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Research article

From The Ground Up: Expert Perceptions of Lower Limb Activity Monitoring in Tennis

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Abstract

Understanding on-court movement in tennis allows for enhanced preparation strategies to improve player readiness and performance. Here, we explore expert physical preparation coaches' perceptions of elite training strategies for preparation and performance in tennis, with special reference to lower limb activity. Thirteen world renowned tennis strength and conditioning coaches were interviewed in a semi-structured method that explored four key topic areas of physical preparation for tennis: i) the physical demands; ii) load monitoring practice; iii) the direction of ground reaction forces application during match-play; and iv) the application of strength and conditioning for tennis. Three higher-order themes emerged from these discussions: i) off-court training for tennis should be specific to the demands of the sport, ii) the mechanical understanding of tennis lags our physiological approach, and iii) our understanding of the lower limb's contribution to tennis performance is limited. These findings provide valuable insights into the importance of improving our knowledge relevant to the mechanical demands of tennis movement, whilst highlighting important practical considerations from leading tennis conditioning experts.

Key words: Racket sports, movement analysis, on-court movement, physical preparation.

Introduction

The physical requirements of professional tennis are complex (Kovacs, 2006; Kumar, 2017), requiring a corollary of aerobic fitness, mobility, strength, speed, coordination, and repetitive high intensity multi-planar efforts (Kovacs, 2006; Ulbricht et al., 2015). Research in tennis has primarily focused on the description of match structure (work:rest ratios (Elliot, 1985), rally length/duration (O' Donoghue and Ingram, 2001), match duration (Mendez-Villanueva et al., 2007)) and metabolic characteristics (heart rate, blood lactate concentration) (Fernandez et al., 2006; Smekal et al., 2001). Although this empirical work has broadly captured the game's temporal and physiological demands, it still lacks specificity in documenting on-court movement kinematics and kinetics. Only recently researchers have explored tennis displacement more forensically (Giles et al., 2020; 2019; Giles and Reid, 2021), providing an evidence-based framework for its evaluation (Giles et al., 2019) as well as examining the coupling of hitting and on-court displacements (Giles and Reid, 2021). Direct practical applications are apparent from this work, where the need for greater levels of strength development is proposed when players execute shots with high movement velocity (Giles et al., 2020), or enhancing the specificity of training by identifying unique player movement profiles (Giles et al., 2019).

Despite players needing to move to almost every shot, the sport's understanding of on-court movement is basic. Hand notation of the movement patterns of eight male players competing at the French Open in 2003 first observed the direction of player movement, documenting it as primarily lateral (72%) followed by forward (17%), backward (8%) and diagonal (3%) (Weber et al., 2007). Regardless of the limited sample size and shortcomings of manual notation (Weber et al., 2007), a major limitation of this approach is the inference that the absolute direction of travel reflects the relative movement of the player. In other words, players may have been moving laterally across the court but running in a straight line, therefore applying force in the anterior/posterior plane. From a strength and conditioning point of view, this distinction is critical given recent findings outlining force/velocity specific profiles for movements in different planes of motion underpinned by training specificity (Baena-Raya et al., 2020; Hawley, 2008; Jimenez-Reyes et al., 2018).

This delineation of the direction of force application (in the vertical/horizontal/lateral planes) in sport has received growing attention (Baena-Raya et al., 2020; Bahamonde and Knudson, 2001; Carlos-Vivas et al., 2020; Jimenez-Reyes et al., 2018; Martin et al., 2020; Martin et al., 2021; Shimokawa et al., 2022), offering a more specific approach to training prescription and player profiling. Despite this, most biomechanical analysis in tennis has focused on characterising the vertical ground reaction forces (GRFs) of tennis movements, even though those movements are multi-directional. Furthermore, given the sport's acceleration and deceleration demands (Giles, 2019; Kovacs, 2009), horizontal force application (in both lateral and forward/backward directions) is critical, albeit under-explored. Currently, this link is purely speculative, likely leaving strength and conditioning coaches in a position where they rely on their intuition to inform training interventions targeting lower limb propulsion.

Understanding this intuition becomes an important first step in addressing the problem of lower limb activity monitoring, with qualitative research approaches providing us a vehicle to better understand the current state of play (Brackley et al., 2020; Giles et al., 2019; Phillips et al.,

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2014). Semi-structured surveys of coaches with very specific domain expertise can help identify areas of interest and need for further investigation (Brackley et al., 2020; Giles et al., 2019; Phillips et al., 2014). Such approaches have been adopted in sports like cricket to explore the perceptions of coaches on the acquisition of fast bowling technique (Phillips et al., 2014); furthermore, some of the world's best strength and conditioning coaches in tennis were previously asked to describe what "good movers" look like in the sport, enhancing our understanding of the experts view of the game (Giles et al., 2019). Given the mismatch between the prominence of preparing the lower limb for tennis play and the research quantifying specific demands, it stands to reason that valuable insight could be garnered in canvassing the views of experts. Consequently, this paper uses a qualitative, inductive approach to elucidate the opinion of expert tennis strength and conditioning coaches regarding the current state of lower limb activity monitoring in tennis. It was hypothesized that little consensus would exist between coaches' opinions, given the limited understanding of lower limb information in the current literature. The outcomes of this approach could be extremely valuable, helping inform researchers on the missing links between knowledge and practice, and to inform current coaches on the potential for training practice enhancement.

Methods

Participants

Thirteen tennis-specific, expert strength and conditioning coaches (12 males and 1 female), currently based in six countries (Australia, France, Spain, Switzerland, United States of America, and United Kingdom) were interviewed. The inclusion criteria were a minimum of 10 years as a strength and conditioning professional, in addition to previous experience working with a top 100 ranked male or female tennis player. Participants had 16.9 ± 7.2 years of experience working as a professional strength and conditioning coach in tennis. This includes experience working across both male (n = 13) and female (n=13), as well as elite junior tennis (n = 12). Participants had coached a total of 160 top 100 players, in addition to working with 11 grand slam winners. This range of experience captures a holistic, contemporary, and practical view of strength and conditioning experts involved in tennis. All participants provided informed consent and the study was approved by the host institution's human research ethics committee (2021/ET000276).

Data collection and analysis

Participants were contacted initially to gauge their willingness to be involved in this study. Once they had agreed to participate, an interview guide was provided to outline the key lines of questioning. Prior to the commencement of data collection, pilot interviews were completed with coaches outside of the inclusion criteria for this study, enabling the interview content to be refined. Semi-structured interviews were conducted over Microsoft Teams (Microsoft, USA) and averaged 55 ± 11 min in duration. At the beginning of each interview, participants were briefed on the interview intent, structure, and recording process. All interviews were recorded on Teams software, and using a handheld device (iPhone XS, Apple Inc, California, USA).

The interview included four general topics of investigation pertaining specifically to tennis: i) the physical demands; ii) load monitoring practice; iii) the direction of force application during match-play; and iv) the application of tennis-specific strength and conditioning practices. During the interviews, specific probing questions were used to elicit expansive responses or seek clarity where needed, while participants opined the force application requirements of four specific tennis actions: **1) Serve -** the action of performing a serve and landing; **2) Volley -** from the baseline, the player moves in a straight line toward the net and performs a volley; **3) Recovery Step -** the player recovers to the centre of the court following stroke execution; and **4) End Range Forehand -** from a centre of the court position, the player moves rapidly and performs a forehand outside of the singles line. Participants' responses to this line of quantitative questioning were collected in Microsoft Excel (Microsoft, USA) during the interview, which were then confirmed with participants for accuracy. This data was imported into R Studio (R v1.4.17, Boston, USA) where descriptive summary statistics were calculated (Figure 1).

Once complete, all interviews were transcribed verbatim using a transcription software (Otter.ai, California, USA). This transcription was then reviewed by the lead investigator to make minor grammatical adjustments (where required) to improve the flow of the text. Subsequently, participants received a copy of this transcript which afforded them the opportunity to make minor adjustments to ensure that their views were accurately reflected. This data was then imported into qualitative analysis software (NVivo 20, QSR International, Melbourne, Australia).

Prior to the commencement of the coding process, the lead investigator read the transcripts multiple times, which stimulated the formation of the general themes and concepts. Using a previously established inductive to deductive approach, higher order themes were conceptualized by coding responses from participants, with lower order themes coded to form the basis of these overarching concepts (Côté et al., 1993). Table 1 presents the higher- and lower-order themes, and some associated coach quotes for context. To optimise reliability and reduce research bias, co-authors participated in peer concept mapping of the coded themes (Miles and Huberman, 1994). Upon the formation of a new theme or concept, the data was coded again. This allowed for the thematic framework to remain dynamic. As per prior research (Braun and Clarke, 2006; Giles et al., 2019; Strauss and Corbin, 1998), themes were deemed significant if they were present in >3 participants answers. This process was continued, and the interviews were successively evaluated until no additional themes emerged.

Results

The Results and Discussion of this paper have been combined in the section below.

Discussion

Upon analysis of the interview transcripts, several key information clusters emerged, allowing the formation of three overarching higher-order themes. These included:

i) Off-court training for tennis should be specific to the demands of the sport
ii) The mechanical understanding of tennis lags the physiological
iii) Our understanding of the lower limb activity in tennis is limited

Quotes are provided throughout the discussion as context to support the identified concepts.

Off-court training for tennis should be specific to the demands of the sport

The training principle of specificity is well-established (Goodwin and Cleather, 2016). Certainly, this sentiment was echoed by the tennis experts. Many coaches stressed the importance of understanding the demands placed on the body during tennis, and subsequently, ensuring training was reflective of this. Importantly, coaches cautioned against the over-prescription of general or alternative training:

> *"If you are training with track and field runs, with running the mountains… at the end of the day when he (tennis player) gets on the court he will say this is not a mountain - this is a tennis court, I need to go forward, backward, side to side" [Participant (P)6].*

Further to this, physical training potentially neglects key components of specificity (such as mechanical representation), therefore limiting optimal adaptations to the particular sporting context:

> *"Many coaches focus on getting faster, but without adequate attention to the direction" [P7]*

This may be due to a reluctance among strength and conditioning coaches to stray from more traditional training practices, or it may represent sport-specific knowledge gaps among certain practitioners in the field.

Individual differences

As part of being specific, experts also noted the importance of individualisation or personalisation. Despite not being a novel concept (Augustsson et al., 2011; Jimenez-Reyes et al., 2016), the specific game styles (i.e. aggressive baseliner) (Crespo and Miley, 1998) and movement mechanics (Giles, 2019), over and above the physiology and morphology of individual players, introduce additional complexity in tennis (Giles, 2019). Therefore, consideration should be given to both factors when designing physical training programs:

> *"I have a look at a player's style, and how they play the game… (that) changes what capacities I need to further develop" [P8]*

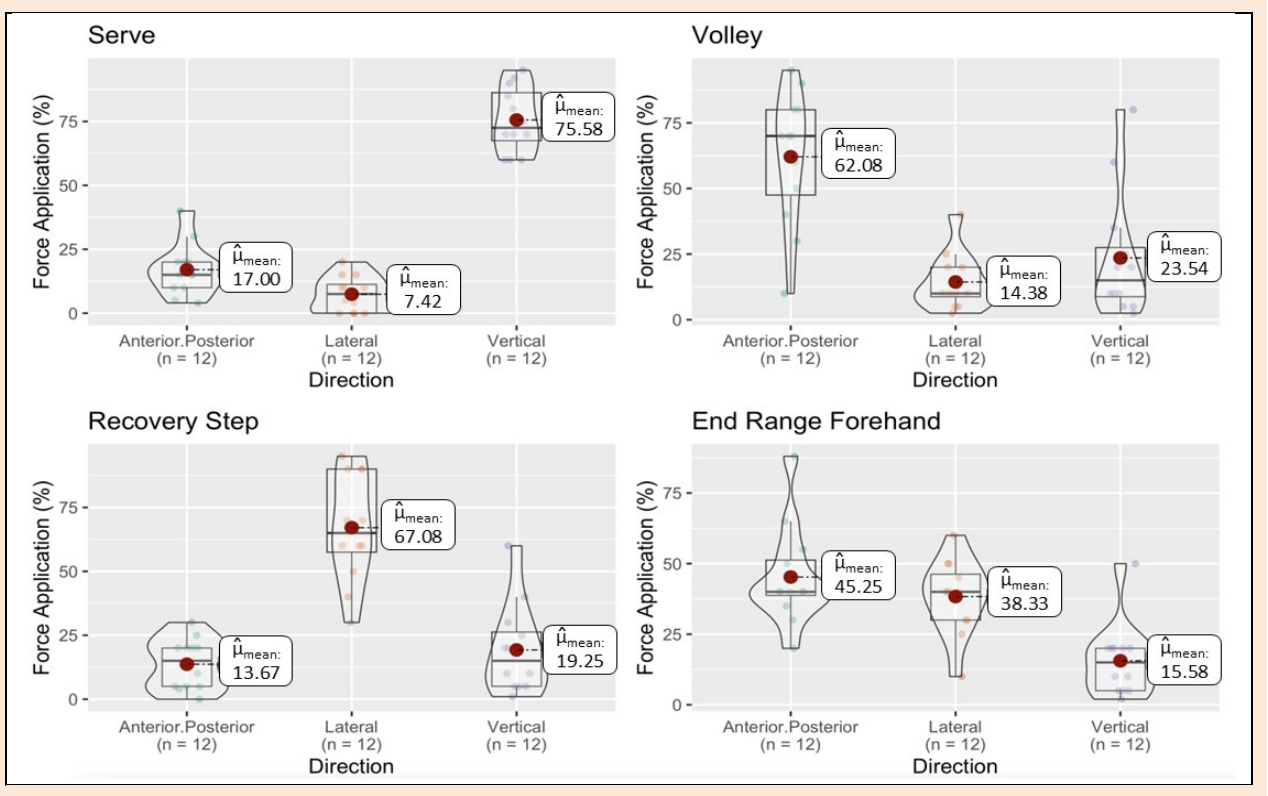

Figure 1. The opinion of expert strength and conditioning coaches regarding the direction of force application in tennis specific actions.

Table 1. Summary of higher and lower order themes

Theme Level	Theme	Quote
Higher-Order Theme	Off-court training for tennis should be specific	P9: "I think you've got to train to stimulate the adaptations required to handle the (match play) landscape" P7: "…it (training) should be closer to that representation than it currently is"
Lower-Order Theme	Individual differences need to be considered	P8: "So I have a look at a player's style, as well, and how they play the game. And (then) what capacities I need to further develop"
	Building a foundation of strength is important	P13: "(When) it's a young…junior player. I'm a strong believer of their overall athleticism and strength. So I want to go a pretty balanced program and not too much focus on those specific stress on the body yet"
	The intensity of current training is not always adequate	P12: "There's a lot of training that is not at the speeds or the loads that are representative of what the athlete needs…or even the body positions. There's a lot of general training that gets done" P10: "You can do some sprints with resistance bands…but an athlete with 10 years of strength experience…it's a little bit of a joke. The load on the muscles…it's not really killing the muscles the way they want to have an impact on it"
	Coaches are inclined to program too many gym movements in the vertical plane	P5: "From my experience, coaches have a tendency to focus on mainly exercises in the vertical plane because it's traditional… tennis involves a lot of lateral and anterior-posterior movement, so I think it's important to maximize this kind of movement in the gym" P8: "I think it's too much on the vertical plane and we don't address the horizontal plane"
Higher-Order Theme	Our understanding of the demands of tennis are limited from a mechanical standpoint	P8: "I think (there is) a lack of understanding of physical preparation coaches in tennis on the actual demands of tennis"
Lower-Order Theme	Coaches are much more comfortable describing the physiological demands vs the mechanical demands of tennis	
	The force application demands of the lower limb are not well understood	P2: "All of us in a way on this force and acceleration/deceleration, we're making lots and lots of educated guesses" P4: "Yeah, I really struggle with it to be honest (the force application demands). I really struggle to kind of answer and define it"
	Understanding the force application demands of the lower limb is of interest to coaches	P2: "The forces are very interesting… so I think this (the lower limb force application demands) immediately becomes a framework of training" P1: "if you were writing a power program or rate of force production program, the application of force in these directions should be trained and emphasised in a particular way, and I think it would be really fantastic relevant information… also in movement training… it would help you construct on court training sessions that apply to the sports more appropriately"
Higher-Order Theme	The activity of the lower limb is not well understood	P12: "Monitoring load is important. The challenge is, we don't have a really great strategy to monitor load in tennis currently… I think the field-based technologies that are out there are giving some misleading information at best" P1: "In my opinion, the number one issue which stops player's careers is an inappropriate amount of external load over the years, and not enough management of load over the years, over a player's career"
Lower-Order Theme	Global Positioning System units are used frequently by coaches, however there are limitations of this technology	P1: "Because the movements are so small and GPS technologies are just not quite up to speed with a sport that has so many small movements"
	The ability to delineate the upper and the lower limb load is of interest, but currently no technology exists that is able to capture this	P2: "I really see speed coming through the roof… So we're going to have to understand the leg loads… tennis is a 70% leg sport" P12: "I think that is where everyone is trying to get to now. And there's some lab-based technologies and camera based systems that are getting better at this, they still, I wouldn't say are practical enough or easy to use with athletes on a consistent basis"
	A lack of context exists surrounding the data that is currently captured at the moment	P1: "I think we are not able to have really good quality conversations with coaches around the data that we're getting, all we can do is infer things"
	The symmetry between load on the lower limbs is not well understood	P5: "It's an asymmetric sport…and I'm not sure about the differences in terms of load from these two legs, when he's playing, so that would be interesting too" P13: "Honestly on the tennis court, I can't tell (loading differences between legs)"

P denotes Participant

Although using training specificity to match the demands of the sport is considered as an overarching rule, training should also aim to reflect the individual needs and their playing style. To illustrate, a player adopting a serve-and-volley playing style [34] may be best suited to having their conditioning short and of high intensity, with an emphasis in the gym on explosive movements, as this reflects the characteristics of the points they prefer to play. In contrast, a 'counterpunch' playing style might focus on longer repeat-effort conditioning, as this style aims to play defensively and drag out points until the opponent makes a mistake. Furthermore, modern change of direction styles could influence strength and conditioning practice, where a 'gear changer' may require more strength and acceleration development, as opposed to a 'cutter', who may require more speed and velocity training (Giles et al., 2021).

The importance of a solid strength foundation

Experts spoke to the significance of building a strength foundation in the context of specificity. When considering the continuum of physical and chronological maturity, experts noted that, before adopting specific training that reflects the demands of competition, players should have "a solid (physical) structure" on which to build. This might mean that more general training is performed at an early stage of development:

> "*It depends on the developmental phase ... a very young and junior player, I am a very strong believer of their overall athleticism and strength and not too much focus on those specific stress on the body yet" [P13]*

This is of particular importance in an early initiation sport like tennis, where structured training often commences at 10 years old (Jayanthi et al., 2013). As such, careful management of this strength base is critical, as mismanagement may have lasting implications for later stages in their playing career:

> *"In my opinion, the number one issue which stops player's careers is an inappropriate amount of external load over the years, and not enough management of load over the years, over a player's career" [P1]*

Intensity of the training stimulus

To train specifically, the intensity and duration of training, mechanical representation (e.g., specific joint angles) and velocity are key (Goodwin and Cleather, 2016). According to experts, the intensity of physical training for tennis is not always truly representative of match-play. This can present as an incomplete understanding of force application technique in tennis:

> "*There is probably an under appreciation of the magnitude of the forces involved (in tennis match-play)… and the sort of physical requirements to be able to handle those forces and equally produce them" [P9]*

Consequently, players may enter tournaments unaware they have not completed appropriate types or volumes of work:

> "*The tissue tolerance to the work they will endure in a match is not at a level that allows them to perform day after day…we see so many retirements and injuries… I don't think the right work is done to prepare their body" [P7]*

This perceived lack of understanding regarding quantification of lower limb activity is likely due to a scarcity of applied mechanical movement research describing the kinematics and kinetics from a match-play setting (Giles and Reid, 2021). Subsequently, this leaves practitioners in the daily training environment to rely on anecdotal evidence and subjective opinion in the prescription of training dose in preparation for match-play.

Horizontally vs vertically oriented training

The use of vertically loaded exercises (such as the barbell back squat or traditional deadlift) are commonly prescribed across many sports (Zweifel, 2017). While these movements undoubtedly have a place in physical preparation programs, the transfer to certain sporting performance can be greater in horizontally loaded movements; such as the generation of racket velocity in a tennis groundstroke (Shimokawa et al., 2022). These horizontally loaded exercises involve external resistance being applied perpendicular to the body, such as a barbell hip thrust or resisted sprinting modalities. For the stimulus to be truly representative of sport demands, the specific interplay of the musculoskeletal system absorbing and producing force in a certain direction, magnitude and timing should be replicated. When exploring this concept in tennis, our expert coaches believed that there is an over-emphasis on the vertical aspect of training:

> *"It's (training in the gym) mainly vertical… and despite tennis involving a lot of lateral movement and anterior posterior… I think it is important to maximize the part which is dedicated to this kind of movement in the gym" [P5]*

Figure 1 reveals the disparate expert opinions of the direction of force application during selected tennis-specific actions. This is compelling given the sample involved expert tennis strength and conditioning coaches who presumably are among those in their field with the highest knowledge base. The only movement in which vertical force vector was rated as the largest contributor to the overall force application profile was during the tennis serve. Yet according to the experts, there is significantly more emphasis overall on vertical exercises in the gym. To our knowledge, no literature has explicitly investigated a link from horizontally loaded gym movements and how they transfer to the effectiveness of on court displacement or stroke production. However, given the emphasis placed on the direction of force application of gym-based exercises by expert coaches, consideration to how training programs are designed with this principle in mind would appear important (Baena-Raya et al., 2020; Jimenez-Reyes et al., 2018). Accordingly, future research investigating the application of different force orientations to tennis-specific movement may bridge the gap between coaches' knowledge and available literature, providing imperative knowledge to help refine strength training practice in tennis.

The mechanical understanding of tennis movement lags the physiological

When probed about the demands of match-play, coaches were immediately drawn to descriptions of work:rest ratios, rally length, maximal aerobic power, and basic movement characteristics. Of the 13 coaches interviewed, seven mentioned mechanical demands, such as the movement cycles of tennis (Giles et al., 2019) or the characteristics of the typical change of direction on court. Even fewer (n = 3) coaches elaborated on the sport's demand on the lower body, its force profile or joint ranges of motion. Multiple coaches (n = 10) did, however, emphasise the importance of better understanding the forces acting on the lower limbs during match-play:

> *"The Holy Grail…is this force data… this immediately becomes a framework of training" [P2]*

The direction of force application

When coaches were asked to describe the typical direction of force application during four different tennis actions, a wide range of responses were provided. In fact, many coaches were uncertain when providing a response, which was unexpected. The results of this force application survey are presented in Figure 1, with twelve of the thirteen participants completing this section of the interview.

When serving, coaches believed that the lower limbs of players produced force in the vertical direction the most (75.6%, IQR: 18.8) followed by anterior/posterior (17%, IQR: 10) and lateral (7.4%, IQR: 11.2). Ratings for the serve were the most consistent between the experts, perhaps owing to it being the most closed skill. A significant interquartile range for the direction of force application was reported for the remaining movements, in particular the recovery step and volley. In the volley, force application was thought to be primarily anterior/posterior (62.1%, IQR: 32.5), then vertical (23.5%, IQR: 18.8) and lastly, lateral (14.3%, IQR 11.2). This contrasted with the profile perceived to characterise both the recovery step (lateral: 67.1%, IQR: 32.5; vertical: 19.2%, IQR: 21.2; and anterior/posterior: 13.7%, IQR: 15.0) and the end range forehand (anterior/posterior: 45.2%, IQR: 12.5; lateral: 38.3%, IQR: 16.2; and vertical: 15.6%, IQR: 15). The large IQRs point to some ambiguity among the coaches and a likely gap in the current understanding of the mechanical demands of match-play. Importantly, including a movement action alongside the execution of the stroke appeared to confound the question, further highlighting the importance of investigating these two actions concurrently.

Our understanding of the lower limb activity in tennis is limited

The concept of measuring the "load" placed on a player during training or match-play, with the aim of quantifying workload, optimising performance, and reducing the likelihood of injury, is commonplace (Colby et al., 2018). When asked about load monitoring practices in tennis, and specifically, how data regarding the lower limb was actioned, the experts commonly remarked that there was no best practice consensus:

> *"Monitoring load is important. The challenge is, we don't have a really great strategy to monitor load in tennis currently" [P12]*

Many experts lamented not having sufficient context around much of the data they were collecting, which constrains how this information is used to alter training design, manage players, and to communicate with coaches:

> *"I still think we're not able to have really good quality conversations with coaches around the data that we're getting, all we can really do is infer things…" [P1]*

The use of technology in tennis (for example, global positioning systems [GPS]) for this objective is relatively new compared to other sports. Indeed, various systems are now available to capture movement-based metrics (video coding, accelerometer data, etc.), yet a clear direction on a gold standard for quantifying the workload in tennis, as well its relationship with internal load metrics, is currently limited.

The limitations of Global Positioning Systems

In tennis, GPS is still an emerging technology, particularly at the highest level. Despite this, a vast majority of experts cited inherent limitations with these devices, even though 10 of the 13 coaches were routinely utilising them. For example, while GPS may be useful in understanding velocity-based metrics, it lacks the sensitivity to accurately measure the change of direction demands of match-play:

> *"Understanding the systematic stress was good… but then in tennis, because of the movement demands and the short distances, it was problematic" [P9]*

Additionally, the position in which GPS units are placed (scapular) reduces the potential to understand, or differentiate, the load on the upper *versus* lower limb:

> *"The GPS is in the back. So, in terms of lower body, it gives you nothing more than acceleration and deceleration and all those values that sometimes are not even useful for a tennis player" [P6]*

Understanding the activity of the lower limb

Coaches consistently emphasised the central role of lower limb drive, yearning to better understand its load profile in match-play:

> *"I think it's going to be crucial (understanding the demands on the lower body)… It's (tennis) a leg sport, the legs are the key to the sport" [P2]*

and to differentiate what is occurring in the upper body compared to the lower body:

> *"I think it is super important, it will be great to dissociate the load of the upper body and the lower body, because it's totally different demands" [P5]*

A consistent theme among the experts was that, despite their interest in understanding lower limb demands, existing technology solutions do not yet provide actionable data:

> *"That's where everyone's trying to get to now (understand the lower limb). And there's some lab-based technologies and camera-based systems that*

are getting better at this, they still, I wouldn't say are practical enough or easy" [P12]

Accordingly, aspects such as the bilateral leg asymmetry were not well understood by the experts:

"*It's (tennis) an asymmetric sport…and I am not sure about the difference in load in the two legs… we are not good in this area*" *[P5]*

Obtaining a firmer grasp of the difference between dominant and non-dominant legs has the potential to better inform physical preparation practice and injury prevention programs (Girard and Millet, 2009). Presently, there is limited appreciation of the inter-relationships between asymmetry scores and performance, injury or fatigue. Notably, some experts pointed to alternative technology, including inertial measurement units, camera-based systems, and/or wearable insoles, as showing promise in advancing the sport's understanding of these concepts. As existing research is sparse, validation of these systems represents an obvious starting place for empirical work.

Limitations and Future Directions

Some limitations require further consideration. First, it is well documented that court surface, sex, ball type, match duration, and style of play influence the proportion of aerobic to anaerobic demands on players (Fernandez-Fernandez et al. 2006); there is, however, comparatively less information documenting the influence of these factors on lower limb activity. The current study was not designed to fully explore these factors, and therefore, more work is required to elucidate their impact. Secondly, coaches from different countries may have developed their coaching philosophy nuanced to their unique experiences. Unfortunately, the current study does not have a sample with enough depth of coaches from any given country to explore this concept, and therefore, future work might explore any cultural or environmental factors that might contribute to a coach's perceptions of movement demand in tennis. Finally, as fatigue induced by prolonged tennis playing decrease force production capacity of lower limbs (i.e., knee extensors; Girard et al. 2008), which in turn may alter the efficacy of on-court movements, studying how fatigue impairs tolerance to ground impact warrants future investigation. Using wearable technology, a better understanding of how to best train the technical ability to apply force effectively in both horizontal and lateral directions (not only vertical ones) in field and gym settings should be an avenue for future research.

Conclusion

The interviews conducted with leading industry experts established three higher order themes, providing a snapshot into the current landscape of strength and conditioning for tennis. These included i) off-court training for tennis should be representative of the demands of the sport, ii) expert strength and conditioning coaches appear more comfortable with the physiological rather than mechanical demands of the game, and iii) our current understanding of the activity of the lower limb during match-play is incomplete. Several lower-order themes further elucidated various gaps in the industry's current understanding of the direction, magnitude and duration of forces applied by the lower extremities. Our findings provide researchers with direction to seed future research into the physical demands of tennis, whilst also offering practitioners with numerous considerations to inform the physical preparation programs of elite players.

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Key points

- Strength and conditioning programs for tennis should be specific to the nuanced demands of the game, with close attention paid to the direction of movement, magnitude of the forces involved, and mechanical characteristics of match-play.
- A player's developmental stage, as well as their individual game and movement style, need to be considered when designing physical training programs.
- The typical direction of force application in tennis is poorly understood; however, coaches believe this information can become an important framework for designing physical training programs.
- At the elite level, there is still reluctance to rely on GPS data to infer information about lower limb activity; therefore, new technology (i.e., camera-based systems, inertial measurement units, and/or wearable insoles) might be considered as promising tools to further our understanding of lower limb activity.

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