at the individual division level. We conclude from this analysis of the 2022 tournament that the algorithm change has not systematically improved WTN classification accuracy given the only improvement is observed in the Girls 18u division.

DISCUSSION

We provide initial evidence on the impact of the 2023 WTN algorithm change for predicting match outcomes at the USTA Junior National Championships. Using UTR classification accuracy as a benchmark for WTN values generated under the new algorithm in the 2023 tournament, we find WTN does not outperform UTR in any division. To the contrary, UTR classification accuracy outperforms WTN but only in the Girls 18u division. Using classification accuracy from original WTN values prior to the 2023 algorithm change as the reference point in the 2022 tournament, we find WTN values restated to retroactively reflect the algorithm change predict match outcomes to a statistically equivalent extent in three of the four tournament divisions. In the Girls 18u division, the restated WTN ratings statistically outperform the original WTN ratings in terms of classification accuracy. Overall, across the eight divisions we examine, six divisions provide no statistically significant support of a WTN classification accuracy improvement from the algorithm change, in one division we find inferiority (Girls 18u in the 2023 tournament), and in one division we find superiority (Girls 18u in the 2022 tournament). This collective evidence does not support the conclusion that the 2023 WTN algorithm change has systematically improved the ability of WTN ratings to predict match outcomes.

Interestingly, the Girls 18u division was the only division to exhibit statistically significant differences, albeit in different directions with respect to the effects of the 2023 WTN algorithm change. Why the Girls 18u division in particular exhibits statistically significant classification accuracy differences in both tournaments while other divisions do not is an import issue to consider in future research. Insights specific to the Girls 18u division are not available in the extant literature, as Im and Lee (2023) only considered boys divisions and Mayew and Mayew (2023) considered girls overall but not separately for the 18u and 16u divisions.

That we observe no systematic improvement in classification accuracy from the 2023 WTN algorithm change is most consistent with the USTA statement that accuracy improvements may not be observed within a player's network. Given USTA junior tournaments are generally conducted within narrow age bands, the age span of players in a given tournament division may not be sufficiently "out of network" to observe WTN algorithm change effects. Our results, therefore, cannot be extrapolated to other tournaments to imply that the 2023 WTN algorithm change had no effect whatsoever on the ability of WTN to predict match outcomes. Future research should therefore consider a wider set of tournaments, such as local USTA open tournaments that do not have age restrictions. In these tournaments, sufficient age differences in participants are likely and potential WTN algorithm change effects may be detectable.

Additionally, we acknowledge that WTN classification accuracy improvements may ultimately not be possible in the context of the USTA Junior National Championships. The players in this tournament are among the most accomplished junior players in the nation, reaching this status by playing many matches per year. As such, their WTN values may be so well calibrated that any algorithm enhancement effects will be difficult to detect. Existing research reveals that, prior to the 2023 algorithm change, WTN predicted match outcomes at the Junior National Championships at better than chance levels and on par with oddsmakers at the professional level (Mayew and Mayew, 2023). If oddsmakers represent the gold standard for classification accuracy, there may be little room to improve WTN for predicting match outcomes at the USTA Junior National Championships.

Table 2. *Reanalysis of 2022 USTA Junior National Championships with Restated WTN Values.*

Panel A. Player Level Descriptive Statistics

	Boys 18u (n=208)		Boys 16u (n=222)		Girls 18u (n=216)		Girls 16u (n=224)		OVERALL (N= 870)	
VARIABLE	MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD	MEAN	STD
ORIGINAL WTN (WTNO)	12.05	2.84	15.31	2.52	16.78	2.96	18.15	2.69	15.63	3.55
RESTATED WTN (WTNR)	12.32	2.86	15.66	2.53	16.52	2.91	17.89	2.65	15.65	3.41
P-value of test^{+++}: WTNO = WTNR	<0.01		<0.01		<0.01		<0.01		0.07	

Panel B. How Often Favored Players Win Matches

	Boys 18u (n=337)		Boys 16u (n=401)		Girls 18u (n=375)		Girls 16u (n=417)		OVERALL (N= 1,530)	
	#	%	#	%	#	%	#	%	#	%
FAVORED PLAYER $WINS_{WTNO}$	252	74.78%	307	76.56%	286	76.27%	313	75.06%	1,158	75.69%
FAVORED PLAYER $WINS_{WTNR}$	251	74.48%	305	76.06%	289	77.07%	312	74.82%	1,157	75.62%
P-value of test of equal proportions^{+}		0.76		0.59		0.37		0.70		0.87

Panel C. Match Outcome Prediction Analysis Based on Logistic Regression Results

	Boys 18u (n=337)		Boys 16u (n=401)		Girls 18u (n=375)		Girls 16u (n=417)		OVERALL (N=1,530)	
VARIABLE	EST	95% CI	EST	95% CI	EST	95% CI	EST	95% CI	EST	95% CI
AUC_{WTNO}	0.830	0.787-0.873	0.845	0.807-0.883	0.839	0.800-0.878	0.818	0.777-0.858	0.832	0.812-0.852
AUC_{WTNR}	0.834	0.791-0.876	0.846	0.808-0.883	0.848	0.810-0.886	0.820	0.781-0.860	0.836	0.817-0.856
P-Value of Test^{++}: AUC_{WTNO} =AUC_{WTNR}	0.34		0.79		0.01		0.41		0.02	
$BRIER_{WTNO}$	0.168	0.147-0.190	0.160	0.140-0.180	0.164	0.143-0.184	0.174	0.155-0.193	0.167	0.157-0.177
$BRIER_{WTNR}$	0.167	0.145-0.188	0.159	0.140-0.179	0.160	0.139-0.180	0.173	0.153-0.192	0.165	0.155-0.175
P-Value of Test^{+++}: $BRIER_{WTNO}$ =$BRIER_{WTNR}$	0.41		0.65		0.02		0.41		0.03	

Table 2 presents data for 870 sample players in Panel A and 1,530 sample matches in Panels B and C from the 2022 USTA Junior National Championships. WTNO is the original WTN value as of the start of the tournament, which was prior to the 2023 WTN algorithm change, and ranges from 40.00 (lowest skill) to 1.00 (highest skill). WTNR is the WTN value restated as if the 2023 WTN algorithm change was retroactively in place instead of the original WTN value, and also ranges from 40.00 (lowest skill) to 1.00 (highest skill). FAVORED PLAYER $WINS_{WTNO}$(WTNR) indicates the player with the lower WTNO (WTNR) won the match. AUC_{WTN} O and $BRIER_{WTNO}$ represent the area under the receiver operator curve and Brier score, respectively, derived from a bivariate logistic regression where the dependent variable is an indicator for whether a randomly chosen reference player from the pair wins the match and the independent variable is the reference player WTNO minus the WTNO of the other player. AUC_{WTNR} and $BRIER_{WTNR}$ represent the area under the receiver operator curve and Brier score, respectively, derived from a bivariate logistic regression where the dependent variable is an indicator for whether a randomly chosen reference player from the pair wins the match and the independent variable is the reference player WTNR minus the WTNR of the other player. AUC (Brier score) values of 0.50 (0.25) represent chance levels of classification accuracy and 1.00 (0.00) represent perfect classification accuracy. EST is the derived estimate and 95% CI indicates the 95% confidence interval. All reported p-values are two tailed. +McNemar test of equal proportions; ++DeLong et al. (1998) test of equal areas called via the roccomp command in STATA; +++Paired t-test.

Our analysis comparing WTN to UTR in the 2023 tournament also serves the purpose of updating prior research investigating the differential ability of WTN and UTR to predict match outcomes. Prior to the 2023 WTN algorithm change, Im and Lee (2023) report AUC values based on WTN of 0.851 for Boys 18u and 0.846 for Boys 16u. We document values equal to 0.814 and 0.837 for Boys 18u and 16u, respectively. For UTR, Im and Lee (2023) report AUC values of 0.862 for Boys 18u and 0.860 for Boys 16u, while we document values of 0.825 and 0.848, respectively. Thus, the classification accuracy we document is slightly lower than Im and Lee (2023) whether using WTN or UTR. One possible reason for the slightly lower ability of both WTN and UTR to predict match outcomes in 2023 versus 2022 is that the USTA decreased the number of participants in the 2023 tournament relative to 2022. Fewer participants has the effect of eliminating lower skilled players, which in turn compresses the skill variation across players and makes predicting match outcomes more difficult.

Mayew and Mayew (2023) also studied the 2022 tournament and report AUC values that are systematically lower than what we document here and what is documented in Im and Lee (2023). This is because the bivariate logistic regression estimations in Mayew and Mayew (2023) that underpin their AUC_{WTN} and AUC_{UTR} values use the higher-rated player as the reference player for constructing rating differences as opposed to a randomly chosen reference player. As Huo and Glickman (2024) show, estimations where the stronger player is used as the reference will generally generate systematically lower AUCs. As such, our findings are not directly comparable to Mayew and Mayew (2023) with respect to updating our understanding of the classification accuracy of UTR and WTN. However, Mayew and Mayew (2023) do provide a mapping function between UTR and WTN prior to the WTN algorithm change and we can assess whether that has changed.

Re-examining the mapping between UTR and WTN is important because some junior players compete in events where UTR is the preferred rating, while others compete in events where WTN is the preferred rating. As such, a given player may not have both a UTR and WTN rating. Given WTN is the official rating of the International Tennis Federation (ITF), we assess how to uncover a WTN from a UTR using the 2023 data that contains post-algorithm change WTN values. Mayew and Mayew (2023) use an ordinary least squares regression where they regress WTN on UTR to uncover a mapping function equal to: (WTN = 39.18 – 2.40*UTR). Our estimation using the 768 players in the 2023 tournament reveals a function with similar parameters (WTN = 37.23 – 2.11*UTR). For reference, the regression model underpinning this function had a reasonable model fit with an R^2 of 71.7%. However, since we observed the 2023 WTN algorithm change impacted boys and girls differently in Panel B of Table 2, we provide a scatterplot of WTN and UTR by gender in Figure 1.

Figure 1 reveals that the mapping of UTR to WTN varies by gender. Estimating the mapping function separately by gender reveals (WTN = 51.7 - 3.34*UTR) for boys and (WTN = 49.89 – 3.65*UTR) for girls. These functions look quite different than the estimation based on all data pooled together. Moreover, estimating the function by gender results in superior model fits, with an R^2 of 91.2% for boys and 94.1% for girls, compared with 71.7% when all players are pooled together. This evidence suggests that gender may be an important consideration when considering the mapping between UTR and WTN. However, we acknowledge that the gender effects we observe are based upon a sample of elite players that participate in the USTA Junior National Championships and future research should consider how WTN and UTR values map to each other for players outside of the WTN and UTR ranges we study here. Moreover, WTN recently underwent an algorithm enhancement on September 11, 2024. Whether the classification accuracy of WTN has subsequently improved and whether the UTR to WTN mapping we observe changes as a result of the 2024 WTN algorithm change is an important area of inquiry for future research.

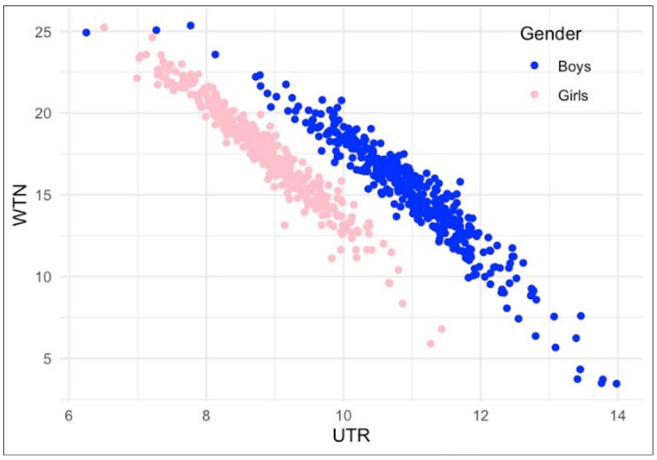

Figure 1: *Scatter plot depicting the relationship between WTN values derived under the revised WTN algorithm (vertical axis) and UTR values (horizontal axis) by gender for the sample of 768 players in the 2023 USTA Junior National Championships.*

CONCLUSION

We provide initial insights on whether the classification accuracy of WTN improved after the 2023 algorithm change using 2,965 matches from the USTA Junior National Championships. We find no systematic evidence of an improvement, which is perhaps a result of players in the tournament being sufficiently within their own age and gender networks, where an accuracy improvement is less likely to occur. Our findings update prior research on the classification accuracy of WTN and can serve as a reference point when evaluating the efficacy of future WTN algorithm enhancements.

CONFLICT OF INTEREST AND FUNDING

The authors declare no conflicts of interest and did not receive funding to conduct this research.

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Psychophysiological responses and heart rate variability in competitive tennis: a case study

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ABSTRACT

This study aimed to monitor an elite tennis athlete during the National Tennis Championships by characterizing matches physiological, psychological, and observational variables, including heart rate (HR), heart rate variability (HRV), perceived exertion (RPE), and assessments at morning rest. Differences were found between the four matches' in-game characteristics and HR, and between service and return games' in-game characteristics and HR except for game 3. Statistically significant correlations were found between the variable's duration of points and recovery time between points for match 2 ($r = 0.349$, $p < 0.01$), match 3 ($r = 0.230$, $p < 0.03$), and match 4 ($r = 0.241$, $p < 0.01$). We found a correlation between match duration and effective playing time ($r = -0.930$, $p < 0.05$); between match duration and RPE ($r = 0.916$, $p < 0.05$), and between RPE and effective playing time ($r = -0.977$, $p < 0.05$). Time spent on the >85% HRmax was 0; 8; 9.2 and 42.7% for matches 1, 2, 3, and 4. Differences in HR before the start of match 4 (the final match) and the previous matches were found. In the sitting recovery periods of match 4, SNSIndex decreased in the last two periods, unlike HR, which continued to increase slightly.

Key words: heart rate variability, perceived exertion, training load, recovery.

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INTRODUCTION

Tennis is a multifaceted sport that has evolved from focusing primarily on technical ability to requiring complex interactions of various physical and metabolic abilities for high performance (Baiget et al., 2015; Edel et al., 2019; Fernandez-Fernandez et al., 2008; Mendez-Villanueva et al., 2010; Ulbricht et al., 2016). Identifying the physiological determinants of performance is crucial for athletes, involving monitoring training and evaluating performance in competition (Kilit et al., 2016). Heart rate (HR), the number of beats per minute, reflects the intensity of physical exertion and cardiovascular demand, which fluctuate in tennis due to the sport's intermittent nature (Baiget et al., 2015; Kovacs, 2006). HR responses can vary significantly between service and return games, as each situation involves distinct physical and mental demands. Heart rate variability (HRV), or the variation in time intervals between consecutive heartbeats, serves as a marker of autonomic nervous system activity, particularly the balance between the sympathetic and parasympathetic branches (TaskForce, 1996; Buchheit, 2014). HRV is widely used to assess an athlete's recovery status, training load, and resilience to stress, making it valuable for understanding how consecutive matches affect autonomic regulation (Stanley et al., 2013; Le Meur et al., 2013). Additionally, the rate of perceived exertion (RPE), a subjective measure of how intensely an athlete feels they are working, complements objective HR data by capturing the athlete's personal experience of exertion, fatigue, and psychological strain across matches (Borg, 1998; Foster et al., 2001). The Stress Index and Sympathetic Nervous System Index (SNSIndex) provide further insight into stress levels and sympathetic activation, highlighting the athlete's autonomic response to match intensity and recovery efficacy (Ayuso-Moreno et al., 2020; Schneider et al., 2018). Together, these physiological variables enable a multifaceted assessment of an athlete's condition, allowing for better understanding of the activity profile and physiological responses in competition that is essential for planning effective training programs and has been the basis for preparing competitive players (Mendez-Villanueva et al., 2010).

However, most research has been conducted in training situations and simulations, which are difficult to replicate the real game conditions (Kilit et al., 2016; Mendez-Villanueva et al., 2010) both at the level of movement characteristics (Hornery et al., 2007) and at the psychophysiological level (Fernandez-Fernandez et al., 2015). Another limitation is the level of subjects involved, as most studies in tennis research, including those by Fernandez-Fernandez et al. (2008), Mendez-Villanueva et al. (2007, 2010), and Kilit et al. (2016), have focused on regional or national-level athletes rather than elite or professional players. This limitation restricts the generalizability of findings to the highest levels of competition, where physiological and psychophysiological demands may differ significantly.

OBJECTIVES

This study aimed to investigate an elite tennis athlete during the National Tennis Championship:

1. Describing the activity patterns, perceived exertion, and cardiovascular parameters of HR and HRV in four matches.
2. Investigating the effects of service and return game situations on HR and match characteristics.
3. Investigating possible associations between HR and HRV and activity patterns during the matches.
4. Describing the behavior of HR and HRV at rest and before each match.
5. Describing the behavior of HR and HRV during rest situations, such as court changeovers, and investigating the potential influence of scoring situations on SNS activity.

METHODOLOGY

Participant

Professional male athlete, 27 years, 22 years practicing Tennis, weighing 68.5 Kg, measuring 178 cm, Basal Metabolism (Kcal) 1996, Fat Mass (%) 4,2, Fat-Free Mass (Kg) 65,5, BMI 21,62, ATP rank 300 (59 best).

HRV and HR Monitoring

HRV and HR were monitored after the participant woke up, before any significant physical activity, in the supine position, for 10 minutes following the recommendations of the European Society of Cardiology and The North American Society of Pacing and Electrophysiology (TaskForce, 1996). Five minutes were taken for analysis, starting at minute 4 and ending at minute 9.

Match Conditions

The tennis matches were held during the National Championship at the Estoril Tennis Club, on a clay court surface, outdoors, with air temperature during the encounters at 25 ± 2ºC. The matches were played at 11:45, 11:15, 14:10, and 14:50 under the rules of the Portuguese Tennis Federation, regulated by the International Tennis Federation (ITF).

Perceived Exertion

The perceived exertion in each match and training session was obtained using Borg's CR-10 scale (Borg, 1998), adapted by Foster et al. (2001). The RPE of each match was collected 30 minutes after its end to ensure it corresponded to the total match/training session and not just the final part (Foster et al., 2001; Singh et al., 2007).

Match Analysis

The matches were fully video recorded using a fixed camera positioned in an elevated location. The duration of each encounter, each point, rest times, number of beats, and changes of direction were analyzed using a protocol developed by Smekal et al. (2001), deemed reliable (Fernandez-Fernandez, Sanz-Rivas, & Mendez-Villanueva, 2009; Mendez-Villanueva et al., 2007). Variables analyzed included:

- Duration of match(s)
- Point duration(s)
- Average duration of point(s)
- Recovery time (s)
- Recovery sitting(s)
- Effective playing time (%)
- Number of points (au)
- Number of total strokes (au)
- Stroke frequency (beat.min^{-1})
- Strokes per point (au)
- Total direction changes (au)
- Direction changes per point (au)
- Recovery between points (au)
- HR and HRV Recording

HR and HRV during matches were recorded using a Polar WearLink® W.I.N.D. sensor and Polar RS800CX™ data recording clock configured for R-R interval. Data synchronization with video recording allowed for detailed analysis. HRV and HR were recorded at rest upon awakening the previous day and on match days. HRV and HR data were analyzed using Polar ProTrainer 5™ software and Kubios HRV software (version 3.5).

Data Analysis

Data are presented as mean and standard deviation, maximum and minimum value. Before using parametric tests, the Kolmogorov-Smirnov test was applied to verify data normality. A Friedman test examined whether the medians of the variables were equal, and pairwise comparisons were made in a post hoc study. Effect size (ES) was measured using the Kendall (W) estimate. Pearson's product-moment correlation coefficient determined relationships between match characteristics and physiological responses. A probability value of $p<0.05$ was defined for statistical validity. All analyses were performed using SPSS 28 software.

Results and Discussion

The average duration of the points was 6.83s, which is in line with values previously reported for international players on clay courts, 6.7 to 7.5s (Mendez-Villanueva, et al., 2010; Hornery et al., 2007; Mendez-Villanueva et al., 2007). The same did not occur for the recovery periods between points, as we found an average duration of 27.3s, while the values reported by those mentioned in the preceding paragraph are between 16.2 and 17.2s. A possible explanation for this discrepancy could be the strict control of game times under ITF rules that studies that seek to simulate real games comply with. The same may not happen in a real situation where the chair referee responsible for enforcing the time available to recover between points may be more flexible. Hornery et al., (2007) for example, when they investigated 14 professional tennis athletes in official matches, they found that the average recovery time between points in matches on hard courts was 25.1s.

Regarding the number of strokes per point, we found average values of 5.3 while the values reported in the literature for clay encounters are lower: 2.7 (Mendez-Villanueva et al.,

2007), and 4.5 (Hornery et al., 2007). This higher average of 5.3 strokes per point may reflect the significant skill difference, with the athlete opting for longer rallies over risky shots, confident that consistency would secure points. Match context and strategic play choices specific to the observed tournament may also have contributed to longer points.

Table 1
Average values of the variables Total duration of Points (s), Number of strokes (au), Changes in direction (au), Total match recovery (s), Recovery standing (s), Total HR (b.min^{-1}) , HR seated recovery (b.min^{-1}), for each match.

	Average	SD	Min	Max
Total duration of Points (s)	6,83	0,53	0,33	32,6
Number of strokes (au)	5,30	0,62	1	23
Changes in direction (au)	0,88	0,32	0	5
Total match recovery (s)	31,25	4,0	26,2	36,7
Recovery standing (s)	27,30	4,0	23,4	32,8
Total HR (b.min^{-1})	149,1	15,5	72	190
HR seated recovery (b.min^{-1})	133,8	7,12	72	176

The average effective playing time (16.98%) that we recorded is lower than what has been observed in various studies, in which the percentages vary between 19.5% (Martin et al., 2011) and 29.3 % (Smekal et al., 2001). Once again, recovery time between points may be an explanatory factor.

Table 2
Duration of each match (s), stroke frequency (stroke.min^{-1}), effective playing time (%) and RPE (Cr-10).

	Match 1	Match 2	Match 3	Match 4	Avg (SD)
Duration of each match (s)	3 063	3936	2670	4868	3634,5 (846,8)
Stroke frequency (stroke.min^{-1})	42,13	42,88	44,10	44,33	43,36 (0,90)
Effective playing time (%)	17,76	17,07	17,5	16,6	16,98 (0,55)
RPE (Cr-10).	3	5	4	8	5 (2,16)

We sought to investigate whether there was any association between the duration of matches and actual playing time. We found that the increase in the duration of matches corresponded to a statistically significant decrease in the percentage of effective playing time. One of the possible explanations could be the increase in accumulated fatigue (the 4 matches were played on consecutive days and the athlete trained the day before and in the first three days of matches), which could influence the athlete to increase recovery between points. We found a positive correlation between the duration of points and the recovery time between points in matches 2, 3, and 4. Gescheit et al., (2015), investigated the effects of 4 consecutive days of prolonged tennis matches in 7 advanced level tennis players and found a statistically significant reduction in effective playing time on days 3 and 4.

Table 3
Correlations between the variables Match duration (s), Stroke frequency (stroke.min^{-1}), Effective playing time (%) and RPE (CR – 10).

	Match duration (s)	Stroke frequency (stroke. min^{-1})	Effective playing time (%)	RPE (CR – 10)
Match duration (s)	-			
Stroke frequency (stroke.min^{-1})	n.s.	-		
Effective playing time (%)	-0,930*	n.s.	-	
RPE (CR – 10)	0,916*	n.s.	-0,977*	-

*Note: * p < 0,05*

We also found a strong correlation between the RPE of each match and their duration (r=0.91; p<0.05), which is in line with the investigations by Mendez-Villanueva et al., (2007, 2010), who found significant correlations (r=0.80 and r=0.47; p<0.05), between RPE and the variables number of beats and duration of points in tennis players, and refer to RPE as a useful technique for regulating the intensity of tennis training.

In addition to the technical, tactical, and physical aspects, the characteristics and physiological returns to the game can be influenced by the service game or return game situation (Kilit et al., 2016). In this sense, we sought to investigate the effects of the service game or return game situation on the characteristics of the encounters. Concerning the duration of service and return points, we found that except in match 4, in all others the duration of return points was longer than that of service, and only in match 3, this difference was statistically significant but with a Moderate ES.

For the variable number of beats, we also found that, except in match 4, in all others, the number of strokes in the return points was higher than in the service, and only in match 3, this difference was statistically significant but with a moderate ES.

For changes in direction, there was a predominance of return games with statistically significant values in games 1 and 3. Finally, in terms of recovery between points, differences were only found during game 2.

The analysis of the HR during the service and return games revealed statistically significant differences in all matches which, except for match 3, showed that the HR in the service games was higher than the HR in the return games. These data are in line with the studies by Kilit et al., (2016b) and Smekal et al., (2001), which showed average values for HR in service games of 146 and 152 b.min^{-1} and for games return rates 138 and 150 b.min^{-1} respectively.

In terms of average values for the four matches, in our study we found slightly higher values for service games – 156 b.min^{-1} and for return games – 154 b.min^{-1}. It should be noted, however, that the studies mentioned were carried out through the simulation of Tennis matches, unlike the present study. In match 3, the possible reason for the reversal of this trend could be linked to two factors: the duration of the return points, which was longer than the duration of the 8s and 4.8s service points, and the number of beats in the return games 5 .9 and in service games 3.6.

From a physiological point of view, the average HR of competitive tennis matches varies between 60 and 80% of HRmax and occasionally, during the most intense and long points, values of 95% of HRmax can be reached (Baiget et al., 2015a; Fernández et al., 2007; Gomes et al., 2011; Hornery et al., 2007; Kovacs, 2006; Mendez-Villanueva et al., 2007).

Considering 3 intensity zones: low - < 70% HRmax, moderate – 70-85% HRmax, and high - > 85% HRmax (Baiget et al., 2015; R. V. Gomes et al., 2011), and considering the athlete's HRmax In this study, according to (Tanaka et al., 2001), we found that in the matches analyzed, the HR percentages above 85% were respectively 8.0; 39.7; 40.4 and 68.2% in matches 1, 2, 3 and 4. If we consider that, as the literature states, HR values can reach 95% of HRmax during Tennis matches, for the athlete in our study this would represent a hypothetical HRmax of 200 b.min^{-1}. If we calculate the time spent above 85% HRmax for this value, we obtain 0; 8; 9.2, and 42.7% in matches 1, 2, 3, and 4 respectively.

Table 4
Intensity zones - % HRmax according to Tanaka et al., (2001).

	Match 1	Match 2	Match 3	Match 4
HR <70%	36.7	6,9	10,3	1,7
HR 70-85%	55,3	53,4	49,3	30,2
HR >85%	8,0	39,7	40,4	68,2

In either situation, the values achieved, especially in match 4, are much higher than those found in the only two studies with elite athletes. Gomes et al., (2011), investigated two professional elite athletes during a simulated match on a hard surface and found values of 8% for one player and 3% for the other player in the time interval spent in the zone > 85% of HRmax. Baiget et al., (2015a) investigated 20 high-level athletes during one set of a simulated match on a fast court and found a percentage of 3% of time spent in the zone > 85% of HRmax. It is necessary to highlight that the average HR in these two studies was 132 b.min^{-1} for Gomes et al., (2011) and 138 b.min^{-1} for Baiget et al., (2015a), while in our study we found an average HR of the 4 matches of 149 b.min^{-1}.

These differences in values can eventually be explained by the fact that the authors investigated simulated encounters versus the real situation in the present study. On the other hand, the simulated matches were played on a hard surface (greenset), which could influence the intensity of the effort. Martin et al., (2011b) investigated 6 elite players in simulated matches of 16 games on 2 different surfaces: fast indoor and clay. They found differences between clay matches mean HR of 154 ± 12 b.min^{-1} and 141 ± 9 b.min^{-1}. We only found in the literature one study that attempts to approximate the conditions of the investigation, (invitational tournament with monetary prizes), with the real conditions of the game in official competition, and in which the surface is clay, however, the professional athletes investigated were feminine. Values of 13% were found for the time interval spent in the zone > 90% of HRmax (Fernandez-Fernandez et al., 2008).

Table 5
Training load (au), Subjective perceived exertion (RPE CR-10 – au), Training sessions (min) Resting Heart Rate (HRrep-b.min^{-1}); Time interval between consecutive beats (R-R-ms); Square root of the mean of the sum of squares of the differences between adjacent R-R intervals (rMSSD-ms); Natural logarithm of the square root of the average of the sum of squares of the differences between adjacent R-R intervals (Ln rMSSD-au); Parasympathetic Nervous System Index (PNSIndex); Sympathetic Nervous System Index (SNSIndex).

	Day 0	Match 1	Match 2	Match 3	Match 4
TL (au)	470	510	570	405	648
RPE (CR-10-au)	5	5	6	5	8
Training sessions (min)	95	60	45	45	
TL (corrected to the day of collection)	-	470	510	570	405
RPE (corrected to the day of collection)	-	5	4,5	5,5	4,5
HR (b.min^{-1})	41	44	48	62	42
R-R (ms)	1463	1359	1250	970	1438
rMSSD (ms)	52,9	67,3	69,1	56,1	66,9
PNSIndex (au)	2,87	2,81	2,33	0,59	3,07
SNSIndex (au)	- 1,97	- 1,89	- 1,85	- 0,54	- 2,14
StressIndex (au)	7,80	7,20	5,6	7,5	6,1

The study of the behavior of HRrep and HRV collected in the morning upon awakening allowed us to find a positive relationship between TL and HRrest and a negative relationship between TL and the R-R intervals and PNSIndex. Thus, HRrest and the HRV variables that represent PNS activity appear to respond to variations in training load. These results are consistent with previous studies reporting the same type of variations (Buchheit, Chivot, et al., 2010; Le Meur et al., 2013; Plews et al., 2012; Plews, Laursen, Kilding, et al., 2013; Schneider et al., 2018; Stanley et al., 2015b).

Considering that there is strong evidence that HRV is influenced by stress and can be used objectively to diagnose health and psychological stress (Kim et al., 2018; Lapo et al., 2022), we sought to understand how each tennis match could influence HR and HRV in the moments before its start.

Table 6
Values of the variables in the time intervals, entry into the court until the start of the warm-up, and sitting period after the warm-up, in the 4 matches: Heart Rate (HR-b. min^{-1}), Mean time between consecutive beats (R-R-ms), Square root of the mean of the sum of squares of the differences between adjacent R-R intervals (rMSSD-ms), Parasympathetic Nervous System Index (PNSIndex), Nervous System Index Sympathetic (SNSIndex) and Stress Index (StressIndex).

		Match 1	Match 2	Match 3	Match 4
Court-Warm-up	HR (b.min^{-1})	91	96	92	104** (ES – 0,42)
	R-R (ms)	660	625	656	578
	rMSSD (ms)	26,0	24,2	25,4	13,2
	PNSIndex (au)	- 1,76	- 2,00	- 1,81	- 2,55
	SNSIndex (au)	2,27	2,54	1,98	4,17
	StressIndex (au)	12,7	12,1	10,5	18,8
Sitting	HR (b.min^{-1})	104	104	108	124** (ES – 0,73)
	R-R (ms)	575	578	557	484
	rMSSD (ms)	9,70	6,90	7,20	4,60
	PNSIndex (au)	- 2,65	- 2,76	- 2,78	- 3,43
	SNSIndex (au)	5,58	6,33	6,21	10,97
	StressIndex (au)	27,3	31,9	29,8	47,9

** *p<0.01*

From the descriptive analysis of the variations in the values of the variables, in the 4 defined time intervals, we verified that, for all the variables investigated, there is a clear difference between the first 3 matches and the 4th match. Thus, from the first 3 matches to the 4th match, there was a decrease in the values of the variables RMSSD, R-R, and PNSIndex, which represent the activity of the SNP, and an increase in the values of the variables FC, SNSIndex and StressIndex, which represent the activity of the SNS. Regarding HR, we found statistically significant differences for the period from entering the court until the start of the warm-up, and the sitting period after the warm-up, with a moderate and high ES, respectively.

The two other time intervals (start of recording until the beginning of the first point and warm-up period) were not considered for statistical analysis, because in the first interval, there was no total recording of video images, and in the second interval, despite the existence of recording of video, a very similar duration between matches (355, 393, 364 and 359s) and a routine of activity similar and common to all official Tennis matches, we consider that the fact that the opponents have different levels could in some way influence the behavior of the variables. However, we continue to observe the same pattern.

The results we found seem to be in line with recent studies. Ayuso-Moreno et al., (2020), investigated HRV and cognitive anxiety in 14 female soccer players (age 23.8 ± 4.9), in two microcycles that corresponded to two different games: one of high demand and the other small requirement. They found significant differences between the two microcycles in which there was a reduction in HRV and an increase in cognitive anxiety in the highly demanding game microcycle. Recently, Fuentes-García et al., (2022), investigated HRV in junior tennis players at two moments: 24h and 20 min before a competition. They found significant reductions in the variables that represent SNP activity and a significant increase in HR.

On the other hand, athletes in individual sports are more likely to be influenced by competitive anxiety (Correia & Rosado, 2019), as the responsibility for the success of their performance depends solely on them (Koronas et al., 2020). In our study, not only does the level of the opponents increase with each match, but as it is a National Championship, it seems reasonable to expect some increase in competitive anxiety in the final.

The investigation of HRV during tennis matches poses some important problems in capturing the signal and interpreting its variables. During exercise, not only is the ANS the main determinant of HRV, but also its intensity (Buchheit, Chivot, et al., 2010b; Sandercock & Brodie, 2006). On the other hand, during exercise, heartbeat recordings contain noise (e.g., ectopic beats or lost recordings due to sensor movement) (Buchheit, 2014a). In this sense and given the intermittent characteristics and intensity peaks of the Tennis modality, we decided to investigate the values of the HR and HRV variables only during the moments of changing the court, when the athlete sits down.

As previously mentioned, the minimum period in which the athlete remained seated throughout the 8 periods was 45s. The software (Kubios, 3.3) used in this investigation allows analysis for minimum periods of 30s. Esco & Flatt, (2014), investigated HRV using the Ln rMSSD index in 23 university athletes before and after exercising in a maximum effort protocol (treadmill), defining collection periods of 10s, 30s and 60s. They found acceptable validity levels for the 60s period, and a gradual decrease in the validity of measurements from 60s to 10s, however this decrease was smaller up to 30s with an ES considered trivial. In a recent study, Araújo et al., (2020), revealed a high test-retest reproducibility for 30s measurements using the Ln SDNN and Ln rMSSD parameters after a maximum effort protocol in an ergometer cycle. Hung et al., (2020), also found very high levels of correlations between Ln SDNN and Ln rMSSD for measurements after 1min of recovery after an intermittent Yo-Yo test, highlighting that these correlations were manifested even at the beginning of recovery.

From the analysis of the sitting recovery periods in the 4 matches (table 13 and figure 13), we found that the statistically significant differences in HR seem to highlight the different characteristics of the 4 matches. This difference is even more evident from the 1st match to the others, namely for the 4th match (Kendall's W 0.73). We also found the same pattern for the other variables analyzed. When we look at matches 2, 3 and 4, we also find variations in the variables, which are, however, less evident, from match 3 to match 4. Some considerations may be relevant: The level of the opponent in the 1st match (experience and national ranking, 66) was lower than that of the opponents in matches 2 and 3 (national rankings, 4 and 1 respectively) and much lower than the opponent in match 4 (ranking ATP-560); The athlete in our study, in addition to the matches held, carried out training sessions on the days of the matches which could lead to some accumulated fatigue, it should be noted that the highest HRrep value it was exactly

the morning of the 3rd match and the highest TL value the day before; finally, as previously mentioned, and investigated by Gescheit et al., (2015), the effect of 4 consecutive days of matches can lead to an increase in accumulated fatigue.

The descriptive study of the 8 sitting recovery periods allowed us to observe the behavior of the various variables throughout the match 4. The average HR value showed a slight and gradual increase. We also observed a slight upward trend for HR for the entire encounter, but with a trivial effect (r= 0.2), which would be in line with Coutts, (2010) and Baiget et al., (2015b), which suggests the possibility of cardiovascular deviation occurring during a tennis match. Another factor contributing to this slight increase would be the loss of fluids and corresponding dehydration (Bergeron, 2014; Hornery et al., 2007).

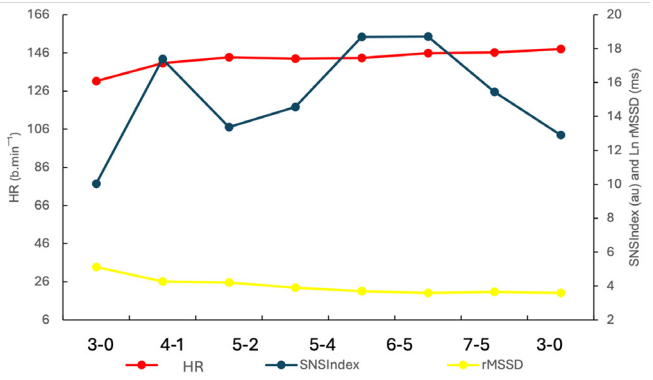

Figure 1. *Description of the variations in the 8 sitting periods of the 4th match, when we project the result of the match with the sitting period, of the variables: Heart Rate (b.min⁻¹), square root of the mean of the sum of the squares of the differences between adjacent R-R intervals (In rMSSD-ms) and Sympathetic Nervous System Index (SNSIndex-au).*

The HRV indices related to PNS activity showed a slight decrease until moment 4 and then remained relatively stable. The same can be said for SNSIndex, which represents SNS activity, but not for the SNSIndex. According to Stanley et al., (2013), after the end of exercise, HR and HRV demonstrate a recovery that is time-dependent and rapid in the first minutes (Kaikkonen et al., 2008; Kaikkonen et al., 2007) , but when exercise is of high intensity, there is a slower recovery of HR and HRV (Al Haddad et al., 2011; Buchheit et al., 2009; Kaikkonen et al., 2008). Therefore, according to Michael et al., (2017), recovery after high-intensity exercise in highly trained athletes results in a delay in the reestablishment of HRV values, which is dependent on the intensity of the exercise.

For the SNSIndex index, we did not find the same variation pattern. Interestingly, when we project the HR and SNSIndex values with the result of the match at the time of recovery while seated (figure 1), we see that this index seems to respond to the increasing difficulty of the match and, after winning the 1st set and with the progress of the 2nd This index dropped considerably and at the end was showing a value relatively close to that at the beginning of the match. It seems reasonable to speculate that when the athlete managed to overcome the greatest difficulties and eventually realized that the chances of winning the match were very strong, this began to be reflected in this index, while at a physiological level, the needs did not ease.

CONCLUSIONS

This case study documented physiological, psychological and match-characteristic returns during the Absolute National Tennis Championship of a professional tennis player. Data analysis allows us to present the following conclusions:

- Differences were found between the 4 matches in the variables of game characteristics and HR.
- Differences were found between service games and return games in game characteristics and FC except for game 3.
- There are associations between the variable's duration of points and recovery time between points, and between RPE and duration of encounters.
- In measurements at rest upon awakening, associations were found between TL and HRrep and R-R, and between TL and PNSIndex.
- Before the start of the matches, differences were found in HR between the final match and the 3 previous ones.
- In the sitting recovery periods, differences were found between matches.
- During match 4, the athlete remained in the high intensity zone a considerable percentage of the time.
- Throughout match 4, the score may have had some influence on the SNS's activity.

PRACTICAL IMPLICATIONS

This study offers several insights for enhancing training and recovery protocols in elite tennis. The findings highlight that managing recovery between matches is crucial, especially in tournaments with consecutive play. By monitoring HR and HRV, coaches can better assess the effects of accumulated fatigue on autonomic nervous system activity, guiding adjustments to training loads and rest periods. The influence of scoring situations on SNS activity also suggests incorporating psychological resilience and stress management techniques, such as pre-point breathing exercises, to help athletes maintain physiological control during high-stakes moments.

Additionally, training regimens could be tailored to address the specific demands of high-intensity points versus extended rallies, with a focus on endurance and recovery strategies that mirror match conditions. Integrating individualized recovery practices, such as active rest sessions, hydration protocols, and sleep optimization, could further improve an athlete's ability to sustain performance across multiple matches. By applying these insights, coaches can support athletes in achieving consistent, high-level performance under competitive conditions.

CONFLICT OF INTEREST AND FUNDING

The authors declare that they have no conflict of interest and that they did not receive any funding to conduct the research.

ETHICAL CONSIDERATIONS

This study was approved by the Ethics Review Committee of Faculty of Physical Education and Sport, Universidade Lusófona de Lisboa. The participants were provided with written information regarding the purpose and content of the study and signed a consent form to authorize the recording of video footage and to provide their perception of effort in each evaluated situation. Non-invasive physiological measurements will also be collected. Biographical data regarding their history in the sport will be gathered as well.

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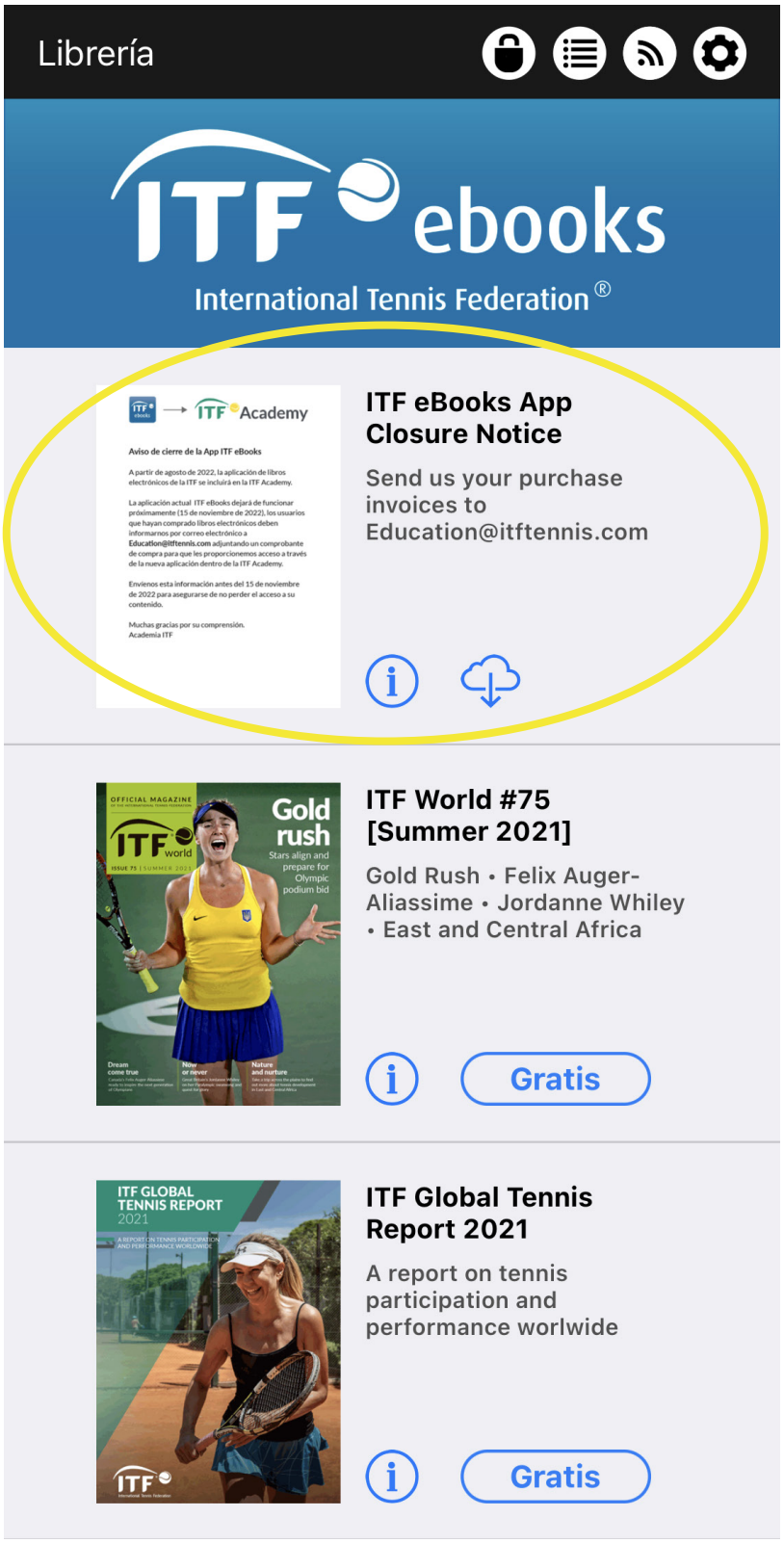
Recommended e-books

ITF EBOOKS

If you previously used the ITF eBook (mobile) App, please visit the app for further details on how to move content to the new eBook platform within the ITF Academy. The deadline to action this is 15 November 2023.



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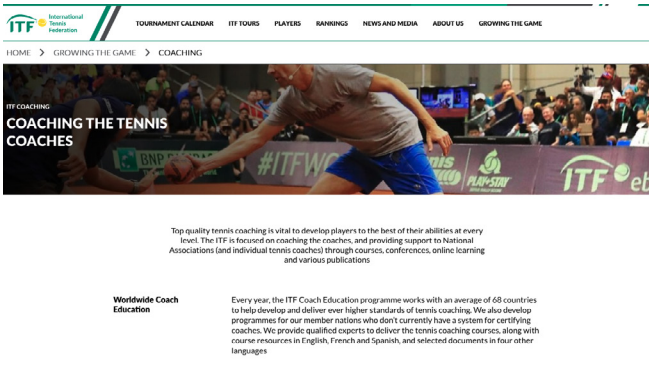

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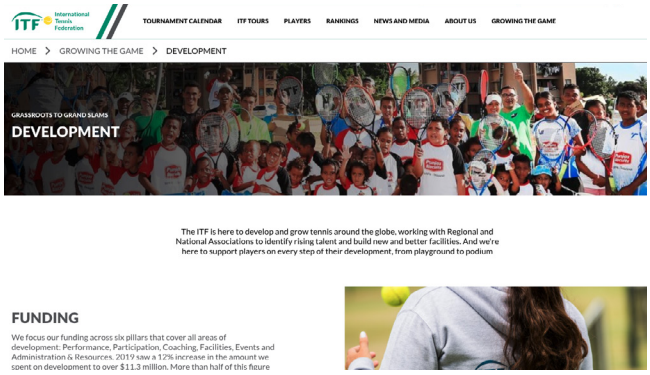

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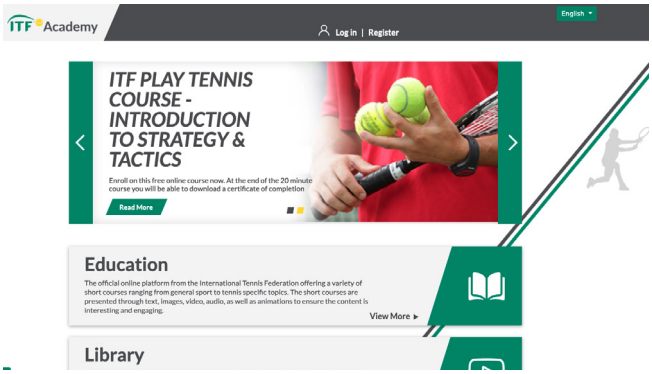

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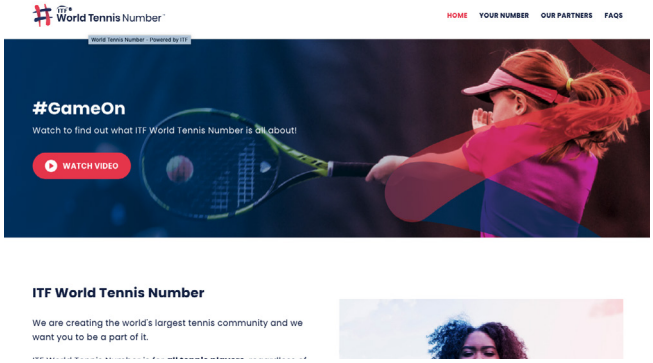

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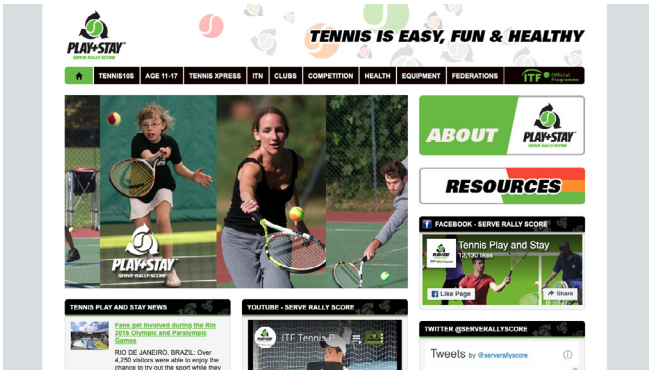

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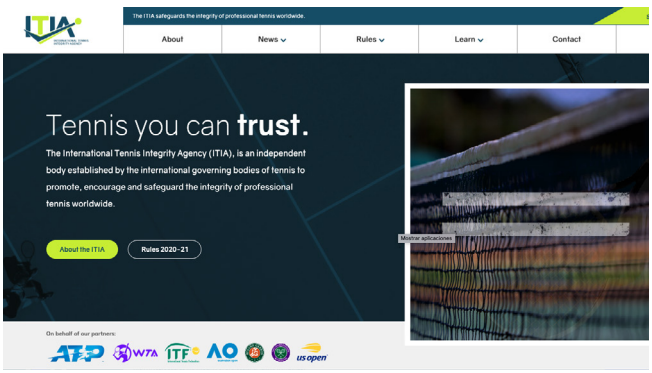

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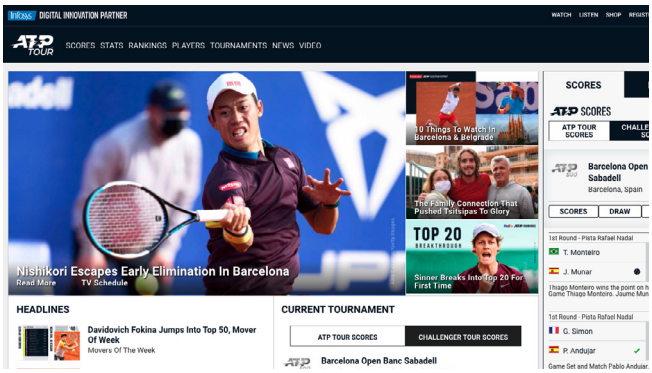

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