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Mechanical load differences between practice and match play in badminton

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Abstract

Badminton is a demanding high-intensity intermittent sport, which has a high injury rate compared to other racket sports. The racket leg and lower back are particularly susceptible to injury due to the high mechanical loads experienced from repetitive jumping actions. The purpose of this study was to evaluate the mechanical load differences on landing between predictable practice activities and competitive match play. Nineteen national and international standard badminton players participated in this study. Participants randomly undertook a match play and multifeed trial with Vicon Blue Trident IMU sensors collecting mechanical load data from the shank of the racket leg and the lower back. All trials were digitally recorded and movements to the four corners (forecourt forehand, forecourt backhand, rear court forehand and rear court around the head) were tagged using Dartfish version 10 video analysis software. Results showed the peak mechanical load in the shank of the racket leg and lower back for forecourt and rear court movements to be significantly higher in match play trials compared to multifeed. Match play trials also presented with a greater variation in peak mechanical load. Findings suggest the mechanical load experienced in competitive match play is not simulated by predictable practice activity. Due to the high prevalence of lower back and lower extremity injuries in badminton, findings support the need for badminton practice to contain unpredictable feeding activities to prepare the body for the high mechanical loads of match play. Unpredictable feeding strategies are suggested for coaches.

Keywords: *visual search behaviour, elite, coaching, representative learning design.*

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INTRODUCTION

Badminton played at an elite level requires significant hours of practice for demanding high-intensity intermittent competitive match play (Phomsoupha & Laffaye, 2015). Previous research states badminton injury rates per player per 1000 hours of exposure to be as high as 5.1 (Miyake et al., 2016). When compared to other racket sports, such as tennis (0.04-3 injuries per player per 1000 hours) (Pluim et al., 2006) and squash (4.78 injuries per player per 1000 hours) (Horobeanu et al., 2019), badminton can be considered as holding a relatively high injury rate. Mechanical load, which refers to the "forces experienced by specific tissues or biological structures" (Kalkhoven et al., 2021), in repetitive jumping sports such as badminton is high and accountable for much of the overload injuries suffered (Couppé et al., 2013).

Elite badminton players commonly report injuries to the lower limbs, lower back, and shoulder (Goh et al., 2013), which has both financial implications (Yung et al., 2007) as well as performance impacts through lost practice and competition participation (Wong et al., 2015). A systematic review of badminton injuries conducted by Fatahi et al. (2022) found that lower back injury was more prevalent than shoulder injury in the upper extremity with ankle (typically sprains) and knee injury being the most common in the lower extremities. The lower back, knee and ankle are subject to repetitive high force landings with significant shearing force in badminton (Hu et al., 2022), which explains the propensity for injury in those joints. A recent review of badminton injuries in elite athletes by Pardiwala et al. (2020) highlighted injuries occurred frequently in the competitive setting, which could be attributed to poor conditioning from the practice environment.

Phomsoupha and Laffaye (2020) suggest that core muscle instability can increase the risk of knee injury when forward lunging due to incorrect knee flexor muscle recruitment, with players performing greater knee flexion to combat injury. Smith et al. (2022) recently undertook the first known badminton study to evaluate the biomechanical differences between practice activities and competitive match play, finding significant differences in the forward lunge technique. For example, Smith and colleagues reported higher wrist and shoulder positions, lesser knee flexion, and decreased forward trunk lean when forward lunging during predictable practice routines compared to competitive match play, which could have a detrimental impact on injury prevention through unconditioned trunk musculature (Huang et al., 2014; Phomsoupha and Laffaye, 2020). Therefore, predictable practice activity led to biomechanical differences in forward lunge technique with the lunge being less deep compared to match play trials that could insufficiently prepare the body for the mechanical loads of match play.

To better understand the competitive demands of sport competition, and how practice can best represent those demands, practice design has attracted much recent research attention (Woods et al., 2020). Araújo et al. (2020) highlights the crucial role spatial-temporal cues play within skill acquisition and practice through the continuous interplay between possibilities and actions. Importantly, practice environments that provide activities that are representative of the perceptual information available in competition, offer athletes an enhanced ability to develop adaptive behaviours and movements to cope with the physical demands of the sport (Pinder et al., 2011). A failure to provide a representative practice environment could inadequately prepare key muscles and physiological systems through maladaptive skill acquisition and practice, which would increase the likelihood of injury.

Badminton practice approaches, that include predictable feeding routines, are commonplace globally as suggested by the Badminton World Federation (BWF) in their Coach Education Level 2 Award. Predictable badminton practice routines can be classified as holding low levels of visual search behaviour (VSB). For example, a predictable practice routine with low VSB would be shuttlecock feeding with the same action (e.g., underarm) from a static location on the court (see Smith et al., 2022) that decreases the attention and decision making required in match play (Natsuhara et al., 2020). Despite previous research finding high physiological loads decreased the efficiency of VSB and response accuracy in artificially created badminton scenarios (Alder et al., 2019), there was no identification of the physiological load differences with varying levels of VSB (i.e., differences between predictable practice and competitive match play). Also, previous badminton movement research is often limited to laboratory-based analysis (e.g., Kuntze et al., 2010; Lam et al., 2020; Nielsen et al., 2020), which is incapable of representing the real-world mechanical load experienced by players in competitive match play situations. Previous badminton research, therefore, has not been able to identify the physiological or mechanical load differences under differing VSB conditions. An understanding of the mechanical loads in different VSB badminton scenarios will better prepare coaches and players to create representative practice designs that prepare athletes for the competitive demands of badminton and decrease injury rate.

The purpose of this study was to evaluate the mechanical load differences on landing between predictable practice (low VSB) activities and competitive match play (full VSB) in key areas of the body that are susceptible to the highest injury rates in badminton. Specifically, mechanical load through the distal tibia of the racket leg and lumbar vertebrae 5 of the lower back. Mechanical load discrepancies between predictable practice and competition environments will provide a justification for practice activities to better represent the competitive environment (e.g., for practice environments to increase VSB). Practice environments predicated on predictable routines, therefore, may cause increased chances of both acute and overuse injury.

METHOD

Participants

Nineteen (16 male and 3 female) national and international standard badminton players participated in this study. Mean age was 20.6 ± 6 years, mean height was 1.74 ± 10.1 m, mean body mass was 70.3 ± 13.3 kg and mean competitive playing experience was 10.7 ± 6.8 years. Participants were representative of several ethnicities, which were White British (13), Chinese (4), British Other (2) and Pakistani British (1). Participants were recruited from clubs and training groups in the south of England, UK. All participants competed in singles events at a minimum of national tournament level.

Design & procedures

Ethical approval was gained from the University ethics board and all participants provided written informed consent. All participants randomly undertook a match play (highest VSB) and multifeed (low VSB) trial. The match play trial consisted of one game to 21 points against an evenly matched opponent based on previous head-to-head record, ranking, and competition level. To create competition similar to tournament play, the winner of the match play trial was award 30 GBP. Yonex AS30 Shuttlecocks were used across all trials.

The multifeed trial consisted of the same high level coach feeding participants 34 sets of 5 shuttlecocks from the central base position on the opposite side of the court. The coach randomly hit all shuttlecocks with a low forehand swing (see Smith et al., 2022, figure 3d) to the four corners of the court, which were forecourt forehand (FCFH), forecourt backhand (FCBH), rear court forehand (RCFH) and rear court around the head (RCATH). Participants were given 20 seconds rest between sets. Previous match analysis research (Abdullahi & Coetzee, 2017; Abian-Vicen et al., 2013; Chiminazzo et al., 2018; Gómez et al., 2021; Iizuka et al., 2020; Leong & Krasilshchikov, 2016; Torres-Luque et al., 2020; Torres-Luque et al., 2019) was averaged to provide the rally shots, rallies per set and rally rest time for the multifeed trial to accurately simulate a competitive match. Participants were given a minimum of 10 minutes recovery between trials.

Data were collected at 1600 Hz using Vicon Blue Trident IMU sensors (9.5 grams, ± 200 g), which have been reported to have very high reliability during functional sport movements (Burland et al., 2021). For each participant, one sensor was securely attached to the shank (distal medial aspect of the tibia) of the racket leg and one centrally to the lower back (lumbar vertebrae 5). An Olympus Tough TG-5 digital camera recorded all trials.

Analysis

Using digital recordings, movement (FCFH, FCBH, RCFH and RCATH) landings were tagged in each trial using Dartfish version 10 video analysis software with times exported in .csv format. Only movements that initiated from a central base position and ended in one of the four corners of the court were analysed. Data were then parsed and processed in Matlab version 9.13. Time series and tagging times were aligned using the landing impact from a vertical jump performed by each participant at the start of each trial.

From the raw data, resultant accelerations were calculated, and 1 g subtracted to remove the effect of gravity. Descriptive data (trial duration, number of movements per movement type, and number of samples above threshold acceleration values) were found for the whole trial. For each tagged event, a window in the data was created at 0.0167 s before the tagged time (to allow up to one frame in case the landing was late in the tagged frame) and until 0.5 s after the time of each event. Within that window, peak g and time to the peak following the last sample greater than 3 g were recorded. Where there was no peak greater than 3 g, no data were recorded for that sensor for that event.

Given that the majority of sensor data were low g (10 g or less), the data were considered non-parametric and therefore the choice of statistics were considered accordingly. Medians and inter-quartile ranges (IQR) were used to describe the average and spread of data whilst a Wilcoxon Signed Ranks test provided a statistical comparison between groups. In total, 24 tests were conducted and so a Bonferroni correction was applied to maintain statistical significance at $P < 0.05$. Where there were different numbers of samples between groups, a random number of samples equivalent to the samples in the shorter data set were taken.

RESULTS

Multi-feed trials were ~1.6 times longer than the match play trials and contained ~3 times as many tagged movements (Table 1). Despite this, the distribution of movements was similar for both conditions (Figure 1). Given that the multi-feed trials were both longer and contained more movements, whole trial data were considered in terms of the frequency of high g samples. Table 2 compares the frequency of samples above thresholds at intervals of 10 g up to 100 g. Clearly, the shank data observed a higher frequency of peaks than the back, and at higher g. Whilst the match-play trials were shorter than the multi-feed trials, both the median frequency of peaks at the shank over all participants, and maximum frequency of peaks by any participant, were higher at each threshold in the match-play condition. The IQR's were also larger in the match-play condition suggesting greater variation in peaks during match-play.

When considering the distribution of high g samples, Figure 2a shows a higher distribution of samples at every threshold over 30 g (for clarity, the lower threshold values at 10 and 20 g were removed from the figure: multi-feed samples > 10 g = 79%, multi-feed samples > 20g = 14%; match-play samples > 10 g = 76%, match-play samples > 20g = 15%). Whilst the peak accelerations were lower in the back sensor, a similar trend was observed with a higher frequency of peaks at all threshold levels (Table 2, figure 2b). The data for each location and movement type (Table 3) show the average impact was higher at the shank in all movements at both the fore and rear court. The IQR was also larger, again suggesting greater variation in impacts during match play. At the back sensor, the average impact was also higher in match play although the IQRs were more similar than for the shank. Whilst this might be expected due to the smaller values overall, it is still smaller when considered as fraction of the value such as for a variability statistic (i.e., IQR divided by median).

Table 1.
Average trial duration and movement locations .

		Trial Duration (s)	Movements Tagged	Forecourt Total	Rear Court Total	FCFH	FCBH	RCFH	RCATH
Match-Play	Mean	629.5	47.9	21.9	26.0	10.4	11.5	13.6	12.4
	SD	126.7	16.1	8.8	8.5	5.7	4.1	4.3	6.1
Multi-Feed	Mean	1008.6	151.2	80.6	70.6	45.7	34.9	36.3	34.3
	SD	213.4	32.2	18.0	15.6	12.2	10.1	8.6	8.6

Table 2
Comparison of peaks above 10 g thresholds

Threshold (g)	Shank						Back					
	Multi-Feed			Match-Play			Multi-Feed			Match-Play		
	Max	Median	IQR	Max	Median	IQR	Max	Median	IQR	Max	Median	IQR
100	1.2	0.1	0.2	6.0	0.6	1.7	0.0	0.0	0.0	0.0	0.0	0.0
90	1.2	0.1	0.3	2.5	0.7	1.2	0.0	0.0	0.0	0.0	0.0	0.0
80	2.7	0.3	0.5	3.5	1.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0
70	6.1	0.7	1.2	6.8	2.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0
60	8.0	1.4	2.7	12.1	4.6	4.2	0.0	0.0	0.0	0.1	0.0	0.0
50	12.8	4.4	6.6	18.4	8.4	8.7	0.0	0.0	0.0	0.1	0.0	0.0
40	26.6	12.8	11.4	36.0	15.3	14.1	0.0	0.0	0.0	0.0	0.0	0.0
30	80.1	30.4	20.5	84.8	39.2	34.0	0.2	0.0	0.0	1.0	0.0	0.0
20	188.3	101.8	77.7	255.0	134.7	132.7	1.6	0.0	0.5	3.6	0.1	0.8
10	1099.8	586.7	152.1	1072.8	631.7	329.4	59.4	17.2	25.5	72.4	29.1	33.6

Table 3
Comparison of impacts for each location on court and movement tagged.

Location/Movement	Shank							Back						
	Multi-Feed			Match Play				Multi Feed			Match Play			
	Maxi-mum	Me-dian	IQR	Maxi-mum	Me-dian	IQR	P. value	Maxi-mum	Medi-an	IQR	Maxi-mum	Me-dian	IQR	P. value
Forecourt (g)	221.9	28.7	23.8	185.3	56.8	39.6	0.00*	15.8	6.1	3.1	30.5	7.8	3.9	0.00*
Rear Court (g)	133.8	23.9	29.8	199.8	29.8	36.2	0.00*	26.4	6.9	4.6	27.3	7.8	4.4	0.03*
Forecourt Forehand (g)	202.1	28.6	25.1	182.1	60.3	42.4	0.00*	15.8	6.1	3.0	30.5	7.8	3.8	0.00*
Forecourt Backhand (g)	221.9	28.9	22.1	185.3	53.4	39.3	0.00*	15.3	6.0	3.4	20.0	7.7	4.2	0.00*
Rear Court Forehand (g)	133.8	33.2	31.3	199.8	37.3	36.4	1.33	26.4	6.9	4.3	27.3	7.4	4.4	0.94
Rear Court ATH (g)	123.5	15.7	21.1	113.5	24.7	28.0	0.02*	23.6	6.9	4.9	23.1	8.2	4.3	7.25

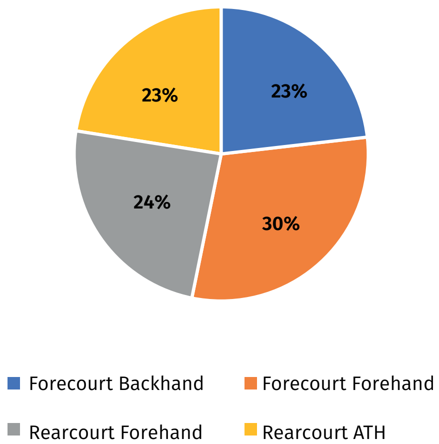

Figure 1a. Distribution of multi-feed movements.

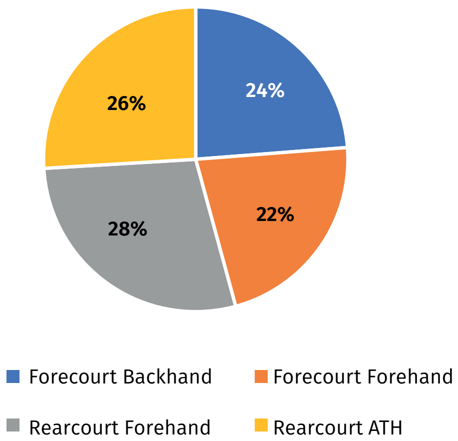

Figure 1b. Distribution of match-play movements.

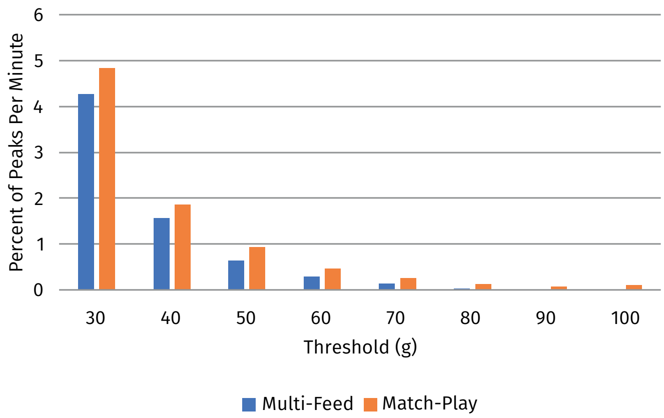

Figure 2a. Shank sensor peaks per minute (percent of movements).

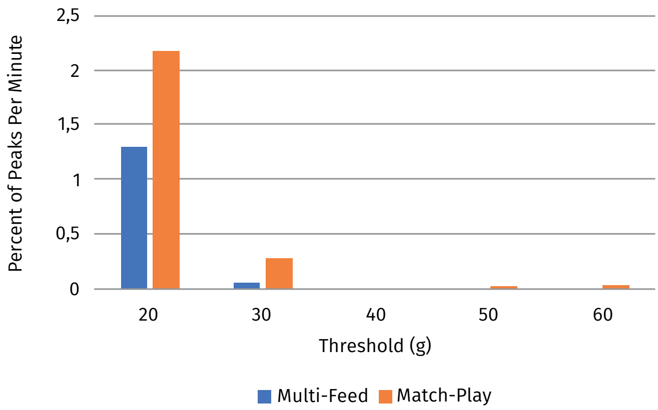

Figure 2b. Back sensor peaks per minute (percent of movements).

DISCUSSION

This study aimed to evaluate the mechanical load differences between predictable multifeed practice with low VSB and competitive match play with full VSB in badminton. Findings suggest that the mechanical load experienced in competitive match play is not simulated by practice activities that contain lower VSB, with match play trials producing significantly more mechanical load in the racket leg and lower back than multifeed trials. Due to the high prevalence of lower back and lower extremity injuries in badminton (Fatahi et al., 2022), findings support the need for increased VSB in badminton practice. In line with Smith et al. (2022), who reported biomechanical variations under different VSB scenarios, the mechanical load discrepancies found in the current study suggest badminton practice activities should contain high levels of VSB to prepare the body for the higher impacts experienced in match play.

The more visual stimuli to interpret, process and execute a response in badminton can produce reactive delays and movement inefficiency (Alder et al., 2014). When associated with previous research findings where full VSB was reported to produce a deeper lunge in badminton (Smith et al., 2022), current study results provide further evidence to suggest players initiate gross movements later with less anticipation and preparation, which increases the mechanical load on landing. The current study collected data from movements initiated at a central base position, and the greater requirement for the processing of spatial and temporal information (e.g., shuttlecock location and opponent body and arm position) in higher VSB scenarios seems to have a relationship with enhanced mechanical load. Importantly for injury prevention, the transfer of energy in the body and how it responds to physical loads is dependent on the nature and type of load, its rate, the frequency of load repetition and the magnitude of energy transfer (Bahr & Krosshaug, 2005). Therefore, practice activities that contain less energy transfer risk not preparing badminton players adequately for the mechanical loads experienced in competition.

When specific movements were isolated, mechanical load at the shank and back were significantly higher in match play trials in forehand and backhand forecourt lunges. The forecourt lunge in badminton has been reported to produce very high ground reaction forces (Hu et al., 2015), which is seen in the current study with noticeably higher mechanical loads at the shank. However, despite recording higher loads in all rear court movements, only the shank in RCATH was significantly higher. Therefore, low VSB practice activity with the forecourt lunge may be more detrimental to physical preparation than at the rear court, which is in line with previous badminton research that identifies high shearing forces experienced during single leg landing (Hu et al., 2022).

Currently there is no research that explores the longitudinal mechanical load differences between badminton practice and match play. Within other sports, load has been reported to be higher in practice than match play (e.g., Fox et al., 2018), however, mechanical load data is not commonly reported. Mechanical load during match play in the current study was found to be more varied and inconsistent with peaks occurring more often over time compared to multifeed trials. When equated to the amount of time spent in the practice environment compared to competition (Smith et al., 2020), the lower rate of impacts recorded during low VSB practice may have a significant influence on injury rate. Also, with a higher rate of peaks in match play, it could be assumed that mechanical load is experienced under differing fatigue levels (i.e., at the start and end of a rally).

Higher physiological loads have been found to decrease VSB efficiency in badminton (Alder et al., 2019), and when coupled with competitive match play that contains higher peaks and rates of mechanical load as indicated by the results in the current study, risk of injury is likely to increase due to enhanced overall load on the body. Therefore, physiological preparation activities should be centred around high VSB practice. Although limited in badminton, sport-specific training research (e.g., Hammami et al., 2018) and the study of perceptual information in representative learning designs (Pinder et al., 2011) have identified player physiological development to be more effective when athletes undertake activity with higher VSB, which is further supported by the results of the current study. Mental fatigue is also likely to have an impact on VSB (Miltner et al., 2004; Zeuwts et al., 2021) and increase mechanical load further. The current study increased threat and arousal in the match play scenario through monetary rewards, which will be difficult to replicate in standard practice activities and provides further evidence for the inappropriateness of low VSB practice activities.

Limitations and future research

The current study collected mechanical load at two prominent injury sites for badminton players, but further research is required to gather additional physiological load and fatigue measures in match play. Mechanical failure of biological tissues is poorly understood (Kalkhoven et al., 2021) and further research of load experienced by badminton players is required to design practice activities that are representative of competitive match play and decrease injury. Although reported as less prominent than the lower back as an injury site in the upper body, the shoulder is still an area for concern. The shoulder has complex mechanics that makes it a high-risk musculoskeletal system in overhead sports (Barnamehei et al., 2021) and future research could assess hitting action variations between different VSB situations to understand load differences. The current study was unable to detect the cause of the increased mechanical under high VSB conditions. The authors suggest that a processing lag contributes to a later initiation of movement, which could be studied by measurement of reaction time to external stimuli (e.g., opponent striking the shuttlecock) under different VSB conditions. Although this study simulated competitive match play to identify mechanical load peaks and rates, a more accurate measurement could be taken from tournament play with data collected over several sets and matches. Finally, average data for the population was reported, but it was visible within the data that loading between participants was likely to have varied. Therefore, future research should examine inter-individual differences to understand loading on an individual basis, along with the potential consequences for injury and training loads. Gender differences should also be assessed due to biomechanical differences (Hu et al., 2023), which was unachievable in the current study due to a low female sample.

CONCLUSION AND PRACTICAL IMPLICATIONS

The findings from this study suggest that badminton practice for high level players should contain activity high in VSB to prepare players for the high mechanical load of match play. Feeding drills should not be predictable. Unpredictability can be increased by the feeder having the freedom to hit the shuttlecock to other locations on the court as well as the target area for practice, which ensures the player can process the appropriate visual cues to initiate movement responses. The feeder should also hit the shuttlecock with an action that is representative of match play (i.e., whole body movement from base position to a returned shuttlecock and appropriate arm swing that replicates that seen in a competitive match). High VSB practice activity should continue throughout a practice session to mimic the high peak and rate of mechanical load found in match play. Coaches are advised that high VSB practice will increase mechanical load and adequate fatigue measurements should be undertaken to decrease injury within the practice environment.

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Tennis and scoliosis: an approach without prejudice

Tenis y escoliosis: un abordaje sin prejuicios

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Abstract

This contribution intends to offer a concise and exhaustive overview of the scientific production on the topic, as well as to provide researchers with theoretical reflections, scientific hypotheses and what can be deduced from the personal baggage of experience in the field, albeit limited. All permeated by the hope that future epidemiological investigations will be conducted, compared to the past, with greater methodological rigor and with a more coherent and incisive modus operandi. It is unfortunately undeniable that until today the medical sciences have not been able or able to deal with the topic except in a fragmentary manner and with sometimes questionable criteria. The consequences? Few valid studies and too many hasty judgments. Judgments that have not infrequently been affected by a certain habit of our time: a sterile prevalence of discussions and abstractions of a physiopathological type, without the necessary attention to “evidence-based medicine” (Lisi, 2018).

Keywords: *tennis, spine, scoliosis, evidence-based medicine.*

Resumen

Esta contribución pretende ofrecer un panorama conciso y exhaustivo de la producción científica sobre el tema, así como brindar a los investigadores reflexiones teóricas, hipótesis científicas y lo que se puede deducir del bagaje personal de experiencia en el campo, aunque limitado. Todo ello impregnado de la esperanza de que las futuras investigaciones epidemiológicas se realicen, en comparación con las pasadas, con mayor rigor metodológico y con un modus operandi más coherente e incisivo. Lamentablemente es innegable que hasta el día de hoy las ciencias médicas no han podido ni han podido tratar el tema sino de manera fragmentaria y con criterios a veces discutibles. ¿Las consecuencias? Pocos estudios válidos y demasiados juicios precipitados. Juicios que no pocas veces se han visto afectados por cierta costumbre de nuestro tiempo: un estéril predominio de discusiones y abstracciones de tipo fisiopatológico, sin la necesaria atención a la “medicina basada en la evidencia” (Lisi, 2018)..

Palabras clave: *tenis, columna vertebral, escoliosis, medicina basada en la evidencia.*

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UNCERTAINTY SINCE THE DAWN OF TIME

In the past, given the purely asymmetric nature of tennis activity, the future physical-motor and sports training of a young scoliotic patient was directed towards swimming disciplines, to which considerable therapeutic properties have been attributed. Scientific evidence does not support the assumption. Some research (Vercauteren et al., 1982; Geyer, 1986) have in fact demonstrated the groundlessness of this belief. In summary, swimming excludes any postural reconstruction due to the impossibility of leveraging on static and stable fixed points of reference and, mechanically, it does not allow to control the torsions of the spine, the inevitable anteversions of the pelvis and the equally inevitable traction vector forces of the back muscles (Lisi, 2018; Lisi & Giuffrida, 2019). On the other hand, however, since there are no rigorous scientific studies, a direct influence of racket sport cannot be excluded a priori, especially if this sporting activity is performed for many hours a day as in the case of young competitive tennis players (Lisi, 2018). Among other things, competitive activity, which today tends to start at an increasingly immature age and is continued for two-three hours a day in the years of growth, can lead to an asymmetrical strengthening of the muscle groups of the shoulder girdle and of the upper limb on one side (as usually occurs and is evident in young champions), while the other side has no other role than that of lifting the ball in the gesture of the serve (Figure 1). But all this, it can be countered, has never been sufficient to induce a developmental spine deformation. To about, it is necessary to use the term "evolutionary" correctly, since the worsening in the course of growth is an indispensable requirement to be able to speak of "true scoliosis". Otherwise, we can only speak of a spine deviation secondary to asymmetrical muscular development, clearly non-evolutionary and not dissimilar from what is observed in the (rather rare, but well-known) cases of agenesis of a pectoralis major or in the much more frequent cases of hypometry of the lower limbs (Lisi, 2018).

FEW STUDIES AND NOT VERY RELIABLE: WHY IS THE CROSS-SECTIONAL STUDY USED?

Reviewing the available scientific literature, we could not fail to notice the presence of few studies, and of those few almost all referable to "cross-sectional study". The methodology used allows us to detect only the prevalence and it is not possible to talk about risk, protective or irrelevant factors. In other words, the aforementioned parameters are demonstrated only with a prospective case-control or cohort study, i.e. a study that allows verifying the onset of the disease among those exposed.

It is worth remembering that several critical issues are observed in the choice of study design and its consequences:

- They collect information relating to exposure to risk factors and their outcomes (onset of the disease) at the same time and on the same patient. They can be thought of as a snapshot of a disease in a population at a particular time. However, given that the exposure and the disease state are measured at the same instant in time, it is not possible with this type of study to establish a cause-effect relationship between exposure to the risk factor and onset of the disease, but only a possible association, since the temporal component is missing. This is why they are often used only initially, and then carry out case-control or cohort studies;
- They offer immediate results and are economically irrelevant as they do not require the use of resources, time and personnel for long periods (unlike case-control or even more cohort studies);
- They are useful for exploring the distribution of a disease at time "0", the association between disease and random factor; they can be considered as a first phase of a study to be explored in depth with other types of designs (case-control or cohort).

Some of the most reliable studies are reported in the next section. Or, better said, those reported in indexed journals but unfortunately not free from methodological and content errors. We wanted to proceed through the so-called "Narrative review" which give a panoramic view of a given topic, generally addressing every aspect of it.

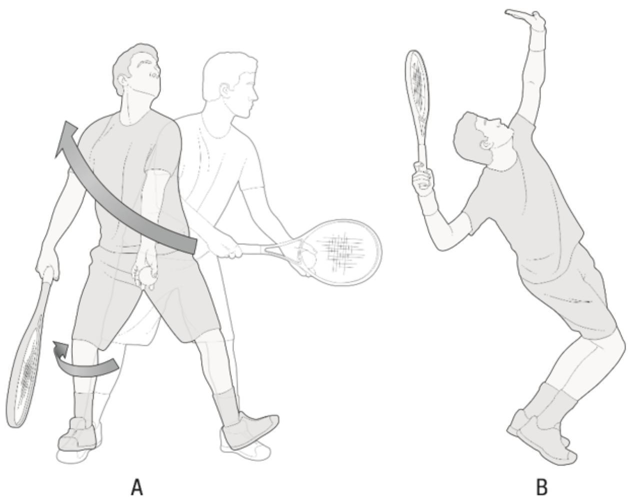

Figure 1. After assuming the position to serve, tennis player carries out the entire loading phase of the game start shot. This phase consists first of all in rotating the trunk around the longitudinal axis in the direction of the arm-racket (Figure 1A), and finally in flexing the legs simultaneously with throwing the ball with the non-dominant hand: the player will thus come to be in the so-called loading position or, also, "trophy position" (Figure 1B).

THE LITERATURE IS CLEAR: FEW STUDIES AND IRRELEVANT STUDY DESIGNS

Study by Zaina and colleagues (Italy)

Zaina and colleagues (2016) proposed a study to verify the prevalence of spinal asymmetries, deformities and low back pain in adolescents who play tennis at a competitive level, compared with healthy controls. Beyond some several critical issues (i.e. software used to carry out the analysis was not reported, nor whether or not the normality of the data was tested) it is not clear why a control group was taken, as it was not required by this type of study. Furthermore, in the text they are defined as "healthy controls", when instead it is expressly stated that for the choice of this group no restriction was placed either on the type of sport practiced or on a previous diagnosis of disease. In the "Discussions" section it is stated that, from the results achieved, the idea that tennis is traditionally considered as a sport that can damage the spinal column and increase the risk of spinal deformities is rejected, as a similar prevalence in the two groups compared. This type of conclusion cannot be reached with the study design used, but rather with a case-control or cohort. At the same time, it is rightly said later that, due to the type of design used, we cannot establish a cause-effect relationship, but simply a correlation, awaiting future studies. In the "Conclusions" the lack of association between Tennis and LBP is rightly reiterated. Given the correct conclusions, and the way of interpreting the results, the title of this work is misleading as it seems to establish a cause-effect relationship by asserting the non-dangerousness of tennis for pathologies related to the spine during growth. In our opinion, a title like "Tennis is not related to pathologies related to the spine during growth: results of a cross-sectional study" would have been more correct (even if less captivating and/or media-expressive).

Study by Gallotta and colleagues (Italy)

Gallotta and collaborators conducted a study (Gallotta et al., 2015) on a sample of tennis students from the sports group belonging to their university and divided into two groups: the first, made up of competitive level players; the second, by amateur level players. The experimental study of the work involved two evaluation sessions using rasterstereography on tennis players before and after two types of training of equal duration on the court: the first training based on baseline shots and the second composed mainly of overhead shots (serve, volley and smash). The results showed how the competence factor, i.e. belonging to the group of agonists or amateurs, influenced two of the numerous parameters measured: the lateral deviation of the spine and the angle of rotation. In this case, the competitive group showed - for these two parameters - higher values than the amateurs, indicating an adaptation of the spine in both lateral inclination and torsion, reasonably linked to the years of tennis practice. However, these values were close to the normal physiological range, suggesting, indirectly, that competitive practice per se is not a factor directly linked to spinal asymmetry. Finally, between the two different sessions, the one focused on overhead shots produced higher lateral deviation values (particularly on the left side), indicating that it produces greater stress on the spine than the one based on groundstrokes.

This study indicates that a single gaming session can still produce acute effects, identifiable as adjustments to the spine; but however, no measured parameter was significantly altered. Compared to the multi-year practice of tennis, the values of the agonists slightly higher than the physiological range seem to confirm that tennis is not in itself a predisposing factor to body asymmetries. In conclusion, the acute effects are not such as to lead us to consider tennis a contraindicated sport for those suffering from mild scoliosis or simple scoliotic aptitudes. The study made use of a non-invasive technique, which reconstructs the dorsal-lumbar spine starting from the superficial analysis of the morphological profile and which would allow a sufficiently accurate and repeatable evaluation, as we read in another work by the same authors (Guidetti et al., 2013), called "rasterstereography". Aside from the critical issues of the study design, the use of rasterstereography itself does not yet convince the scientific community: although the first meta-analysis on the reliability and validity of rasterstereography showed satisfactory results (Krott, Wild & Betsch, 2020), further studies are needed, focusing on the properties of both static and dynamic raster-stereographic measurements.

Study by Swärd and colleagues (Sweden)

In their study, Swärd points out that scoliosis was found in over 80% of subjects who practiced typically asymmetric activities, such as tennis (Swärd et al., 1990). The scholar specifies, however, that in these cases it is perhaps unjustified to speak of true scoliosis, as these are very mild forms, but at the same time recognizes that it would be simplistic to define them as simple functional scoliosis. In the case of tennis players, Swärd was able to establish, together with some colleagues, that there was a rotation of the vertebral bodies and, therefore, one of the fundamental characteristics of scoliosis. Furthermore, the rotation was accompanied by a curve that did not exceed, in any of the athletes examined, 15°: out of a total of 30 male professional tennis players, aged between 17 and 25 years, only 4 (13.3 %) presented a frank scoliotic picture, ascertained by radiographic examination. In order to be used correctly, the term scoliosis should exclusively refer to conditions of true scoliosis, the specific characteristic of which is that of being permanent and evolutionary. Strictly speaking, therefore, not even the alterations (13.3%) detected by Swärd are to be considered true scoliosis, since it is the Swedish scholar himself who states: «This type of scoliosis is not evolutionary. In my opinion, evolution depends on the load supported by the spinal column during growth. At the end of growth, or when the individual stops practicing tennis, evolution stops. If the pressure on the growth plate (or part of it) is high, growth slows down, while tensile forces accelerate it. During tennis practice, a torsional load is applied to the spine which causes minor scoliosis» (Swärd, 2002). In conclusion, "minor scoliosis", although not in itself evolutionary, could however become so if associated with a particular type of load and, therefore, sporting activity. Given that in the context of the sport of tennis the spine is reasonably stressed by asymmetric torsion and flexion movements, a consequent asymmetric development of the vertebrae in accordance with the Hueter-Wolkmann law is conceivable. This law constitutes the principle on which the construction of corsets for the bloodless treatment of structured scoliosis is based. Swärd's analysis is however very clear regarding the prognosis for the evolution of scoliosis during growth: one of the conditions for containing scoliotic evolution is the interruption of tennis practice. That said, Swärd's contribution, in some respects meritorious, is far from explaining the effects of physical exercise on the spine in young athletes. In fact, despite some subsequent considerations by the author, research focused on tennis has involved male individuals, almost all with complete bone maturity (Risser=5).

Study by Dalichau and Scheele (Germany)

The aim of the study was to verify the existence of a relationship between the mechanical-dynamic commitment in competitive tennis and the thoracic and lumbar profile of the spine (Dalichau & Scheele, 2002). The study, which lasted 5 years (1995-2000), involved athletes from 9 sports disciplines. Below we report the results relating to athletes who practiced tennis at a competitive level. Of the 1470 male subjects, 123 were competitive tennis players (23.8±4.5 years; 181.5±5.3 cm; 76.4±6.3 kg), with a training frequency of 7.5± 1.9 hours/week, while the remaining 1347, part of the control group, were subjects who practiced sports at an amateur level or who did not practice any sport (24.2±4.1 years; 179.6±9.5 cm; 79.2±8.6 kg). In the sagittal projection, no significant or trend differences emerged between the two groups, and not even the division of the group of tennis players into subgroups according to the criteria of "dominant arm", "serving technique" and "type of player". had an impact on the data relating to the dysmorphisms covered by the research (kyphosis, lordosis and inclination). Instead, the dominance of the arm with which the racket was held induced statistically significant differences on all the relevant parameters for the description of the shape of the spinal column on the frontal and transverse planes, in which the angles measured in the competitive athletes were greater than in the group control. Furthermore, the technique of executing the two-handed shots, both forehand and backhand, caused a further clear increase in the values detected (lateral inclination of the spine, inclination of the pelvis and shoulder/pelvis and shoulder/pelvis rotation). The investigation made use of a device, patented by the German company "Zebris", which is based on an ultrasonic targeting system. Regarding the validity of the system, the authors cite one study (Schreiber, Anders & Katterwe, 1998). Unfortunately, the same critical issues reported for rasterstereography remain. Among other things, some authors (Takács et al., 2013), who used the "winspine measurement software" developed specifically for the "Zebris CMS-HS measurement system", despite the excellent results (strong correlation with the values calculated from the rays using the Cobb technique), they clearly state that "[...] the accurate assessment of the degree of scoliosis can only be done with an Xray" (Takács et al., 2013). It should be remembered that studies based on objective and non-invasive detection procedures, due to the use of different equipment and the absence of quantitative results, cannot be compared and consulted for further research. Among other things, the number of the sample examined is very limited while the age of the players involved in the program did not concern the so-called period of rapid spinal growth, where scoliosis appears more frequently and where it tends to evolve more quickly. It would have been more useful to evaluate whether boys (especially girls, given the presence of menarche) between the ages of 10 and 14, with or without scoliosis, had developed —or worsened— this deformity.

CONCLUSION

As can be seen in this contribution, the articles present in the literature are few, and those few are not very reliable. The cohort study, certainly the most accurate, requires scrupulous planning, a very large population to be sampled and an availability of resources such as to make its implementation practically prohibitive.

The case-control approach, on the other hand, might be less difficult. It consists in recruiting a group of subjects with scoliosis, possibly (although not necessarily) accidents, to avoid changes in behavior and possible "bias" of information, and an adequate number of checks. Another approach, much more expensive and with a greater risk of bias from non-responders, is the population case-control study, where the controls are selected from the general population with a randomized procedure (simple, or with matching according to the characteristics of the cases): this selection can take place, for example, by drawing on the database of the health register. In the case in question, it would be necessary to pay close attention to any selection bias or confounding due, in particular, to the fact that the subjects who practice the sport of tennis generally belong to medium or high social strata, which could possess characteristics different from general population (take into account greater diagnostic attention, with overestimation of the occurrence of scoliosis, different risk factors - or rather protective ones - for the same pathology).

It should also be kept in mind that any research must in any case be subjected to rigorous biomechanical studies that also take into account the "kinetic chains", i.e. the movements and muscle activation "upstream and downstream". These studies, in turn, will make use of suitable instrumentation, such as surface EMG, optoelectronic systems for 3D movement analysis and complex biomechanical models: all, obviously, in relation to the morphotype, the racket and the degree of tension of the stringing. And, obviously, in line with the principles of the now well-known "evidence-based medicine", future scientific publications will require objective and repeatable evidence (Lisi, 2018).

Reflections and operational proposals

Although some specialists even believe that «[...] in the presence of right dorsal, right dorsal-lumbar or right dorsal and left lumbar scoliosis with rotation, the torsional deformity, in some cases, may even have a benefit due to the traction on the spine produced by the movements of the upper limb (which is almost always the right) mainly due to the serratus major and the abdominal obliques» (Pirola, 1994), we do not believe it is possible to reach a definitive conclusion on the relationship between tennis and scoliosis. For the times, methodologies and costs that the types of studies mentioned above require. It is difficult to imagine the possibility of a serious, long-term study using, among other things, x-graphy as an evaluation methodology. No parents would agree - rightly - to entrust their child to repeated x-ray examinations, also given the close relationship between the use of radiation and the onset of tumors (Doody et al., 2000).

And then, even if science might object, it is necessary to rely on common sense, as there is no data to support it. A serious professional, infused with notions of anatomy, biomechanics and muscular physiology and positively open to collaboration with other professional figures, will take responsibility for whether or not a scoliotic individual can practice tennis (each individual case is unique and requires a different approach and in relation to different factors).

However, let's try to answer some frequently asked questions asked by professionals. For example, doesn't mild scoliosis cause harm to competitive tennis players? Unfortunately, the answer will have to wait for more convincing studies. There are many, too many parameters to take into due consideration. These include: chronological age; position of the scoliotic curve (lumbar, thoracolumbar, thoracic, etc.); severity of the scoliotic curve; intensity of tennis activity and, unfortunately, also gender. In fact, several studies (Suh et al., 2011; Daruwalla et al., 1985; Lonstein, Bjorklund & Wanninger, 1982; Rogala, Drummond & Gurr, 1978; Asher, Green & Orrick, 1980) report about higher Cobb angles in girls than in boys, indicating that scoliosis in girls progresses to a higher grade of severity. For patients with a Cobb angle of more than 30° the prevalence ratio gets as high as 10:1 (Soucacos et al., 1997; Weinstein et al., 2008; Raggio, 2006; Luk et al., 2010).

Structured scoliosis certainly determines a series of obvious anatomical-functional limitations that would discourage the practice of competitive tennis. In essence, it involves subjecting afragile spine (factors that determine idiopathic scoliosis are numerous and partly unknown) to loads that are perfectly bearable by "normal" spinal columns. In other cases, fortunately much more numerous and frequent (i.e. cases in which the scoliosis has not reached a recognized severity and tennis is practiced only at an amateur level), the subject's condition can coexist with the presence of this deformity, without neglecting scientifically targeted and disciplined kinesitherapy (Lisi, 2018), based on compensatory exercises of the upper limb and the contralateral shoulder girdle but, above all, on core strengthening exercises, so as to build a sort of muscular corset that could conceivably protect spine from the insults of tennis practice.

CONFLICTS OF INTEREST

Authors declare the absence of conflicts of interest.

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Inter-and intra-individual differences in landing impacts during badminton match-play versus a feeding drill

Diferencias interindividuales e intraindividuales en los impactos al aterrizar durante un partido de bádminton frente a un ejercicio de alimentación

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Abstract

It is not understood the extent to which individuals experience impacts in badminton, and how this might relate to performance and injury risk. Little data are available on landing during match-play due to the limitations on collecting such data. This study aimed to capture acceleration data for badminton athletes in order to quantify individual differences. 19 athletes performed MF (multi-feed) drills and were paired to play matches. Each wore an accelerometer on their right lower tibia. Players were seen to have different patterns in the distribution of their impacts and hence "lighter" and "heavier" landers were identified. Typically, these were similar players across shot types, but not always ($r2 = 0.7326$ and $P < 0.001$). Those who won their matches encountered higher accelerations in all trial and shot types (though not all P. values were significant). Whilst both winners and losers encountered higher accelerations in match play ($P < 0.001$), the percentage increase was lower for winners (30%) than losers (42%). Results show that badminton players experience landings on an individual level. Better players experience higher g impacts more often, particularly in the training drill observed, which might indicate better efficiency of movement around the court or greater effort in training.

Keywords: *Racket sport, accelerometer, training versus match-play, winners versus losers.*

Resumen

No se conoce hasta qué punto los individuos experimentan impactos en bádminton y cómo esto podría relacionarse con el rendimiento y el riesgo de lesión. Hay poca información disponible sobre el aterrizaje durante un partido debido a las limitaciones que hay para recolectar los datos. El objetivo de este estudio fue capturar los datos de aceleración en atletas de bádminton con el fin de cuantificar las diferencias individuales. 19 atletas realizaron ejercicios de alimentación múltiple y fueron emparejados para jugar partidos. Cada uno usó un acelerómetro en la parte inferior de tibia derecha. Los jugadores tuvieron diversos patrones en la distribución de los impactos y, por tanto, se identificaron jugadores que aterrizaban más ligeramente y más fuertemente. Por lo general, los jugadores eran similares en todos los tipos de golpes, pero no siempre ($r2 = 0.7326$ y $P < 0.001$). Aquellos que ganaron los partidos tuvieron mayores aceleraciones en todos los tipos de ejercicios de práctica y golpes (aunque no todos los valores P. fueron significativos). Aunque tanto los ganadores como los perdedores tuvieron mayores aceleraciones en el partido ($P < 0.001$), el aumento en el porcentaje fue menor para los ganadores (30%) que para los perdedores (42%). Los resultados demuestran que los jugadores de bádminton experimentan aterrizajes a un nivel individual. Los mejores jugadores experimentan mayores impactos g más a menudo, particularmente en el ejercicio de práctica observado, lo cual puede indicar una mejor eficiencia en el movimiento alrededor de la cancha o mayor esfuerzo durante el entrenamiento.

Palabras clave: *Deporte de raqueta, acelerómetro, entrenamiento versus partido, ganadores versus perdedores.*

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INTRODUCTION

Badminton is played across some 194 countries by ~300 million people worldwide (BWF, 2019). It is a racket sport characterised by short bursts of fast play featuring jumps, lunges, overhead shots and multi-directional movement (Phomsoupha & Laffaye, 2015). As such, the ability to move with speed and agility offers players a competitive advantage (e.g. Cronin et al., 2003) however, with fast movements comes high loads and risk of injury. Injury rates for badminton are around 0.9 to 5.1 injuries per 1000 hours of playing time (Miyake et al., 2016). The consequence of such injury rates means the requirement of covering costs of medical treatment for immediate care and rehabilitation, as well as time spent recovering. Fahlström et al. (1998) considered that badminton accounts for around 1.2% of all sports injuries with an average 42 days sick leave for injuries that required emergency treatment in hospital.

Badminton injuries predominantly occur in the lower limb, which account for up to 83-92% of badminton injuries (Fahlström et al., 1998; Krøner et al., 1990) although overuse injuries are more common than acute ones (Ogiuchi et al. 1998 cited in Pardiwala, 2020). With this in mind, care should be taken when attempting to understand badminton injury epidemiology as incidence rates are often sourced from hospital admissions, which may not include a high proportion of certain injury types, and the focus might potentially become centred on more severe, acute injuries. With this in mind, ankle sprains, knee sprains, patella tendinopathy, anterior cruciate ligament injury and stress fractures are all cited as common lower limb injuries in badminton (Kaldau et al., 2021; Milon, 2017; Sandheera, 2019).

The mechanisms causing these injuries tend to be linked to jumping/ landing, lunging and changing direction which demand the production and absorption of high forces and accelerations (e.g., Milon, 2017; Robinson & O'Donoghue, 2008). Kimura et al. (2010) found that single-leg landings following backward step and overhead stroke was a significant cause of ACL injury on the knee opposite the racket side. The other main mechanism identified was from 'plant-and-cut during short steps' which injured the knee of the racket side. Guermont et al. (2021) specifically noted the lunge to be the footwork with the highest associated injury risk and accounted for 32% of lower limb injuries in elite players. Hong et al. (2013) noted that the direction of lunge influences peak impact force with the left-forward lunge generating significantly higher vertical force. Yu et al. (2021) further reinforced this linking left-side lunges to higher patellofemoral joint loads.

A question therefore exists as to when these badminton injuries occur. Phomsoupha and Laffaye (2020) recognised a higher rate of injuries in September which coincides with a greater proportion of scheduled tournaments. Indeed, injury rates in competition (11.6 injuries/ 1000 hrs playing) are higher than in training sessions (2.8 injuries/ 1000 hrs playing), and tend to occur more in the first third of play (Guermont et al., 2021). The reason for this may be linked to the loads that players experience when playing badminton matches being higher than those they experience during training (Smith et al., IN REVIEW). This therefore supports that the intensity of training, and its ability to prepare players for match situations, is crucial not only for skill related factors but also fitness and injury prevention.

High forces are a requirement for fast, explosive movements. This is a demonstration of Newton's second law of motion, explained by the formula, force is equal to mass multiplied by acceleration ($F = ma$). For example, Young et al. (1995) noted a series of strength-based predictors of sprint-start performance, the best of which was peak force relative to body weight. Interestingly, Cronin and Hansen (2005) observed correlations between selected leg strength measures and speed to be not significant. It is suggested therefore that producing high peak force rather than strength alone may be beneficial for the dynamic lunges, landings and changes of direction involved in badminton.

When the factors above are combined with individual differences related to BMI, anthropometry, strength and mobility, it is easy to see why not all players might experience the same accelerations and are not at the same risk of injury (Adae et al., 2017; Phomsoupha and Laffaye, 2020). Studies assessing impact kinetics have tended to use force plates which means it unlikely that data can be captured during match-play (e.g., Lam et al., 2018). It is therefore useful to understand how loads change on an individual basis between shot types, between match-play and training and according to player level (winners vs losers). The aim of this study was to assess inter-individual and intra-individual differences in accelerations recorded during match-play and training in order to provide insight to the extent to which different players expose themselves to contrasting loading conditions.

MATERIALS AND METHODS

The methods for this study have been previously presented in Smith et al., IN REVIEW). 19 high level badminton players (age 20.6 ± 6 years, stature 1.74 ± 0.11 m, mass 70.3 ± 13.3 kg, playing experience 10.7 ± 6.8 years) volunteered to perform a series of MF (multi-feed) drills (Smith et al., 2022), with the shot location and timing dictated by the coach. Athletes were then paired up at similar levels and played a match (MP, match-play condition) where a monetary prize (voucher) was given to the winner as incentive.

For each activity, athletes wore a Vicon Blue Trident IMU (inertial measurement unit) (Vicon Motion Systems Ltd, Oxford, UK) securely fastened to their lower shin on their lead leg. Tri-axial acceleration data were collected at 1600 Hz and all activities were also filmed using an Olympus Tough TG-5 camera (Olympus

Corporation, Tokyo, Japan) recording at 60 Hz. The video data allowed all shots of interest to be tagged using Dartfish (v10, Dartfish, Fribourg, Switzerland) (front court forehand, front court backhand, rear court forehand, rear court ATH (around the head)). Sensor and video data were synchronised based on the landing of a vertical jump performed at the beginning of each trial using Matlab (v9.13, MathWorks, Natick, MA, USA).

A window of 0.0167 s (the time for one frame of video) was created in the data around the time of each tagged event and the highest resultant acceleration was recorded. Acceleration data were resolved, converted to '*g*' and 1*g* was removed from each measurement to account for gravity.

Data were examined according to distribution of acceleration peaks observed by peaks above thresholds specified at every 10*g* up to 100*g*. Furthermore, the median peaks were used to help understand the distribution, and players were ranked accordingly where the player with the lowest rank had the 'lightest' landings (lowest median), and the player with the highest rank had the heaviest landings (highest median). Data were not normally distributed so Spearman Rank correlations were used to assess relationships whilst Wilcoxon Rank tests were used to assess differences between conditions.

RESULTS

The majority of impacts recorded occurred at lower acceleration thresholds. Some example distributions of the data can be seen in Figure 1 which shows forecourt shots. The Figure demonstrates large differences in the distribution of impacts between individuals. Taking the value of the median data point for each trial provides an indicator of the distribution of the data and hence the likelihood of the athlete being a 'heavier' or 'lighter' lander.

Typically, it appears that where players experienced higher *g* landings in MP, they also experienced high *g* landings in the MF trials. Figure 2 shows the average rank for players when ordered from 1-19 according to their average median impacts across all shots where a rank of 1 is the lowest median impact and 19 is the highest. Indeed, Spearman rank correlation provides an r-squared value of 0.7326 and $P < 0.001$. However, the large standard deviation bars suggest that these ranks are not consistent across all shot types.

Taking the four 'lightest' landers (those with the lowest mean rank across shots during MP), it can be further seen that none of them were in the lightest landers for all four shot types (Figure 3a). Also, when viewing the same four players during MF trials, their ranks were not always similar than during MP. For example, player 9 had ranks six and eight places higher for fore-court backhand and fore-court forehand respectively, but four places lower for rear-court forehand.

The four 'heaviest' landers (those with the highest mean rank across shots) show similar characteristic patterns to the lightest landers. Their ranks are still high whether in the MP or MF condition but there are large differences between shots for each player (Figures 3c and 3d).

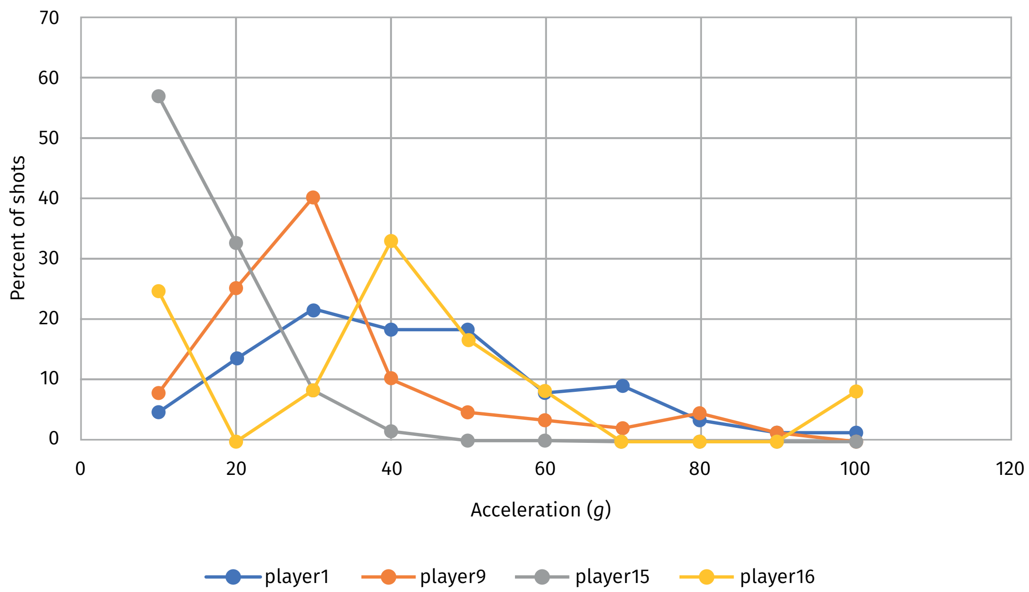

Figure 1. Example distributions of impact data during trials. This is from all fore-court shots during MF (multi-feed) trials for participants 1, 9, 15 and 16.

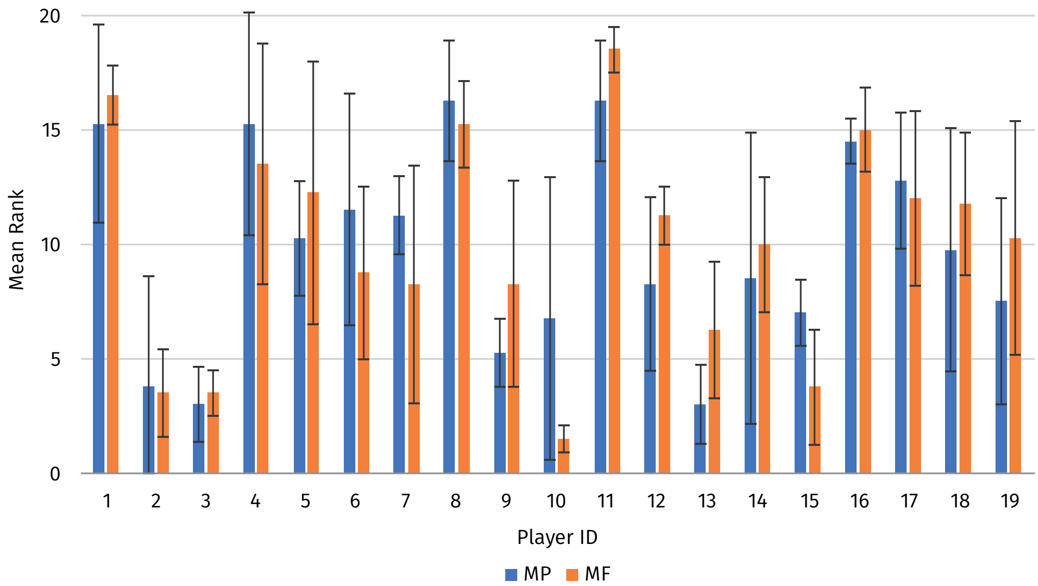

Figure 2. Player's mean rank according to median impact across all shots.

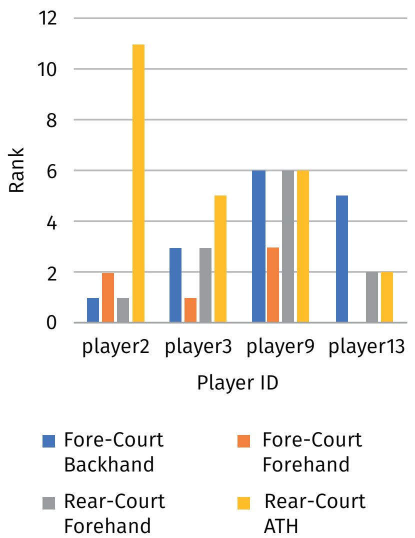

Figure 3a. The lightest landers in MP trials

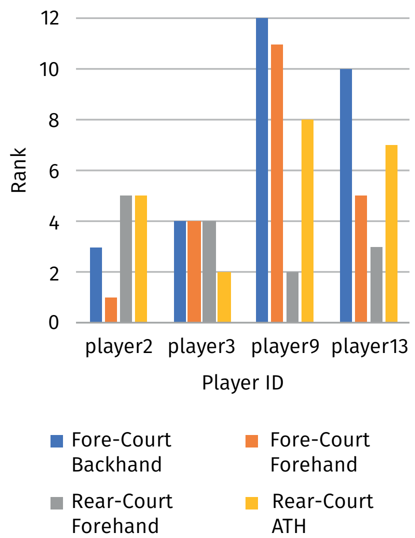

Figure 3b. The lightest landers from MP trials in the MF condition

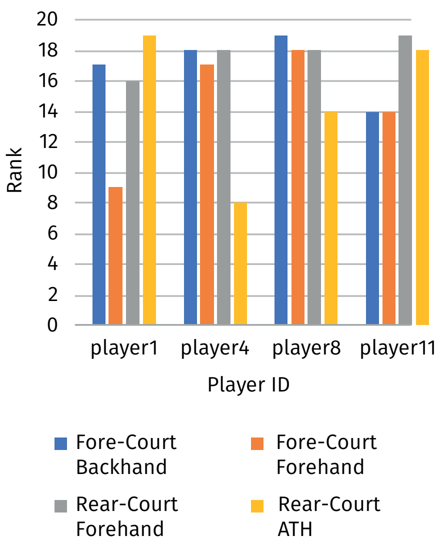

Figure 3c. The heaviest landers in MP trials

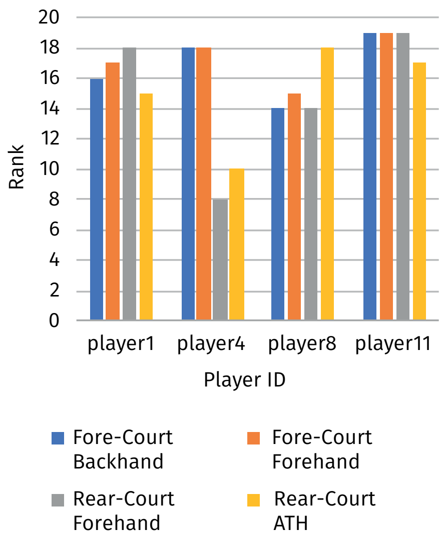

Figure 3d. The heaviest landers in MP trials in the MF condition

Finally, players were grouped by those who won their matches against those who lost. Of the example athletes given above for the four lightest landers, players 2 and 3 lost their matches but 9 and 13 won. Whereas for the four heaviest landers, all four won their matches. Overall, there were no significant differences in descriptive characteristics between winners and losers. However, comparison of means showed winners slightly younger (18.1 ± 2.6 vs 23.2 ± 7.7 years), with less experience (8 ± 2.8 vs 13.1 ± 8.9 years), shorter (1.72 ± 0.07 vs 1.77 ± 0.09 m), and lighter (69.0 ± 10.6 kg vs 73.3 ± 15.6 kg). Despite this, winners tended to record higher accelerations overall. Table 1 shows the ranks for winners and losers based on the size of accelerations recorded. For every shot type, the average acceleration was higher for winners in both MP and MF trials, although for MP this was only statistically significant for forecourt backhand shots (p=0.011, ES = -0.13) when grouped. During MF trials, the difference between winners and losers was significant for all shot types (p<0.001, ES = -0.19 - -0.3). Whilst these differences exist between groups, the increase in load from MF to MP for each is similar. When comparing, the difference in accelerations between groups between MF and MP (Figure 4), the average difference is 3.5 *g* in the rear court and 0 *g* in the forecourt although the largest difference was 9.6 *g* for forecourt forehand. However, when viewing the differences as a percentage of MP levels, winners experienced 70 % in MF compared to losers whose impacts were 58 % of those seen in MP. This difference is mainly due to large differences in forecourt shots where winners and losers experienced 55 % and 47 % of MP levels compared to 84 % and 68 % in the rear court shots respectively.

Table 1.
Average player rankings based on acceleration during landings.

Shot	Winners				Losers			
	MP		MF		MP		MF	
Rear-Court	11.4	± 4.9	12.6	± 5.5	9.4	± 6.1	7.8	± 5.2
Fore-Court	11.0	± 5.7	11.4	± 6.1	9.2	± 6.0	8.1	± 5.1
Fore-Court Backhand	11.7	± 5.5	11.9	± 5.6	8.3	± 5.9	7.6	± 5.1
Fore-Court Forehand	11.0	± 6.2	11.7	± 5.9	9.2	± 5.5	8.1	± 5.4
Rear-Court Forehand	11.3	± 5.9	11.3	± 6.4	8.6	± 5.7	8.6	± 5.0
Rear-Court ATH	11.4	± 5.9	12.2	± 5.3	9.6	± 4.9	8.6	± 5.4

MP = Match-play, MF = Multi-feed drill

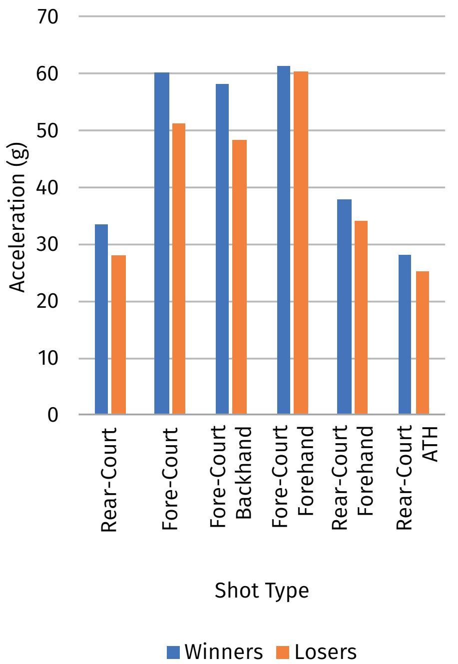

Figure 4a. Comparison of median accelerations during shots between winners and losers during MP (match play).

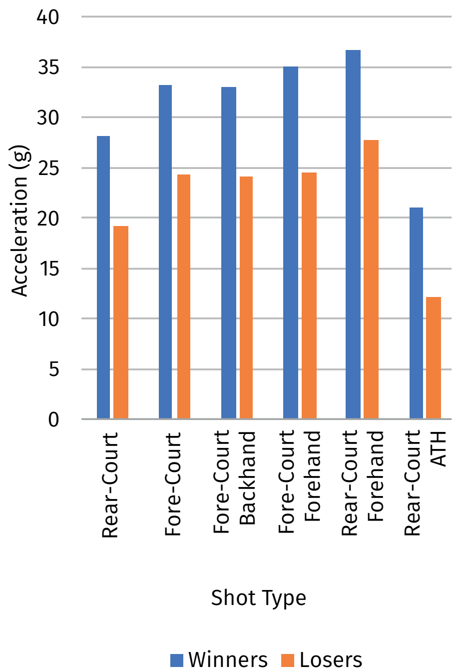

Figure 4b. Comparison of median accelerations during shots between winners and losers during MF (multi-feed) trials.

DISCUSSION

The aim of the study was to investigate intra-individual and group (winners vs losers) differences in acceleration data recorded during specified badminton moves. The data presented supports previous observations that larger impacts are seen during MP than MF trials (Smith et al., IN REVIEW). When the data were broken down into individual participants, it was largely seen that some players tended to be 'heavier' landers than others, whilst correlation exists, it was not necessarily consistent across shots. This suggests a level of difference in movement ability, strategy, or technique between players. This study therefore provides initial insight into the intra-individual differences that exist between badminton players.

It is particularly interesting that players who won their matches tended to exhibit higher accelerations than their opponents. It is therefore useful to consider why this might be an advantage and if these players are putting themselves at a greater risk of injury. Mechanically, higher accelerations should mean faster completion of movements such as landings and changes of direction although a high peak doesn't necessarily mean overall faster movement. However, it is peak forces which often best predict performance in explosive activities (Cronin and Hansen, 2005; Young et el., 1995). For example, Cronin et al. (2003) specifically noted that their best predictor of lunge performance was the ability to "produce peak force earlier in the concentric phase" on a supine squat. Lam et al. (2018) also observed that shorter foot contact time in the lunge coincided with higher peak horizontal forces whilst in fencing, Guan et al. (2018) observed that elite fencers produced a higher peak horizontal force which contributed to a higher velocity of the centre of mass.

The results for winners and losers are also interesting in light that there were no significant differences in group descriptive characteristics. If anything, it might be expected that the slightly higher stature and mass of the losers' group might result in larger impacts. However, as accelerations were measured rather than force, the lighter, shorter group might therefore be expected to be more agile and in turn, produce the higher numbers.

The differences between acceleration data for winners and losers were most pronounced in the MF condition, although this is exaggerated by the scale of the plots. The differences though are highlighted when viewing them as a percentage of match levels, where winners were working at 70 % compared to losers whose impacts were only 58 %. It could be postulated that this indicates the winners are likely more dynamic or "trying harder" in training drills. This then could have potential advantages for overall physical preparation in the short and long-term. Whilst it has been noted that higher training loads can contribute to injuries/ risk, it is also likely that training 'smart' helps in conditioning and hence injury prevention (Gabbet, 2016). Given that the median acceleration in MF were often ~25 *g* less than in MP, it also seems likely that the injury risk in this specific drill is also lowered.

Court location has been seen to have an influence on injury risk in relation to some movement/ shot types (e.g. Kimura et al., 2010). In the present study, athletes appeared to experience accelerations during MF closer to those seen in game levels in the rear court, than the forecourt. Again, it should be considered that the training drill observed in this study is not a representation of all training drills. Nonetheless, knowing how training drills reflect match-play, including the loading mechanics, is something that coaches may wish to consider when attempting to balance training load vs injury risk.

Landing with higher accelerations might suggest a higher level of conditioning. These players may be able to withstand higher forces without injury and therefore be able to make more efficient movements around the court. It is a common misconception among coaches that reducing forces is a requirement in movements such as landings. Whilst this might be desirable, as a reduction in peak force might relate to a reduction in injury risk, it is by no means a requirement for fast movements. A reduction in peak force is characterised by movements such as greater flexion in the hip and knees. However, these movements take time and higher accelerations are likely to mean less loss of height or less time spent slowing of the centre of mass, and hence the overall movements are completed more quickly.

Fu et al. (2017) noted differences in lunging kinetics and kinematics between professional and amateur players and linked this to probable differences in conditioning and potential injury risk. Whilst Lam (2018) also noted unskilled athletes to have a larger knee flexion moment and larger peak horizontal ground reaction force, their overall peak GRF was less, associated to lower loading rate and longer contact time. Again, this points towards different conditioning and ability to lunge at speed in players of lower ability.

Herbaut et al. (2018) compared injuries between French and Chinese badminton players and in-particular noted higher rates of injury in French players. This could have been due to numerous factors, such as anthropometry, approach to training, playing technique, healthcare etc. Given the discussion here, it would be interesting to understand if this might also be related to the types of training undertaken, year of experience, equivalent loads encountered, and if this provides equivalent preparation.

LIMITATIONS

The study was reliant on the attachment of the IMU's being consistent across participants. Whilst every step was taken to ensure this, it is possible that factors such as variations in the connection to the underlying bone, or even choice of footwear (e.g. Bouché et al., 2010), could affect the results. However, if this were the case to a considerable extent, it might be expected that greater consistency would have been seen in the ranking data across the different shot types.

The use of IMU's is also convenient for collecting data in match-play due to being light and unobtrusive, however the inclusion of three-dimensional coordinate data would be useful linking movement kinematics and therefore comprehending how the accelerations seen are linked to the movements performed.

CONCLUSION AND PRACTICAL IMPLICATIONS

It has been shown that loading differences exist between players and that, even when athletes are paired up to play based on being similar levels, the winner is likely to be able to utilise higher loads in their game. Landing with higher accelerations might be an advantage for breaking, changing direction and recovery from the shot. Where players experience higher loads, they are likely to do this across different shots (although there is large variation). However, the impacts seen in training drills may not replicate those seen in match-play and this may even vary according to shot-type and court location within the drill. Badminton coaches should therefore aim to ensure that where training exercises aim to reflect match-play, attention should be paid to the variety and intensity of practice.

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The confounding effects of serve speed and ball placement on success of male and female tennis players at The Championships, Wimbledon

Los efectos de confusión de la velocidad del saque y la ubicación de la pelota en el éxito de tenistas hombres y mujeres en el Campeonato de Wimbledon

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Abstract

The impact of serve direction and serve speed on the success of the server winning the point in singles tennis was analysed using data from the Championships, Wimbledon from 2004 to 2019. The direction and speed of the serve are two crucial factors when determining the outcome of a serve and subsequently the point. Gaining maximum advantage from the serve is a priority for tennis players, particularly when competing at The Championships due to the nature of the grass court surface. The data used in this study was collected for Wimbledon Information System (IBM) from The Championship's male and female singles competitions from 2004 to 2019, with permission given by the All-England Lawn Tennis Club. Multi-way ANOVAs were performed for sex of player, server handedness, receiver handedness, serve number, serve side, serve placement, serve speed, and serve success with post-Hoc Tukey and Scheffe tests independently completed for males and females. Data was weighted by frequency and Pearson's chi-square tests (contingency coefficient, Phi and Cramer's V, and Lambda) were conducted independently for males and females for the aforementioned categories. Additionally, z-tests were used to compare proportions, and standardized residuals with adjusted p-values were used to analyse significant effects. The analysis revealed that in male singles, servers are more likely to win the point regardless of other serve characteristics, with serve placement into the centre and wide areas further increasing the probability of winning the point. In female singles, the likelihood of the server winning the point varied more with certain serve combinations, largely influenced by serve placement and serve number. The relationship between serve placement and serve speed indicated that certain speeds were favoured for both male and female matches in all serve directions, with two distinct peaks and serves around 190 km/h being disfavoured.

Keywords: *Grand Slam, Wimbledon, speed, placement, handedness.*

Resumen

Se analizó el impacto de la dirección y la velocidad del saque en el éxito del servidor que gana el punto en el tenis individual usando datos de los Campeonatos de Wimbledon de 2004 a 2019. La dirección y velocidad del saque son dos factores cruciales para determinar el resultado de un saque y, posteriormente, del punto. Obtener la mayor ventaja en el saque es prioritario para los tenistas, particularmente, cuando compiten en el Campeonato de Wimbledon, debido a la naturaleza de la superficie del campo de césped. Los datos usados en este estudio fueron recolectados por el Sistema de Información de Wimbledon de IBM en las categorías individuales masculinas y femeninas de los campeonatos de 2004 a 2019 con el permiso de All England Lawn Tennis Club. Se aplicaron modelos ANOVA multifactoriales para el sexo del jugador, la mano dominante del servidor, la mano dominante del receptor, el número de saques, el lado del saque,

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la ubicación del saque, la velocidad del saque y el éxito del saque con pruebas post hoc de Tukey y Scheffe realizadas de manera independiente para hombres y mujeres. Los datos se ponderaron por frecuencia y las pruebas de ji al cuadrado de Pearson (coeficiente de contingencia, Phi y V de Cramer, y Lambda) se realizaron de forma independiente para hombres y mujeres en las categorías ya mencionadas. Adicionalmente, se realizaron pruebas Z para comparar las proporciones, y se usaron residuales estandarizados con valores p ajustados para analizar los efectos significativos. El análisis evidenció que en los individuales masculinos es más probable que los servidores ganen el punto sin importar las otras características del saque, y cuando el saque llega al centro y a las zonas amplias aumenta aún más la probabilidad de ganar el punto. En los individuales femeninos, la probabilidad de que la servidora gane el punto varió más con ciertas combinaciones de saque, influenciado en gran parte por la ubicación del saque y el número de saque. La relación entre ubicación y velocidad del saque indicó que ciertas velocidades eran preferidas por tanto hombres como mujeres en todas las direcciones del saque, y que dos picos distintivos y los servicios de cerca de 190 km/h son menos preferidos.

Palabras clave: *Grand Slam, Wimbledon, velocidad, ubicación, mano dominante.*

INTRODUCTION

The tennis serve is an important factor in controlling the outcome of the game, being the only closed skill in the sport. Gaining maximum advantage from the serve is a priority for tennis players (O'Donoghue & Ingram, 2001) and it is well reported that players win more points when serving (Brown & O'Donoghue, 2008; Fitzpatrick et al., 2019). For both male and female players, points from a one-shot rally comprise almost half of all short points for male players and over a third of all points for female players. This highlights the importance of the serve in the outcome of the point and subsequently the match. Players who can serve and win the point through aces or unreturned serves have a greater than 70% probability of winning the match (Fitzpatrick et al., 2021).

This study focussed exclusively on grass courts at The Championships, Wimbledon. Brown and O'Donoghue (2008) reported that average rally lengths at Wimbledon are shorter than those at other Grand Slam tournaments. Therefore, the server has an even greater advantage at Wimbledon than at other tournaments (Paserman, 2020). Compared with clay, grass reduces the angle at which the ball bounces and grass has less of a slowing effect on the ball due to a decreased friction coefficient (Vaverka et al., 2018).

There have been numerous studies that have shown that faster serve speeds are associated with increased success in winning points (McMahon et al., 2002; O'Donoghue & Ballantyne; 2004; Whiteside et al., 2015; Brown, 2021). However increased serve speed is also associated with reduced accuracy of ball placement. O'Donoghue & Ballantyne (2004) proposed this as the rationale behind the common strategy where players hit powerful first serves, making the return shot harder for the receiver, but reduce the speed of the second serve putting more focus on serve placement accuracy.

The purpose of this study is to examine the relationship between serve speed and ball placement and the impact of variables such as sex of player, server handedness, serve number and serve side on the probability of the server winning the point. Previous studies have explored handedness, serve speed and ball placement, however, this study focuses on analysing the confounding effects of all these factors on the server winning the point in both the men's and ladies' singles events at The Championships, Wimbledon, providing new insights into the serve strategies for grass court specialists.

METHOD

Sample

This study used official championship performance information from the Wimbledon Information System (presented by IBM) from The Championship's men's and ladies' singles competitions from 2004 to 2019. This data is not in the public domain so permission to access this data was given by IBM with permission granted by the All-England Lawn Tennis Club.

For the purpose of this study, serve success is defined as the number of points won by the server as a percentage of all points played that were won within five shots. Serve placement was determined by data collectors positioned on the side of each show court and was based on the angle of the ball's trajectory from the server's racket to the location within the service box where the serve lands. Serve placement within the service box was categorised into one of three areas, the innermost division (centre), outermost division (wide), and the body segment, flanked by the centre and wide segments as illustrated in Figure 1. This subjective measurement was made relatively objective by validation using data collected by Hawkeye cameras (hawkeyeinnovations.com, n.d.) for automated ball-tracking data collection, rendering a minimum of 97% accuracy and consistency rate by the data collectors.

Serve speed was recorded as an integer value in miles per hour using a radar gun that measured the maximum speed of each serve as soon as the ball left the server's racket. Robinson & Robinson (2016) demonstrated the reliability of these radar guns to record the ball throughout its flight path to accurately determine the ball's speed from when the served ball leaves the server's racket.

Data was separated based on whether the first or second serve was played out for the point as players tend to adopt a more conservative approach for their second serve. For second serves, serve speed decreases by 24.1% on average and the ball's trajectory moves further from the edges of the service box into the middle (Chow et al, 2003).

Procedure

The data was filtered to include: sex of player, serve number (first or second serve), serve side (advantage or deuce), serve placement (body, centre or wide), handedness (right-handed server to right-handed receiver (RvR), right-handed server to left-handed receiver (RvL), left-handed server to right-handed receiver (LvR) or left-handed server to left-handed receiver (LvL)), serve speed, and serve success. The data was further filtered to remove points that continued longer than 5 shots as serve characteristics are most influential for rallies of length up to four shots and 66% of points at Wimbledon end within the first four shots (Carboch et al., 2019). Double faults were also not included as these are unsuccessful serves that do not satisfy the serve placement criteria (Fitzpatrick et al., 2021). The total number of points included in each serve combination ranged between 42 and 29 896 points for males and 5 and 24 192 points for females (Table 1).

Statistical Analysis

All statistical analyses were performed with SPSS ver. 28 (and values are expressed as mean ± standard deviation) to determine the strength of association between serve speed and serve placement and each of the examined variables. Successful serve frequencies for each combination were checked for normality using the Kolmogorov Smirnov test to ensure distribution of data for the comparison of the impacting variables. Significance of differences between serve combinations were compared using significant standardised residuals from Pearson's chi-square cross tabulations and likelihood ratios. Due to there being too few points played between two left-handed players in female matches for meaningful analysis, these data were excluded from these analyses.

Table 1
Total number of points analysed in this study for each combination of handedness for singles matches at The Championships, Wimbledon 2004-2019

Group	n
Female RvR	151590
Female RvL	9000
Female LvL	393
Female LvR	9132
Male RvR	223986
Male RvL	31668
Male LvL	6646
Male LvR	31708

Legend: RvR: Right-handed player vs Right-handed player. **RvL:** Right-handed player vs Left-handed player. **LvL:** Left-handed player vs Left-handed player. **LvR:** Left-handed player vs Right-handed player. **n:** number of points in each category.

Multi-way ANOVAs, completed with post-Hoc Tukey and Scheffe tests were performed for males and females separately (sex of player, server handedness, receiver handedness, serve number, serve side, serve placement, serve speed, and serve success) to find the effects of the given variables on the probability of the server winning the point. Statistical difference was set at $p < 0.05$.

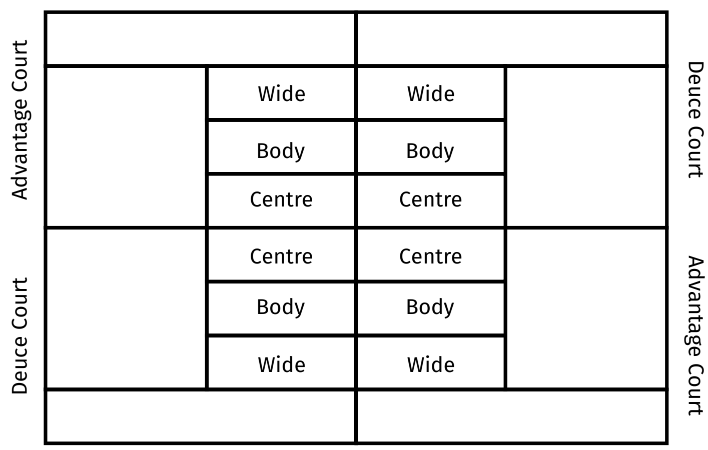

Figure 1. A representation of the deuce and advantage boxes divided into their respective Body, Centre and Wide regions.

Data was weighted by frequency and Pearson's chi-square tests (contingency coefficient, Phi and Cramer's V, and Lambda) were conducted independently for males and females for the categories of sex of player, serve handedness, receiver handedness, serve number, serve side, serve placement, and serve success. The contingency coefficient and Cramer's V test measured the interdependence between each pair of categorical variables which can be used to compare the strength of relationship between each category and serve speed and placement. The Phi test was performed to indicate the direction of the degree of relevance measured by the contingency coefficient between each pair of variables. The Lambda test assessed the strength and direction of association between a dichotomous variable and categorical variable based on how the dichotomous variable influences the distribution of categories in the categorical variable. *z* tests to compare proportions, and standardised residuals with adjusted p values were used to analyse significant effects. Statistical difference was set at $p < 0.05$.

RESULTS

Four-way interaction (handedness, court side (advantage/deuce), service number and serve placement interaction) was significant for both males and females, male likelihood ratio $x^2(1) = 2165.05$, $p < 0.000$ and female likelihood ratio $x^2(1) = 424.82$, $p < 0.001$. The combined effects of these four factors in this interaction has some of the most significant effects on serve success, (z=17.530 for males) and (z=6.421 for females). The effect of this interaction is significantly higher for males than for females but is nonetheless significant for both.

The cross-tabulation test shows that significantly fewer points than expected are won by the server for Centre, first serves from the advantage court for LvR, as depicted by the negative significant standardised residual values of -6.9 and -2.1 for men and ladies respectively in Tables 2 and 3.

Table 2

Percentage of points where the server wins the point for each combination of serve placement, courtside, service number and handedness for males at The Championships, Wimbledon 2004-2019

									Body							
Court Side	Advantage								Deuce							
Service Number	1st				2nd				1st				2nd			
Server, Receiver Handedness	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L
% Server Wins Point	73.9	65.4	69.1	67.2	58.6	56.6	59.4	56.2	69.5	67.8	67.3	68.4	58.3	56.4	57.5	57.2
Sig Standardised Residual	-1.7	1.1	-1.4	-0.4	0.4	0.5	-1.5	0.4	-0.4	0.0	0.3	-0.3	0.4	0.4	-0.6	-0.4
									Centre							
Court Side	Advantage								Deuce							
Service Number	1st				2nd				1st				2nd			
Server, Receiver Handedness	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L
% Server Wins Point	76.5	72.5	78.7	71.4	55.2	59.7	62.6	57.1	69.9	77.5	70.9	78.2	54.2	57.1	57.4	61.7
Sig Standardised Residual	1.0	-1.1	-6.9	2.2	1.0	-0.5	-1.5	1.7	4.3	-3.5	9.1	-2.4	0.9	0.5	0.0	-2.3
									Wide							
Court Side	Advantage								Deuce							
Service Number	1st				2nd				1st				2nd			
Server, Receiver Handedness	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L
% Server Wins Point	73.7	75.2	73.2	78.5	56.3	56.3	59.7	61.9	73.1	73.7	74.8	74.3	54.5	61.3	61.5	57.5
Sig Standardised Residual	1.0	0.1	3.1	-4.3	0.2	1.5	-2.0	-3.1	0.4	0.5	-1.2	-0.6	1.8	-1.4	-0.6	2.5

R: Right-handed. L: Left-handed

Table 3

Percentage of points where the server wins the point for each combination of serve placement, courtside, service number and handedness for females at The Championships, Wimbledon 2004-2019

									Body							
Court Side	Advantage								Deuce							
Service Number	1st				2nd				1st				2nd			
Server, Receiver Handedness	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L
% Server Wins Point	55.6	59.0	61.3	59.8	36.8	51.8	52.5	52.8	51.7	59.4	59.9	60.3	51.6	53.2	49.6	57.6
Sig Standardised Residual	0.3	0.2	-0.7	0.2	0.9	0.2	-0.4	0.5	0.7	0.1	-0.2	0.3	0.1	0.1	1.3	-1.6

Table 3

Percentage of points where the server wins the point for each combination of serve placement, courtside, service number and handedness for females at The Championships, Wimbledon 2004-2019 (Continued)

	Centre															
Court Side	Advantage								Deuce							
Service Number	1st				2nd				1st				2nd			
Server, Receiver Handedness	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L
% Server Wins Point	74.6	64.4	67.9	64.8	50.0	53.1	57.2	53.7	62.3	67.9	61.8	69.8	52.0	52.5	53.9	54.7
Sig Standardised Residual	-1.3	0.5	-2.1	-0.2	0.2	0.2	0.9	0.2	0.8	-1.0	4.9	-1.6	0.1	0.3	-0.6	-0.6
	Wide															
Court Side	Advantage								Deuce							
Service Number	1st				2nd				1st				2nd			
Server, Receiver Handedness	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L	L, L	R, R	L, R	R, L
% Server Wins Point	72.4	66.6	65.2	64.9	57.6	53.0	54.0	53.9	69.7	65.9	65.9	65.5	47.8	55.1	61.1	55.0
Sig Standardised Residual	-0.9	-0.5	1.1	1.1	-0.4	0.2	0.4	0.3	-0.6	-0.1	0.0	-0.3	0.5	0.3	-1.8	0.1

R: Right-handed. L: Left-handed

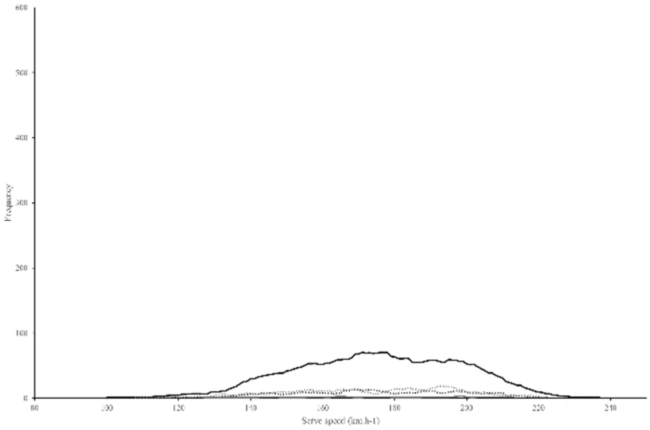

Figure 2. *Relationship between serve speed (km/h) and serve frequency for male first serve right handed player to right handed player (solid, black line), male first serve right handed player to left handed player (dotted, black line), male first serve left handed player to left handed player (solid, grey line) and male first serve left handed player to right handed player (dotted, grey line) when the serve landed down the body from the ad side at The Championships, Wimbledon 2004–2019.*

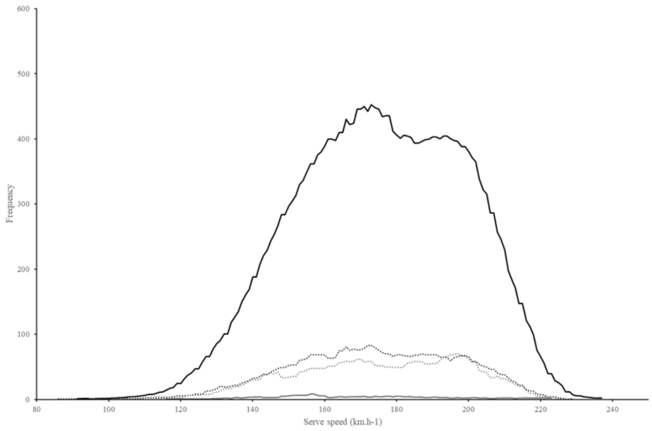

Figure 4. *Relationship between serve speed (km/h) and serve frequency for male first serve right handed player to right handed player (solid, black line), male first serve right handed player to left handed player (dotted, black line), male first serve left handed player to left handed player (solid, grey line) and male first serve left handed player to right handed player (dotted, grey line) when the serve landed down the body from the ad side at The Championships, Wimbledon 2004–2019.*

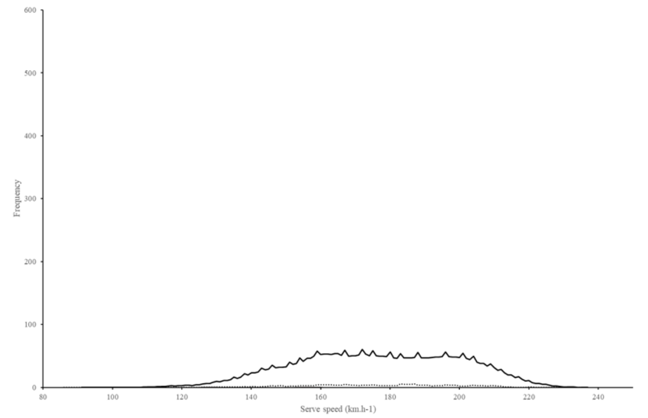

Figure 3. *Relationship between serve speed (km/h) and serve frequency for female first serve right handed player to right handed player (solid, black line), female first serve right handed player to left handed player (dotted, black line), female first serve left handed player to left handed player (solid, grey line) and female first serve left handed player to right handed player (dotted, grey line) when the serve landed down the body from the ad side at The Championships, Wimbledon 2004–2019.*

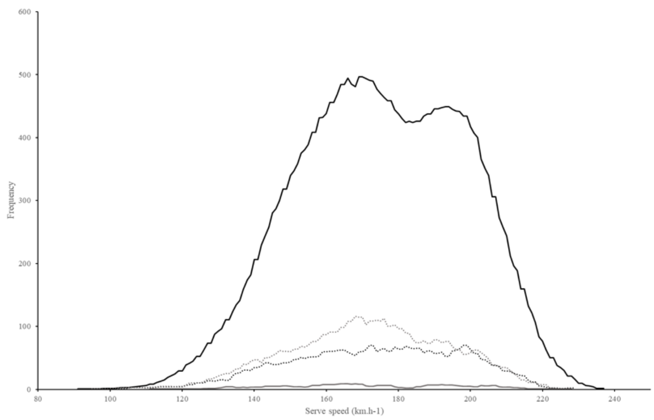

Figure 5. *Relationship between serve speed (km/h) and serve frequency for male first serve right handed player to right handed player (solid, black line), male first serve right handed player to left handed player (dotted, black line), male first serve left handed player to left handed player (solid, grey line) and male first serve left handed player to right handed player (dotted, grey line) when the serve landed down the wide from the ad side at The Championships, Wimbledon 2004–2019.*

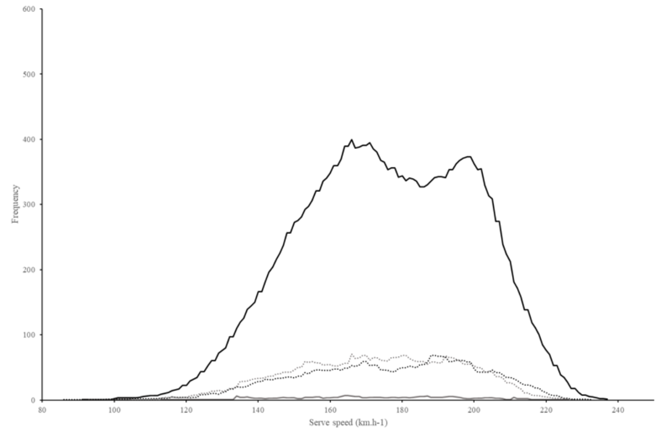

Figure 6. *Relationship between serve speed (km/h) and successful serve frequency for male first serve right handed player to right handed player (solid, black line), male first serve right handed player to left handed player (dotted, black line), male first serve left handed player to left handed player (solid, grey line) and male first serve left handed player to right handed player (dotted, grey line) when the serve landed down the centre from the deuce side at The Championships, Wimbledon 2004–2019.*

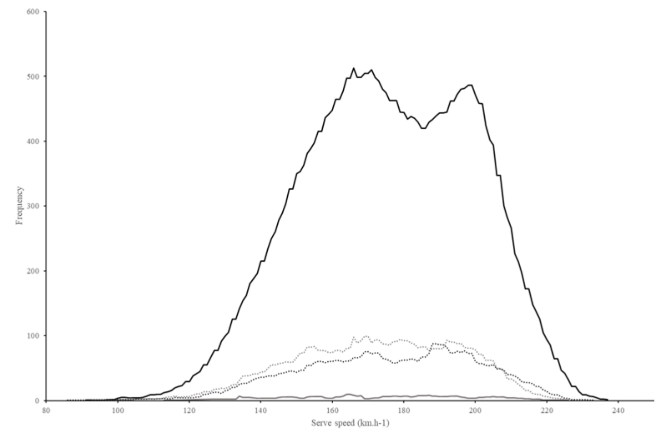

Figure 7. *Relationship between serve speed (km/h) and serve frequency for female first serve right-handed player to right handed player (solid, black line), female first serve right handed player to left handed player (dotted, black line), female first serve left handed player to left handed player (solid, grey line) and female first serve left handed player to right handed player (dotted, grey line) when the serve landed down the centre from the deuce side at The Championships, Wimbledon 2004–2019.*

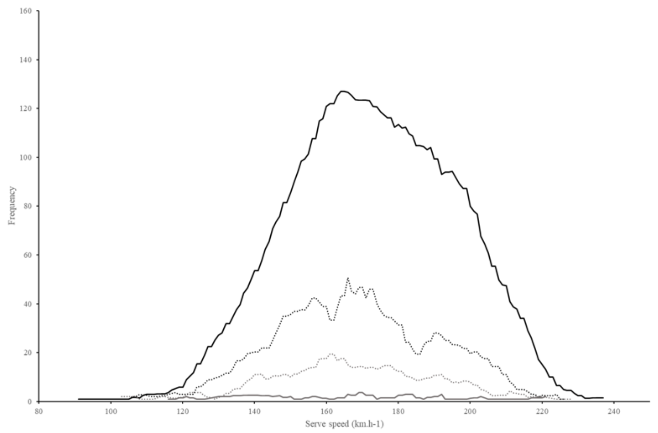

Figure 8. *Relationship between serve speed (km/h) and serve frequency for male second serve right handed player to right handed player (solid, black line), male second serve right handed player to left handed player (dotted, black line), male second serve left handed player to left handed player (solid, grey line) and male second serve left handed player to right handed player (dotted, grey line) when the serve landed down the body from the ad side at The Championships, Wimbledon 2004–2019.*

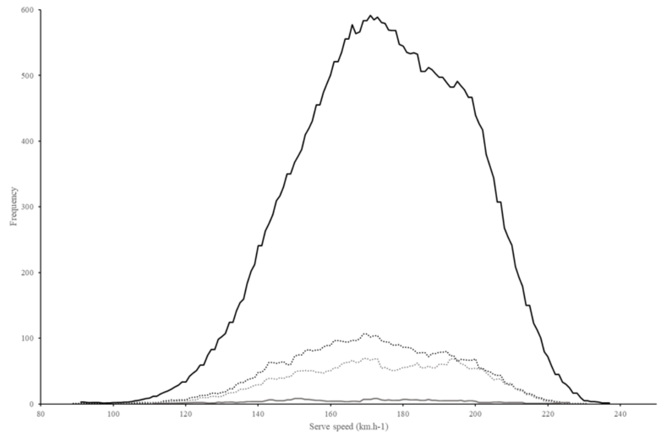

Figure 9. *Relationship between serve speed (km/h) and serve frequency for male first serve right handed player to right handed player (solid, black line), male first serve right handed player to left handed player (dotted, black line), male first serve left handed player to left handed player (solid, grey line) and male first serve left handed player to right handed player (dotted, grey line) when the serve landed down the wide from the deuce side at The Championships, Wimbledon 2004–2019.*

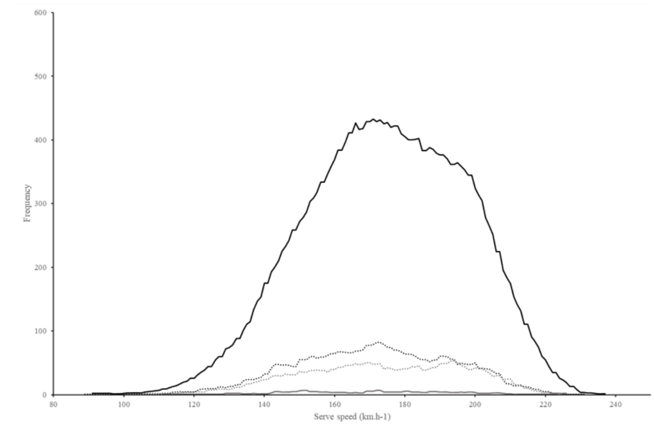

Figure 10. *Relationship between serve speed (km/h) and successful serve frequency for male first serve right handed player to right handed player (solid, black line), male first serve right handed player to left handed player (dotted, black line), male first serve left handed player to left handed player (solid, grey line) and male first serve left handed player to right handed player (dotted, grey line) when the serve landed down the wide from the deuce side at The Championships, Wimbledon 2004–2019.*

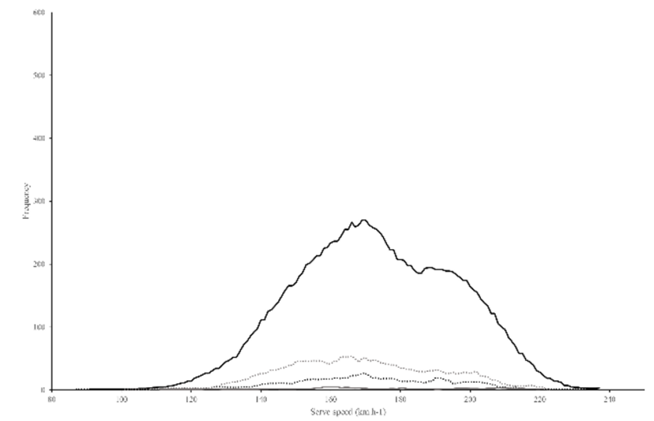

Figure 11. *Relationship between serve speed (km/h) and serve frequency for male second serve right-handed player to right handed player (solid, black line), male second serve right handed player to left handed player (dotted, black line), male second serve left handed player to left handed player (solid, grey line) and male second serve left handed player to right handed player (dotted, grey line) when the serve landed down the centre from the deuce side at The Championships, Wimbledon 2004–2019.*

DISCUSSION

Table 1 shows that for males, servers are more likely to win the point regardless of their handedness, the handedness of their opponent, serve placement, courtside or serve number. Serve placement into the centre and wide areas was found to increase the likelihood of players winning the point (Mecheri et al., 2016). This echoes previous findings that male players adopt more strategic serving patterns as this significantly contributes towards increasing the probability of them winning the point outright through an ace or forced error, or through increasing their control over the next few shots in the rally so that the server is more likely to win the point (Hizan et al., 2015). For RvR points, servers have the highest likelihood of winning the point for first serves from the deuce court side directed towards the centre of the court. This may be due to the receiver covering the tramlines, so they are less prepared for a serve down the centre line and have less reach to make their return. This serve is directed towards the receiver's backhand which is usually weaker and may lead to a single-handed slice backhand which is less likely to be a winner. For RvL points, servers are most likely to win the point for first serves directed out wide from the advantage court side as these serves may have topspin that causes the ball to move towards the tramlines and draws the receiver away from the centre of the court, so they have further to recover before the next shot. For LvL points, servers have the highest probability of winning the point for first serves directed to the centre of the court from the advantage court side as these serves are directed towards the receiver's backhand which tends to be weaker, and the receiver may have less reach particularly if they have a double-handed backhand which further weakens the return of serve. This result aligns with Gillet et al. (2009), who showed that flat serves are the favoured serve type on the grass surface due to their higher winning point rate compared to topspin and slice serves, particularly when serving down the centre of the court. This is largely due to flat serves achieving faster speeds and lower bounce which reduces the time receivers have to execute a strong return, particularly if the receiver has to move from near the tramlines towards the "T", increasing the probability of the server winning the point. For LvR points, servers have the highest likelihood of winning the point for 1st serves directed towards the centre of the court from the advantage court side as these serves are aimed towards the centre line which may be difficult to return if the receiver is covering the tramlines. Loffing et al. (2009) suggested that because there are far fewer left-handed players, the lack of experience of right-handed players in receiving shots with different spins from left-handed players creates a significant advantage for the latter.

Table 2 shows that for females, servers are less likely to win the point on the following serve combinations; LvL second serves directed towards the body from the advantage court side; LvR second serves directed towards the body from the advantage court side; and LvL second serves directed towards the body of a left-handed receiver from the deuce court side. Receivers were more likely to win the point for these serve combinations as second serves tend to be slower than first serves (Mecheri et al., 2016) and these serves are directed towards the receiver making it easier for them to make a winning return of serve. The second serve is a different proposition where the server adopts a safer approach as a fault leads to the loss of the point so a larger proportion of second serves are directed towards the body of the receiver (Hizan et al., 2015). This study shows that the LvL and RvL wide serves from the deuce side have a higher probability of the server losing the point as the serve is directed towards the backhand of the receiver which is likely to be a double-handed backhand that is a strength of female players (Hizan et al., 2015). For all other serve combinations, the server has a higher likelihood of winning the point. This includes for body serves which are a relatively safer approach for servers (Hizan et al., 2015) but may lead to the receiver hitting a forced error in their return if the body serve is executed well (Crespo and Miley, 1998).

Mecheri et al. (2016) showed that the most first serves were directed toward the centre and wide serve placement locations in a similar manner on both deuce and advantage courts for both males and females. The first serve is usually faster than the second serve and more likely to land in the centre and wide serve placement locations as these serves are directed further away from the receiver so returns of serve are weaker and more difficult (Crespo and Miley, 1998, Hizan et al., 2015, Unierzyski et al., 2004, Gillet et al., 2009). This study shows that for second serves those on the deuce court are more likely to be directed towards the centre of the court and on the advantage court second serves are more likely to be directed towards the tramlines. This choice of second serve placement enables the server to aim for their opponent's backhand which will more likely result in a weaker return of serve. Second serves on the deuce court side are more likely to be directed towards the centre of the court with more topspin to push the receiver behind the baseline whereas second serves on the advantage court side are more likely to be wide and with less topspin to open up the court.

Figures 2 and 3 suggest that serve speeds to the body are not significantly different to the speeds of the other serve directions for males while the distribution of serve speeds are different for females. This is reflected in the post hoc Tukey and Scheffe test, which show that the serve speeds to the body are not significantly different compared to the centre and wide serves. For females, handedness has a significant factor in the frequency of successful serves.

Figures 4, 5, 6 and 7 reflect a trend of having two clear peaks, where speeds near 190 km/h are less favoured. Further analysis uncovered that this is because of two peaks that are superimposed on each other. When dividing the data into the earlier time period (2004 -

2011) and the later time period (2012 - 2019), the two peaks were visible, with the earlier time period peaking at the lower speed and the later time period peaking at the higher speed. This trend can also be seen on Figures 8, 9 and 10 where the serve frequency seems to gather near one serve speed. There is approximately a 40 km/h difference between where the serve frequency is highest in the earlier time period (160 km/h) compared with the later time period (200 km/h). This may be for several reasons such as racket material and a change in the strength and conditioning of players. Mainstream racket material has not changed significantly in the past 20 years, major changes in materials of rackets was the change from graphite combined with Kevlar to carbon fibre combined with certain types of resins at around 2010 (Koronas and Tohanean, 2021). However, the improvement on rackets have been largely focused on increasing reliability rather than power being shot (Koronas and Tohanean, 2021). Another factor that may affect the speed of serves in a short time period is the types of strings used on the racket. While strings have not changed much, changing technologies have improved player performance (Ozdemir et al., 2019).

Finally, another factor that may affect the speed is strength and conditioning. The increased popularity of strength and conditioning has allowed players to focus on increasing power behind each of their shots. For example, current younger players who are training with the Youth Physical Development model will have trained to improve all physical qualities, including muscular strength from an early age (Fernandez-Fernandez and Kovacs, 2018). Increased muscular strength will lead to shots with more power and more speed. Strength training from a young age under the correct supervision is proved to be beneficial (Fernandez-Fernandez and Kovacs, 2018). As youth players receiving strength training reach the age to qualify for The Championships, Wimbledon, the results may be mirrored into the increased speed of serves.

Figures 8 and 11 show that the most popular serve direction on the second serve is down the centre at 163 km/h. This direction is favoured as players often focus on putting the ball into the service box rather than the powerful, higher speed serves seen in the first serve. By serving down the centre, it allows the player to improve the chances of serving into the service box, as well as serving to the area where the distance between the player serving and the serve direction is the shortest, however, it allows the receiving player to hit harder return shots, as it allows them to have the longest reaction time. However, these shots can be easily returned, and so they have the lowest absolute success frequency compared to other serve directions.

Since higher seeded players are more likely to progress to further rounds and qualify to compete for many years during their career, these players will be overrepresented in this study. Further studies to reduce this effect would be valuable. Other limitations include the subjectivity of the measure of serve placement and the fact that radar gun only measures the exact bounce spot of the serve and does not provide any data for the direction of the serve after it bounces. (Whiteside et al., 2015; Mecheri et al. 2016).

Previous studies have shown that players' serve performance, particularly serve speed, both peak and average, decreased gradually between the first and fifth set so the number of serve winners declined (Cui et al., 2020). Further research could be conducted to analyse the impact of match fatigue on the success of each serve combination.

This study depicts the significant impact of these confounding variables on serve speed and ball placement and therefore due to the influence of the serve for the rest of the point, the probability of the server winning the point. These results are useful for informing players and their coaches about the most successful serve strategies for winning points when competing at The Championships, Wimbledon and other tournaments.

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Overuse Injuries and Epicondylalgia in Recreational Pickleball Players

Lesiones por sobreuso y epicondilalgia en jugadores de nivel recreativo de pickleball

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Abstract

Little is known regarding pickleball-related overuse injuries. The purpose of this study was to determine the prevalence of overuse injuries in recreational pickleball players. Given the high frequency of elbow overuse injuries in other racket sports, this study also sought to determine the relationship between epicondylalgia in pickleball players, player characteristics, and various playing variables. A web-based survey was distributed to a convenience sample of recreational pickleball players. Of the 128 participants (70 females, 58 males) who completed the survey, 28% reported at least one overuse injury. Most did not seek medical interventions and reported no time lost from play. Overuse injuries were significantly associated with higher playing volume, lower level of play, and playing in pickleball tournaments. Epicondylalgia was the most common overuse pickleball-related injury amongst recreational pickleball players. Females and those who participated in pickleball tournaments were more likely to report a history of lateral epicondylalgia. Medial epicondylalgia was not significantly associated with any variable. Overuse injuries amongst pickleball players are common, yet most did not seek medical attention. Epicondylalgia was the most common overuse injury. Epicondylalgia was not a time loss overuse injury, yet the effect on pickleball player's playing abilities unknown. Education on common overuse injuries, the impact of playing volume, and the importance of proper technique may maximize symptom-free pickleball participation.

Keywords: *Pickleball, racket sports, overuse injury, chronic injury, epicondylalgia.*

Resumen

Poco se sabe acerca de las lesiones por sobreuso relacionadas con el pickleball. El propósito de este estudio fue determinar la prevalencia de las lesiones por sobreuso en jugadores de pickleball de nivel recreativo. Dada la alta frecuencia de lesiones por sobreuso del codo en otros deportes de raqueta, este estudio también trató de determinar la relación entre la epicondilalgia en los jugadores de pickleball, las características del jugador y diversas variables de juego. Se distribuyó una encuesta en línea a una muestra de conveniencia de jugadores de nivel recreativo de pickleball. De los 128 participantes (70 mujeres, 58 hombres) que completaron la encuesta, el 28 % reportó al menos una lesión por sobreuso. La mayoría no buscó atención médica y no informó de ninguna pérdida de tiempo de juego. Las lesiones por sobreuso fueron asociadas significativamente con un mayor volumen de juego, un menor nivel de juego y la participación en torneos de pickleball. La epicondilalgia fue la lesión por sobreuso más común entre los jugadores de nivel recreativo de pickleball. Las mujeres y los participantes en torneos de pickleball eran más propensos a declarar antecedentes de epicondilalgia lateral. La epicondilalgia

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medial no se asoció significativamente con ninguna variable. Las lesiones por sobreuso entre los jugadores de pickleball son comunes, aunque la mayoría no buscó atención médica. Aunque la epicondilalgia no fue una lesión por sobreuso con pérdida de tiempo, se desconoce el efecto sobre las habilidades de juego de los jugadores de pickleball. La educación en lesiones comunes por sobreuso, el impacto del volumen de juego y la importancia de una buena técnica pueden maximizar la participación en pickleball sin síntomas.

Palabras clave: *Pickleball, deportes de raqueta, lesión por sobreuso, lesión crónica, epicondilalgia.*

INTRODUCTION

Pickleball is one of the fastest-growing sports in the United States among all age groups. Since its invention in 1965, participation in pickleball has risen exponentially with national associations developing in more than 20 countries. Many individuals play pickleball as a means of attaining or maintaining physical fitness. (Buzzelli & Draper, 2020; Casper & Jeon, 2018) Participation in pickleball also has psychological and social benefits, particularly for older adults. (Casper & Jeon, 2018; Cerezuela et al., 2023) Despite its popularity, little is known about pickleball-related injuries.

An acute injury happens suddenly, often quite dramatically. Acute injury leads to cessation of activity at the time of injury and often requires medical care. One study investigated acute pickleball-related injuries where care was sought in US emergency departments and recorded in the National Electronic Injury Surveillance System (NEISS) data set. The most common acute pickleball-related injuries reported were fractures, sprains or strains. (Forrester, 2020) In contrast, an overuse injury involves damage to bones, muscles, ligaments, or tendons due to repetitive demand over a prolonged period of time. (Aicale et al., 2018) Excessive loading, insufficient recovery, and under-preparedness of tissues to tolerate spikes in loading may increase the risk of an overuse injury. (Gabbett et al., 2016) While overuse injuries may cause pain during or after sports participation, most individuals are able to continue to play, (Jørgensen & Winge, 1987) but may play at a lower level or reduce their playing volume to control symptoms. If severe, some overuse injuries may require prolonged time away from sport to allow time for tissue recovery. (Carroll, 1981) Unfortunately, information regarding pickleball-related overuse injuries is lacking.

The most common overuse injuries reported in tennis (Hassebrock et al., 2019) and paddle sports (Tagliafico et al., 2023) involve the elbow complex. Elbow overuse injuries also account for 11-13% of badminton injuries (Fahlström & Zeisig, 2022; Rangasamy et al., 2022) and 5.9% of table tennis injuries. (Rangasamy et al., 2022) Lateral epicondylalgia is the most frequent overuse injury of the elbow complex. Commonly referred to as “tennis elbow” due to the high incidence among recreational tennis players, lateral epicondylalgia is a progressive overload of the wrist extensor muscles, especially the extensor carpi radialis brevis just distal to its attachment on the lateral epicondyle. (Ma & Wang, 2020; Ranger et al., 2015; Stegink-Jansen et al., 2021) It is estimated that 30-50% of tennis players experience lateral epicondylalgia, (Ahmed et al., 2023; Gruchow & Pelletier, 1979; Hume et al., 2006) with persons playing recreational racket sports infrequently but for long durations (i.e. weekend warriors) being at particularly high risk. (Hartnett et al., 2022) Medial epicondylalgia, commonly referred to as “golfer’s elbow,” is the second most common overuse elbow injury in tennis. While significantly less common than lateral epicondylalgia, (Alrabaa et al., 2020; Cutts et al., 2020) medial epicondylalgia involves the flexor-pronator muscle group near the attachment to the medial epicondyle. (Amin et al., 2015; Hartnett et al., 2022) In both golfers and racket sports players, medial epicondylalgia appears to be related to improper technique (Patel et al., 2021; Vigouroux et al., 2017) and over-gripping. (Jayanthi & Esser, 2013) In tennis players, medial epicondylalgia is associated with the use of spin (Jayanthi & Esser, 2013).

Understanding overuse injuries in persons playing pickleball may lead to specific strategies for injury prevention and treatment. The purpose of this study was to determine the prevalence of overuse injury in recreational pickleball players and to examine player characteristics, playing variables, and injury care. Given the high frequency of overuse elbow injuries in other racket sports, this study also sought more specifically to determine the relationship between epicondylalgia in recreational pickleball players, player characteristics, and various playing variables.

MATERIALS AND METHODS

Participants

Convenience sample of 128 participants (70 females, 58 males) recreational pickleball players at indoor and outdoor pickleball facilities. Participant ages ranged from 18-85 years, with the median age range 50-54 years (Table 1).

Design & Procedures

A confidential web-based survey was developed using the Qualtrics survey platform (Provo, UT). The survey included sections on demographics, pickleball-related overuse injuries, and pickleball playing variables such as level of play and playing volume. A draft of the survey was trialed by 10 individuals familiar with the sport of pickleball and revised for content, clarity, and brevity. The final survey link was distributed to a convenience sample of recreational pickleball players at indoor and outdoor pickleball facilities. The survey could be completed via computer, tablet, or mobile phone. The survey remained open for three months. Inclusion criteria were voluntary participation, age at least 18 years, signed informed consent, and current participation in the sport of pickleball. Participants were informed of the purpose of the study and were not required to answer every question. The study was approved by the Institutional Review Board of the University of Tennessee at Chattanooga.

Table 1
Participant age range

Age	Female	Male
18-24	11	9
25-29	9	10
30-34	2	6
40-44	1	6
45-49	6	1
50-54	10	2
55-59	8	4
60-64	11	3
65-69	8	5
70-74	2	2
75-79	1	7
80-84	1	1
85-89	0	2

Analysis

Deidentified survey results were imported into SPSS version 29.0 and scanned for duplicate responses. Unanswered questions were coded as missing and not included in data analysis. For overuse injuries, frequency data was reported. A Chi-squared analysis with an a = 0.05 was used to determine associations between both overuse injuries and elbow overuse injuries and the following variables: sex, age, court type, warm-up, volume of play, level of play, years of participation, and tournament play. Effect sizes for significant associations were calculated using phi. For this study, the interpretation of phi with one degree of freedom was as follows: 0 = no relationship; .10 = negligible effect; .20 small effect, .30 medium effect; and .50 large effect. (Kim, 2017) A power analysis using G*Power for a chi-square with 1 degree of freedom and 128 participants to be 94.5%.

RESULTS

128 participants, with ages ranging from 18 to 85 years, completed the survey. Of these, 36 participants (28.1%) reported sustaining at least one overuse injury, with some reporting an overuse injury in more than one body region (Figure 1). Most participants did not seek formal medical interventions for their overuse injuries (Figure 2) and reported no playing time loss due to their pickleball-related overuse injuries (Figure 3).

Overuse Injuries

Overuse injuries were significantly associated with volume of play, level of play, and tournament play (Table 2). Participants who played pickleball more than 6 hours per week reported significantly more overuse injuries than those who played for lower volumes, c^2 (df, N= 1) = 5.265, p = .022, with a small effect (phi = .221). Reported pickleball-related overuse injuries were significantly greater among lower-level players than more advanced players, c2 (df, N= 1) = 1.089, p <.001, with a medium effect (phi = .320). Participants who played in pickleball tournaments reported significantly more overuse injuries than those who did not play in tournaments, c2 (df, N= 1) = 9.041, p = .003, with a small to medium effect (phi = .289). Reporting an overuse injury was not significantly associated with sex and age (less than 55 years of age versus at least 55 years of age). The cut point for age was chosen both because this corresponded to the median participant age group level and many individuals begin to retire or reduce their work hours near 55 years of age, thereby allowing them more time to explore recreational activities such as pickleball more consistently. Reporting an overuse injury was also not significantly associated with court type (indoor versus outdoor), warm-up performance (warm-up versus no warm-up), or years of participation in pickleball (playing for two years or less versus playing more than two years).

Epicondylalgia

The elbow was the most common site for pickleball-related overuse injuries, accounting for 25% of all overuse injuries. Lateral epicondylalgia accounted for 63% of all elbow overuse injuries (and 16% of all overuse injuries), while medial epicondylalgia accounted for 38% of all elbow overuse injuries (and 9% of all overuse injuries). Lateral epicondylalgia was significantly associated with sex and tournament play but not to any other variable (Table 3). Females were more likely to have lateral epicondylalgia than males, χ^2 (df, N= 1) = 5.713, p = .017, with a medium to large effect (phi = .398). Participants who played in pickleball tournaments were more likely to have lateral epicondylalgia than those who did not play in tournaments, χ^2 (df, N= 1) = 4.092, p = .043, with a medium to large effect (phi = .337). In contrast, medial epicondylalgia was not significantly associated with any variable (Table 4).

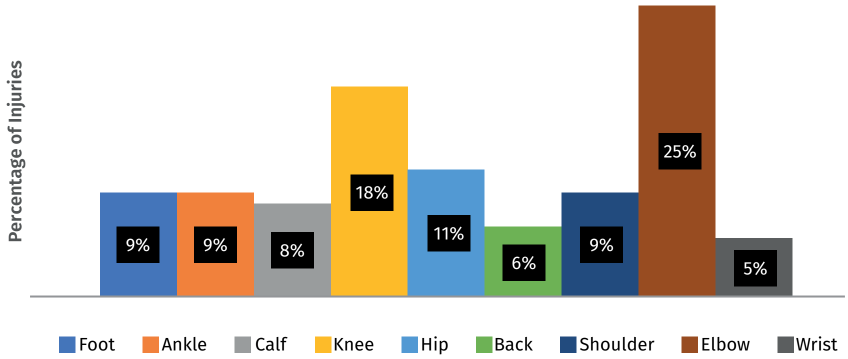

Figure 1. Body regions affected by overuse injuries in pickleball players

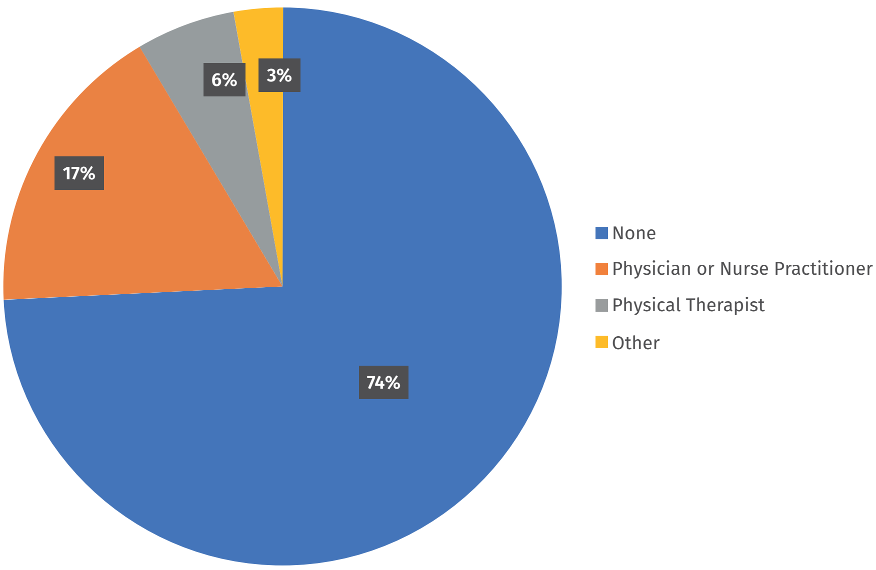

Figure 2. Medical professionals seen for pickleball overuse injuries

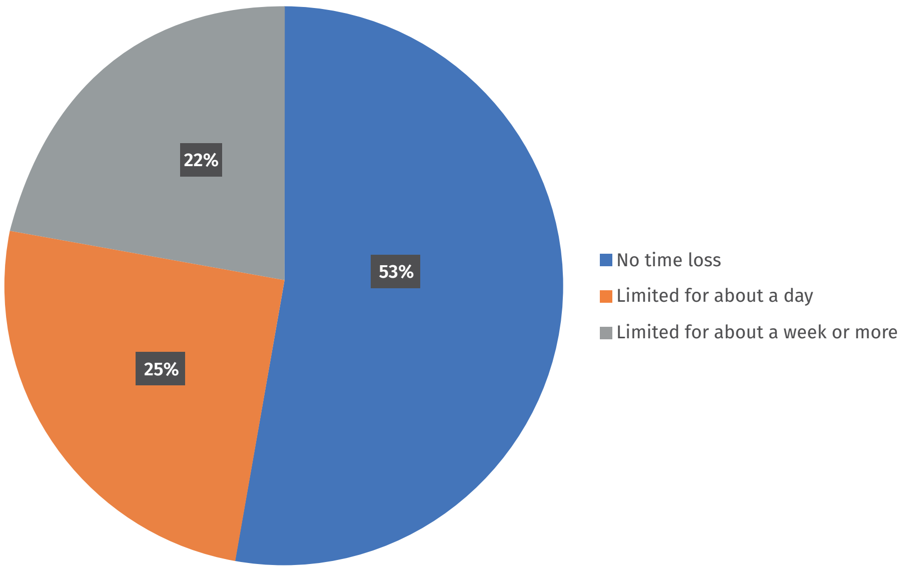

Figure 3. Playing time loss due to overuse injuries

Table 2
Relationship between pickleball and overuse injuries

	Pearson Chi-Square (Degrees of freedom = 1)	*p*
Sex	.023	.880
Age	1.812	.178
Court type	.040	.842
Warm-up	.555	.456
Volume of play	**5.265**	**.022**
Level of play	**11.089**	**<.001**
Years of participation	1.686	.194
Tournament play	**9.041**	**.003**

Table 3
Relationship between pickleball and lateral epicondylalgia

	Pearson Chi-Square (Degrees of freedom = 1)	p
Sex	**5.713**	**.017**
Age	.000	1.000
Court type	1.517	.218
Warm-up	2.757	.097
Volume of play	1.731	.188
Level of play	.224	.636
Years of participation	1.662	.197
Tournament play	**4.092**	**.043**

Table 4
Relationship between pickleball and medial epicondylalgia

	Pearson Chi-Square (Degrees of freedom = 1)	p
Sex	.206	.650
Age	.000	1.000
Court type	.400	.868
Warm-up	1.283	.257
Volume of play	.900	.343
Level of play	.024	.877
Years of participation	.267	.606
Tournament play	.024	.877

DISCUSSION

Racket sports are associated with improved aerobic fitness, optimal body mass index, good bone health, healthy lipid profile, and decreased risk of cardiovascular morbidity and mortality. (Pluim et al., 2007) However, overuse injuries are common in racket sports. In this study, over 25% of recreational pickleball players reported an overuse injury, which is similar to overuse injuries reported among tennis players. (Fu et al., 2018) Overuse shoulder injuries are frequently reported in tennis players (Abrams et al., 2012) and in badminton. (Marchena-Rodriguez et al., 2020) In this study, only 9% of overuse injuries in pickleball players involved the shoulder region. Shoulder overuse injuries in pickleball players may be less frequent because the underhanded serve in pickleball is less stressful to the shoulder complex than the overhead serve in tennis.

Epicondylalgia was the most common overuse injury in pickleball players. In this study, epicondylalgia accounted for 25% of overuse injuries in pickleball players, which is similar to the 30% reported in paddle players. (Castillo-Lozano, 2017) This study's findings that 16% of overuse injuries were due to lateral epicondylalgia are also consistent with the rate of lateral epicondylalgia found in badminton players. (Fahlström & Zeisig, 2022; Rangasamy et al., 2022) In contrast, up to half of tennis players may have epicondylalgia. (Ahmed et al., 2023) The lower rate of epicondylalgia in pickleball players is not surprising because the lighter and shorter pickleball paddle and less heavy ball should result in reduced elbow torque during play.

About a quarter of pickleball players reduced their playing volume for a week or longer due to an overuse injury. While the majority of pickleball players were able to "play through" their injuries and did not seek assistance from a medical professional, it is unclear if these injuries affected how they played, such as how hard they tried to hit the ball, their choice of shots, or their ability to return a hard shot. Given the success rates of physical therapy (Day et al., 2021; Landesa-Piñeiro & Leirós-Rodríguez, 2022; Shahabi et al., 2020) including exercise, (Chen & Baker, 2021; Ortega-Castillo & Medina-Porqueres, 2016) manual therapy, (Girgis & Duarte, 2020) and dry needling on lateral epicondylalgia, (Lucado et al., 2022) it might be wise for pickleball associations to educate their constituency about common overuse pickleball-related injuries and encourage assessment by a medical professional to minimize time loss from play and maximize performance during play.

In this study, sex was strongly associated with lateral epicondylalgia, with females significantly more likely to report lateral epicondylalgia. In contrast, studies on tennis players (Abrams et al., 2012; Fahlström & Zeisig, 2022) found similar injury rates for males and females, while in badminton, males were more likely to have lateral epicondylalgia than females. (Rangasamy et al., 2022) Given these inconsistencies across sports, larger studies are warranted to determine the relationship between sex and epicondylalgia. The prevalence of lateral epicondylalgia in tennis players appears to increase with age, (Kamien, 1988; Pluim et al., 2006) while this study found no such association. It is possible that the lower elbow torque generated during pickleball is dissipated more readily among players of all ages.

Years of participation in pickleball was not related to overuse injuries nor epicondylalgia. Newer players may have had prior experience playing tennis and decided to try this new fad sport due to the relatively lower physical demands of pickleball, including a smaller court, propensity for doubles play, lighter equipment, and no overhead serve. For newer players such as these, their familiarity with common strokes and changes of direction may have been protective of overuse injuries related to pickleball. A study of lateral epicondylalgia among tennis players found no association between years of play and symptom onset and a lower rate of symptom recurrence among those who had played the longest. (Gruchow & Pelletier, 1979) Proper stroke mechanics among tennis players have been associated with a lower occurrence of lateral epicondylalgia. (De Smedt et al., 2007) It is possible that newer pickleball players participated in other activities such as weight training, jogging, walking, or swimming and, thus, were as prepared for the physical demands of pickleball as those who have been playing longer.

This study found no association between level of play and epicondylalgia. In tennis, amateur/ recreational players were more likely to have lateral epicondylalgia (Gabriel et al., 2021; Patel et al., 2021) while professional players were more likely to have medial epicondylalgia. (Chung & Lark, 2017) The lack of professional pickleball players in this study may explain this finding. Since many recreational players do not know their skill level (2.0-5.0), this study compared lower-level players (those who can hit the ball in play for several hits) with more advanced players (those who consistently hit the ball in, hit third shot drops, and play with strategy). This method of describing pickleball player abilities may have insufficiently distinguished between levels of play. However, it is also possible the mechanics of pickleball, e.g. no overhead serve (Dines et al., 2015) and lower torque, makes epicondylalgia less common among pickleball players than tennis players.

Tournament play was related to both overuse injuries and lateral epicondylalgia. One assumption might be that those participating in pickleball tournaments simply play more pickleball, increasing their risk of injury. Similar to tennis players, (Jayanthi & Esser, 2013; Lucado et al., 2020) a higher volume of play was related to a higher rate of pickleball-related overuse injuries. Interestingly, as with tennis, (Lucado et al., 2020) playing volume did not appear to be related to lateral epicondylalgia in pickleball players. Most pickleball tournaments require players to compete in multiple games in one day. Therefore, tournament play, especially if performed infrequently, may increase the risk of these overuse injuries due to the sudden increase in playing volume over a short period of time. Since poor technique is related to epicondylalgia in tennis players, (Ahmed et al., 2023) epicondylalgia in pickleball players may result from the combination of high playing volume with poor technique.

Performance of a warm-up prior to play was not protective of either an overuse injury or epicondylalgia. While these findings are consistent with a recent systematic review, (McCrary et al., 2015) they are in contrast with commonly recommended injury prevention strategies as well as a survey of recreational badminton players in which a lack of warm-up was associated with increased injury risk. (Rangasamy et al., 2022) Court type was also not related to overuse injuries in pickleball. Outdoor pickleball courts are made from concrete or asphalt making them hard and with little shock absorption. Pickleball-specific indoor courts are made of a concrete or asphalt base with a layer of acrylic on top for cushioning, but many indoor pickleball courts are created in spaces designed for other sports. For examples, indoor pickleball may be played on converted basketball courts made of wood or indoor courts may simply be painted on existing concrete surfaces. In tennis, it is believed that the increased pace of play, higher coefficient of friction, and lack of shock absorption found in hard courts result in higher injury rates for professional players. (Fu et al., 2018) However, similar to this study's findings, playing surface was not related to injury in recreational tennis players. (Fu et al., 2018)

This study found no association between medial epicondylalgia and any variable. In tennis, medial epicondylalgia appears to be related to valgus stress at the elbow. (Hartnett et al., 2022) Valgus stress in tennis is greatest during the overhead serve, (Bahamonde, 2005) when hitting an open-stance forehand, or if players use poor form, such as contacting the ball too close to the body. (Patel et al., 2021) Therefore, the rules of the game (i.e. lack of overhead serve) and the equipment used (i.e. shorter and lighter weight paddle) may render medial epicondylalgia less common than in tennis.

Limitations to this study exist. First, survey data is at risk for recall bias and, to a certain extent, on participants' interpretation of the definition of an injury. Second, it is possible that there are interactions between age, sex, and playing variables that cannot be determined without a significantly larger study population. Third, because the survey addressed playing volume, it is not possible to determine the effect of prolonged play time (more than 2 hours) with extremely low play frequency (less than weekly) on overuse injury. As noted previously, the survey did not address if participants were new to exercise or simply new to pickleball. It is also unknown if participants had significantly changed their workout routine (Ahmed et al., 2023) or used suboptimal equipment (Ahmed et al., 2023; Hennig, 2007; Rossi et al., 2014) (e.g. running shoes rather than court shoes or improperly sized grip) which are known to be associated with overuse injuries and epicondylalgia. Last, it was not possible in this study to examine the potential influence of poor mechanics or the use of spin on overuse injuries in pickleball players.

CONCLUSION

Overuse injuries affect up to a quarter of all pickleball players, yet most players did not seek medical attention. Overuse injuries were significantly associated with higher play volume, lower level of play, and participating in pickleball tournaments. Controlling playing volume may be a modifiable risk factor to prevent overuse injuries, particularly for players new to the sport. Epicondylalgia was the most common overuse injury amongst recreational pickleball players. Females and those who participated in pickleball tournaments were more likely to report a history of lateral epicondylalgia.

While epicondylalgia was not a time loss injury, the effect on pickleball player's playing abilities is unknown. Pickleball associations and players should be educated on common overuse injuries and the benefits of interventions, such as exercise and technique training, to maximize symptom-free participation in the sport of pickleball.

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The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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A Narrative Review - Exploring the Influence of the Menstrual Cycle on Badminton Performance and ACL injury occurrence

Revisión narrativa – Exploración de la influencia del ciclo menstrual en el rendimiento en el bádminton y la aparición de lesiones del LCA

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Abstract

To date, there exists a notable gap in research specifically exploring the influence of the menstrual cycle on female badminton athletes' performance during trainings and competitions. Existing scientific literature on the relationship between the menstrual cycle and sports performance, found through platforms like PubMed, Google Scholar among others, primarily draws insights from studies conducted in other sports such as handball, rugby, football, volleyball or athletics. The literature review for this study included fifteen articles, two of which were systematic reviews. The selected studies focused on healthy eumenorrheic female athletes, aged 17 to 30 years, who were not using contraceptive pills and were competed to at least in a national level. However, due to the natural diversity among women, and the multifactorial environment that influences the human being, reassuring that a certain type of training must be followed on a determined menstrual cycle's phase or that a certain injury does occur primarily in a certain period of the cycle, remain unclear. Nevertheless, what it is evident is that numerous hormonals and physiological changes occur through the cycle, and that these changes might have an impact on the female athlete's performance. Exploring this area through dedicated research and understanding these nuances can facilitate tailored training approaches to enhance performance and mitigate any associated challenges. Hence, normalizing discussions around the menstrual cycle and gaining familiarity with it, will play a role not only on the athlete performance but also on their well-being.

Keywords: *badminton, menstrual cycle, awareness, ACL, strength training.*

Resumen

Hasta la fecha, existe un vacío notable en la investigación que explora específicamente la influencia del ciclo menstrual en el rendimiento de las atletas de bádminton durante los entrenamientos y las competiciones. La literatura científica existente sobre la relación entre el ciclo menstrual y el rendimiento deportivo encontrada a través de plataformas como PubMed, Google Scholar, entre otras, se nutre principalmente de estudios realizados en otros deportes como balonmano, rugby, fútbol, voleibol o atletismo. La revisión bibliográfica para este estudio incluyó quince artículos, dos de los cuales son revisiones sistemáticas. Los estudios seleccionados se centraron en atletas mujeres eumenorreicas sanas de entre 17 y 30 años que no utilizaban pastillas anticonceptivas y que competían al menos a nivel nacional. Sin embargo, debido a la diversidad natural entre las mujeres y al entorno multifactorial que influye en el ser humano, asegurar que un determinado tipo de entrenamiento debe seguirse en una determinada fase del ciclo menstrual o que una determinada lesión se produce principalmente en un determinado periodo del ciclo, sigue siendo incierto. No obstante, lo que es evidente es que a lo largo del ciclo se producen numerosos cambios hormonales y fisiológicos que pueden repercutir en el rendimiento de las atletas. Explorar este ámbito mediante una investigación específica y comprender estos matices

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puede facilitar enfoques de entrenamiento adaptados para mejorar el rendimiento y mitigar cualquier dificultad asociada. Por lo tanto, normalizar los debates en torno al ciclo menstrual y familiarizarse con él no solo influirá en el rendimiento de las deportistas sino también en su bienestar.

Palabras clave: *bádminton, ciclo menstrual, concienciación, LCA, entrenamiento de fuerza.*

INTRODUCTION

Despite increasing research into the menstrual cycle (MC) and female performance over the years, it remains unclear whether there is an optimal phase in the cycle for performance (Meignié et al., 2019; Julian et al., 2017). However, it is evident that women experience continuous variations in serum concentrations of several female sex steroid hormones throughout the cycle (Anckaert et al., 2021). These fluctuations in the MC, along with associated physical and psychological symptoms such as dysmenorrhea, flooding, reduced energy levels, worry, distraction, fluctuating emotions, and reduced motivation, can often have a negative impact on daily life and activities, including work, school, or physical performance (Findlay et al., 2020).

In addition, badminton stands out as one of the sports with a heightened risk of ACL injuries, particularly among female athletes (Hu et al., 2023). While literature exists on common movements predisposing athletes to ACL injuries in badminton, the potential correlation with the menstrual cycle phase remains largely unexplored. Understanding the MC's functioning and extrapolating it into the characteristics and physiology of badminton, could prompt discussions and potentially introduce new opportunities to optimize athletes' performance and reduce injury risk.

Menstrual Cycle functioning

Throughout the menstrual cycle, all women experience consistent fluctuations in the levels of various female hormones in their bloodstream. These fluctuations, primarily involving estrogens, progesterone, follicle stimulating hormone (FSH), and luteinizing hormone (LH), play a crucial role in regulating the ovulatory cycle's patterns. They lead to two principal phases: the follicular phase and the luteal phase, with a brief ovulation period (and potentially considered as a third phase) between them. The follicular phase typically comprises the early follicular phase (EFP), characterized by low estrogens and progesterone levels and where the menses take place, and the late follicular phase (LFP), marked by a peak in estrogens alongside low progesterone levels, culminating in a surge of luteinizing hormone just before the ovulation. The luteal phase commences after luteinizing hormone levels return to baseline and is defined by elevated levels of both estrogens and progesterone (being the last one significantly higher). Peak concentrations of these hormones usually occur during the mid-term of the luteal phase (MLP) (Romero-Moraleda et al., 2019) (figure 1). In the mentioned figure, the hormonal fluctuations of estrogens and progesterone during the menstrual cycle and the different phases that encompasses it has been displayed:

Although the primary function of estrogens and progesterone is to support reproduction, research has demonstrated that the fluctuating concentrations of these hormones across the MC also exert diverse and complex effects on various physiological systems, including cardiovascular, respiratory, metabolic, and neuromuscular parameters. These hormonal variations can significantly impact exercise performance, with reductions observed during the early follicular phase of the MC compared to other phases (McNulty et al., 2020). Additionally, physical symptoms, mood disturbances, and decreased motivation to train have been reported during this phase as well (Brown et al., 2021). According to Findlay et al. (2020), in her research regarding how the menstrual cycle and menstruation affect sporting performance in elite female rugby players, the 93% of the athletes reported having menstrual cycle-related symptoms such as dysmenorrhoea, flooding, reduced energy levels, worry, distraction, fluctuating emotions or reduced motivation. Thirty-three per cent perceived heavy menstrual bleeding and 67% considered these symptoms clearly impaired their performances.

Studies show that estrogens induce anabolic, and muscle building processes in females, and its impact is not necessarily shown by increased muscle but instead, by enabling muscle fibers to generate greater force (Lowe et al., 2010). Additionally, estrogens have been shown to have antioxidant and membrane stabiliser properties, which might offer protection against exercise-induced muscle damage and reduce inflammatory responses (Mihm et al, 2011).

On the other hand, progesterone has the complete opposite effect. As such, progesterone has been associated with protein catabolism, possibly attenuating muscle strength (Oosthuyse and Bosch, 2010). Furthermore, it causes a slight increase in basal body temperature, which can be tracked as an indicator of ovulation. This factor might as well affect athletes' endurance and thermoregulation.

The decrease of both oestrogens and progesterone (see figure 1 from days 1-5) causes the endometrium to shed, resulting in the menstruation.

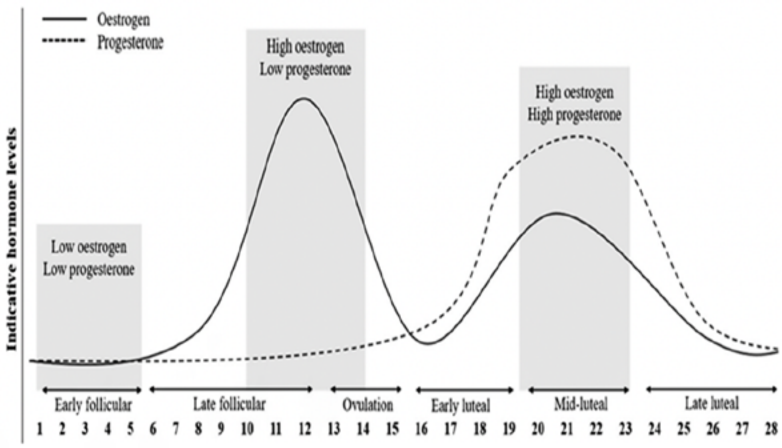

Figure 1. Schematic displaying the hormonal fluctuations across an idealized 28-day MC, with ovulation occurring on day 14 (adapted from Pitchers and Elliott-Sale and extracted from Mcnulty et al, 2020).

METHODS

The literature review for this study included fifteen articles, two of which were systematic reviews. The selected studies focused on healthy eumenorrheic female athletes, aged 17 to 30 years, who were not using contraceptive pills.

Due to the lack of research specifically related to the menstrual cycle and badminton, studies from other sports such as soccer, handball, volleyball, and rugby were reviewed. The findings from these sports were extrapolated to badminton to draw relevant conclusions.

The female athletes profiled in these studies were between 17 and 30 years old and competed at least at a national level. Additionally, three articles specifically related to badminton were included to better understand gender differences in neuromuscular control during the preparation phase of single-leg landing and the associated risk of ACL injury.

RESULTS AND DISCUSSIONS

Strength training & menstrual cycle in badminton

The purpose of this section is to enhance comprehension of the menstrual cycle in female athletes, with a specific focus on female badminton players, and provide with some guidance that could be taken into consideration in female badminton players' routines to optimize their strengthen conditioning.

There is a clear lack of evidence-based recommendations on individualizing strength training according to the menstrual cycle in female badminton athletes.

Nevertheless, it is well established that strength training is a crucial component of performance for badminton athletes, both male and female. It builds muscular strength and endurance, reducing the risk of injuries by stabilizing joints and supporting connective tissues during explosive movements, quick changes in direction, and repetitive motions. Strength training also enhances muscle power and explosiveness, enabling badminton athletes to generate more force in strokes and movements such as smashing, jumping, or lunging. Improved speed and agility are essential for reacting quickly to opponents' shots and maintaining optimal positioning during rallies. Additionally, strength training improves muscular endurance, delaying fatigue onset and enabling sustained performance throughout matches and training sessions. It also contributes to factors such as balance and stability, muscle imbalance correction, and psychological benefits.

For female badminton athletes, optimizing strength training can add value to training and competition, not only for high-performance and elite players but also for younger categories such as junior players. Understanding the physiological changes in their bodies and how they manifest can help players and coaches optimize their training sessions.

While recent research remains unclear regarding whether one menstrual cycle phase offers better strength improvement than another (follicular phase vs. luteal phase), clear physiological patterns play a key role and should be taken into consideration when planning a female badminton player program.

Physiologically, estrogen levels rise during the late follicular and ovulatory phases and remain elevated in the mid-luteal phase. Estrogens induce anabolic and muscle-building processes in females, enabling muscle fibers to generate greater force (Lowe et al., 2010). Additionally, free testosterone levels increase in the late follicular phase, which may be related to increased muscle diameter (Sung et al., 2014). Furthermore, during the late follicular and ovulatory phases, estrogens concentration is not affected by the rise in progesterone concentration, unlike the mid-luteal phase where both hormones remain high, potentially impacting estrogen's anabolic effect negatively due to the catabolic influence of progesterone (McNulty et al., 2020).

Considering these physiological responses, and taking into consideration how the catabolic effect of progesterone can notably influence the estrogens' role, it could be beneficial to emphasize strength training during the late follicular and ovulatory phases of the menstrual cycle where the estrogens are acting at their highest peak without being influenced. On the contrary, it would make sense to reduce it at the beginning of the follicular phase, just when menses occur and where there is a significant drop in oestrogen and progesterone levels, which could unleash to flooding, reduced energy levels, worry, distraction, fluctuating emotions, and reduced motivation (Findlay et al., 2020). In addition, during the late luteal phase and despite the estrogen's levels being still high, the effect of progesterone prevails, which might as well reduce the ultimate outcome. Nevertheless, it is important to always bear in mind that a female badminton athlete's performance is multifactorial, influenced not only by the menstrual cycle and its hormones, but also by factors such as sleep quality, personal life, nutrition, lifestyle, previous injuries, training loads, stress, among many other factors. Consequently, it is recommended to adopt a personalized approach based on each female badminton athlete's response to exercise performance across the menstrual cycle, as everyone can have a different response depending on the environment and circumstances that are being faced at a particular time.

Risk of ACL injury in female badminton players and menstrual cycle

The aim of this section is to explain the relationship between hormonal fluctuations in the MC and anterior cruciate ligament (ACL) injuries in badminton players. Additionally, it aims to identify the phase of the menstrual cycle during which women may be more susceptible to sustaining such injuries.

In general, women are estimated to be approximately five times more prone to ACL injuries than men when engaging in comparable levels of exercise. In badminton, one common scenario leading to such injuries is the execution of a single-leg landing task following a backcourt backhand side overhead stroke (Zang et al., 2023). According to Kaldau et al. (2024), data from the Danish National Patient Register, covering patients in Denmark from 2000 to 2018 with a diagnosis of ACL rupture who identified badminton as their primary sport, were analyzed for return to sport (RTS) and return to performance (RTP) after ACL injury. Out of these patients, 396 (63%) returned to playing badminton, but only 117 (19%) regained their pre-injury performance level. Additionally, both RTS and RTP rates were higher in male compared to female badminton players, highlighting the importance of continued investigation into this matter.

Several relevant factors contribute to the origin of ACL injuries, including musculoskeletal and neuromuscular differences. Zang et al. (2023) found that female athletes exhibit significantly lower absolute and normalized leg stiffness, as well as knee stiffness during landing, compared to male athletes. This suggests that female athletes may be more susceptible to non-contact ACL injuries during landing motion due to lower leg dynamic stability and higher knee hypermobility.

Another contributing factor is weak gluteal strength, which predisposes individuals to hip muscle fatigue and subsequent knee instability (Hu et al., 2023). Moreover, Anne Benjaminse et al. highlighted the significant effect of fatigue on ACL injury risk during exercise. This underscores the importance of addressing muscle fatigue, particularly in the gluteal muscles, to mitigate ACL injury risk in female badminton players. Injuries in badminton players, including ACL injuries, are influenced by a variety of factors such as biomechanical, anatomical, environmental, and hormonal aspects.

One hormonal factor that might as well impact the predisposition to ACL injury is the hormonal fluctuations during the menstrual cycle. Although the precise relationship between the menstrual cycle, fluctuation of female sex hormones, and subsequent injuries still remains to be clarified, there are correlations associated with physiological variations resulting from increased estradiol levels. These variations include joint and ligament laxity, reduced strength, and impaired neuromuscular control (Martinez-Fortuny et al., 2023; Khowailed et al., 2015), which are correlated with an increase of injury.

A systematic review of 408 athletes revealed an increased incidence of non-contact ACL injuries during the preovulatory (first half) phase of the menstrual cycle, occurring between the menses (1-5 days) and the ovulation (6-15 days).

The ovulation phase corresponds to the period of highest estradiol levels. However, this factor does not necessarily coincide with the peak risk of injury (Hewett et al., 2007).

In badminton, where injury risk is multifactorial and individual, it is imperative for players and coaches to recognize the physiological variations associated with the menstrual cycle that may affect their neuromuscular control and being able to identify them (in some of the cases), as well as communicate them. Awareness of these factors enables coaches to tailor physical preparation programs, on and off court, to mitigate the incidence of ACL injuries.

By acknowledging the unpredictable nature of badminton and being aware of the phases where the release of certain hormones such as relaxin and estradiol occurs, the coaches and athletes may find it beneficial, (as long as the athlete's time and schedule allow it) an approach that involves reducing the unpredictability of on-court exercises, to minimize the risk of injury caused by increased joint and ligament laxity combined with impaired neuromuscular control together with a major focus on strength conditioning during the preovulatory phase, and most particularly during the late follicular phase when estrogen levels peak, could be beneficial too.

Emphasizing strength training during this time could be an optimal period to incorporate specialized exercises to reduce the ACL injury risk. Current research suggests that programs including isokinetic strength exercises for knee flexor and extensor muscles might help badminton players with movement control. Furthermore, strengthening the hip and gluteal muscles is crucial, as this can improve knee stability (Hu et al., 2023) and maintain dynamic valgus control (Pournasiri et al., 2023).

By implementing certain adaptations in the athlete's sessions, coaches could potentially mitigate ACL injury risks and optimize performance, recognizing the physiological nuances that might impact female athlete's well-being and performance.

CONCLUSION

The relationship between the menstrual cycle and sports performance, particularly in badminton, remains largely unexplored. While some findings in strength training and injury predisposition have provided valuable insights, they do not offer a comprehensive understanding of this complex interaction.

Both coaches and athletes often lack awareness in this area. Understanding the menstrual cycle extends beyond recognizing hormonal changes and physiological aspects; it involves comprehending the entire process, normalizing the associated symptoms, and acknowledging their impact on athletes throughout their careers.

Raising awareness about the menstrual cycle should begin early in player development, rather than being confined to elite levels. Initiating research on the menstrual cycle and badminton performance could reveal critical physiological patterns, equipping players and coaches with a solid foundation of knowledge that could eventually enhance performance and well-being.

Even in the absence of extensive research, coaches should strive to understand their female athletes' menstrual cycles better. Encouraging open discussions and utilizing questionnaires to gather data on cycle length, blood flow intensity, and symptoms (such as cramps, headaches, mood swings, and concentration issues) can provide valuable insights. Understanding how these factors affect athletes both physically and emotionally will enable more effective adaptation and support.

Additionally, tracking fatigue levels on a Borg scale can help coaches and players identify patterns and make informed decisions when organizing and adapting training plans.

This proactive approach can significantly enhance player-coach communication, leading to better stress management and overall health.

By openly discussing menstrual health, athletes and coaches can identify optimal training times, anticipate and manage symptoms, and adjust workloads to prevent overtraining or injuries. This strategy not only reduces stress but also enhances performance monitoring. Additionally, it promotes a supportive and empathetic environment, encouraging athletes to prioritize their well-being and long-term career sustainability.

In the absence of menstrual cycle research and badminton, here are some potential key areas to consider as a starting point in this still unknow field:

- How changes in estrogen and progesterone levels during the menstrual cycle affect physical performance, endurance, muscle strength and recovery.
- Whether different phases of the menstrual cycle might affect reaction time, coordination, and precision in badminton-specific skills such as service, smash or footwork.
- Assess how mood swings, anxiety, and motivation levels fluctuate during the menstrual cycle and how these changes impact training intensity, competition performance, concentration and/or decision-making.
- Explore whether nutritional requirements change during the menstrual cycle and how athletes can optimize their diet to maintain peak performance and recovery.

By exploring these areas, valuable insights could be obtained that may help female badminton players optimize their training and performance throughout their menstrual cycle.

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