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Editorial

Articles

Editorial

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Gratitude is extended to David Cabello and Adrian Lees for the invitation to contribute to the International Journal of Racket Sport Science, both in the capacity of associate editor and by offering editorial reflections for volume 6.

My recently completed doctoral thesis, titled Effectiveness of using portable technologies for monitoring performance and health indicators in tennis players, reflects my deep interest in and alignment with the journal's focus on racket sports. Therefore, I reiterate my sincere appreciation to the entire editorial team for the opportunity to contribute my knowledge and experience to this Volume 6 of the journal, which is committed to publishing high-quality research in the field of racket sports, including tennis, badminton, and related disciplines. Its primary aim is to consolidate significant advancements and findings that will influence the development and future directions of racket sports science.

Specifically, the first issue of Volume 6 features a total of six articles: four focused on badminton (Sundström et al., Phomsoupha et al., Quirante Mañas et al. and Kumar et al.), one on tennis (Takeda et al.), and another on racket sports in general (Chia-Smith).

Among the articles dedicated to badminton, one examines shoulder pain in comparison with wrestlers, another explores the socio-educational impact and legacy of volunteering during the 2021 Badminton World Cup, the third analyses the deflection of different badminton rackets based on the type of stroke, and the fourth analyses the perceptual training in badminton. The tennis article analyses the relationship between the kinematics of the tennis serve and ball impact sound, post-impact ball speed, and spin. Finally, the last article in this issue analyses how the cumulative impact of mental injury and positive punishment affects junior players across various racket sports disciplines, including tennis, badminton, table tennis, and squash.

Therefore, once again, the International Journal of Racket Sports Science continues to provide research and scientific evidence with a direct impact on the technological and human progress of the key factors influencing performance, health, and context in racket sports.

In conclusion, it is a privilege to be part of such a prestigious publication, and I am honoured to contribute to the ongoing advancement of racket sports science. I look forward to the continued progress of this journal, as it remains a key platform for disseminating specific research with strong practical applications. From the editorial team of the journal, we encourage authors to submit their articles on any topic related to racket sports.

Shoulder pain in badminton players and wrestlers

Dolor de hombro en jugadores de bádminton y luchadores

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Abstract

The purpose of the study was to study painful conditions in the shoulders among badminton players, to describe them and compare with wrestlers. Testing was conducted on 63 badminton players and 56 wrestlers with Constant Score and a shoulder injury questionnaire. Previous or on-going shoulder pain was reported by 29 (46%) of the badminton players - 24 (48%) male and 5 (38%) female and by 30 (54%) of the wrestlers - 20 (63%) male and 10 (42%) female. Three badminton players (5%) had on-going shoulder pain, while eighteen of the wrestlers (32%) had on-going shoulder pain ($p=<0.001$, $φ=-0.36$). More male than female wrestlers had on-going shoulder pain [14 (44%) vs. 4 (17%), ($p=0.032$, $φ=0.29$)]. In badminton players the shoulder pain was located to subacromial structures in the dominant shoulder, while the distribution of shoulder pain in wrestlers was widespread and included both dominant and non-dominant side on various locations. Male wrestlers with on-going shoulder pain had a higher BMI compared to male wrestlers without on-going shoulder pain [25.2±2.6, 25 kg/m² vs. 23±2.3, 23 kg/m² ($p=0.011$, $r=0.44$)], while female wrestlers with ongoing pain had a lower BMI compared to pain-free female wrestlers [19.4±2, 18.9 kg/m² vs. 21.7±2.1, 22.2 kg/m² ($p=0.045$, $r=0.41$)]. The badminton players in this study had a lower prevalence of on-going shoulder pain compared to in previous studies on badminton players. Wrestlers with on-going shoulder pain had lower scores for shoulder mobility in several directions compared to pain-free wrestlers. On-going shoulder pain is likely to affect sports performance and might lead to development of other injuries.

Keywords: *Badminton, wrestling, shoulder, pain, sports, constant score.*

Resumen

El propósito del estudio era analizar las condiciones dolorosas en los hombros entre jugadores de bádminton para describirlas y compararlas con las de los luchadores. Se realizaron pruebas en 63 jugadores de bádminton y 56 luchadores y un cuestionario sobre lesiones de hombro y el puntaje de Constant. Un total de 29 (46 %) jugadores de bádminton, que corresponden a 24 (48 %) hombres y 5 (38 %) mujeres, y 30 (54 %) luchadores, que corresponden a 20 (63 %) hombres y 10 (42 %) mujeres, manifestaron dolor de hombro en el pasado o actualmente. Tres jugadores de bádminton (5 %) tenían dolor de hombro en el momento, mientras que 18 luchadores (32 %) tenían dolor de hombro en el momento ($p=<0,001$, $φ=-0,36$). Había más luchadores que luchadoras con dolor de hombro en el momento; 14 (44 %) vs. 4 (17 %), ($p=0,032$, $φ=0,29$). En los jugadores de bádminton el dolor de hombro se localizaba en las estructuras subacromiales del hombro dominante, mientras que la distribución del dolor de hombro en los luchadores era generalizada e incluía tanto el lado dominante como el no dominante en varios lugares. Los luchadores hombres con dolor de hombro en el momento tenían un IMC más alto en comparación con los luchadores hombres sin dolor de hombro en el momento; 25,2±2,6, 25 kg/m² vs. 23±2,3, 23 kg/m² ($p=0,011$, $r=0,44$). Por otra parte, las luchadoras con dolor en el momento tenían un IMC más bajo en comparación con las luchadoras sin dolor; 19,4±2, 18,9 kg/m² vs. 21,7±2,1, 22,2 kg/m² ($p=0,045$, $r=0,41$). Los jugadores de bádminton de este estudio tenían una menor prevalencia de dolor de hombro en el momento en comparación con estudios anteriores sobre jugadores de bádminton. Los luchadores con dolor de hombro en el momento tenían puntuaciones más bajas en la movilidad del hombro en varias direcciones en comparación con los luchadores sin dolor. Es probable que el dolor de hombro afecte el rendimiento deportivo y pueda provocar la aparición de otras lesiones.

Palabras clave: *bádminton, lucha, hombro, dolor, deportes, puntaje de Constant.*

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Key points

- Previous or on-going shoulder pain was common in badminton players and wrestlers.
- On-going shoulder pain was more frequent in wrestlers.
- Badminton players seemed to mostly have subacromial pain, while shoulder pain in wrestlers was more of a widespread localization.
- Shoulder pain affects sports performance and might lead to development of other injuries and should therefore be well noticed by trainers and physios.

INTRODUCTION

Shoulder pain is common among athletes, both due to direct traumas, such as collisions in contact sports, and due to repetitive movements above shoulder height ("overhead"), that occur in racket sports (Anderson & Alford, 2010; Hulstyn & Fadale, 1997). The risk for an athlete to develop shoulder pain is closely related to the character of the sport and is highest in sports with overhead shoulder loading (Doyscher et al., 2014). Also, in throwing sports, such as baseball, shoulder pain is commonly occurring. During a season, half of young baseball pitchers had experienced shoulder pain (Lyman et al., 2002).

Badminton includes many repetitive overhead motions and previous studies have shown that up to 30% of players on both the highest elite level (Fahlström et al., 2006) and at recreational level (Fahlström & Söderman, 2007) suffer from shoulder pain that affects daily life. Young female elite badminton players have an imbalance in strength and mobility in the shoulder muscles (Couppé et al., 2014), which can contribute to painful subacromial conditions. Under-17 badminton players with a shoulder internal rotation range of motion of 55º or less, were shown to have increased risk of shoulder pain one year later (Cejudo, 2022) A study performed on 62 female overhead athletes on elite level and recreational level among different sports has shown larger acromio-humeral distance in the dominant side than in the non-dominant side. In addition, the elite level athletes had a larger dominant side acromio-humeral distance than the recreational level athletes (Maenhout et al., 2013). A larger acromio-humeral distance in overhead athletes means that the shoulder is less stable and the risk for pathologies in the area due to repeated subluxation is increased (Chambers & Altchek, 2013). It has also been suggested in a recent study on Danish elite badminton players that greater shoulder external rotational strength is strongly associated with an increased acromio-humeral distance. This suggests hypertrophy of the supraspinatus tendon which could lower the risk of injury (Schmidt et al., 2021).

Wrestling is among the oldest sports known to man (Martin & Margherita, 2021), it puts high demands on the shoulders, and wrestlers have a different type of loading on their shoulders compared to athletes with repetitive overhead shoulder loading. The wrestlers´ shoulder is affected by twisting and leverage, as well as falls, with sudden contact with the carpet. Shoulder injuries can occur when a wrestler is trying to escape a hold, which can force the shoulder joint past its normal range of motion (Halloran, 2008). An American study that followed 458 male high school wrestlers, aged 14-19 years, for a season found an incidence of 52 injuries/100 wrestlers/season. The most injured body part was the shoulder (rotator cuff, glenohumeral joint and AC-joint) (24%), followed by the knee (17%). The injured wrestlers were older on average and had been wrestling longer than other wrestlers participating in that study. The most common mechanisms of injury were found to be direct forces or blows (42%) and twisting forces (23%), while only 6% of all injuries were due to overuse or repetitive activity (Pasque & Hewett, 2000). A study comparing the prevalence of shoulder injuries for different sports at high school level found wrestling to have the second highest incidence for shoulder injuries behind American football. Wrestlers had more shoulder injuries than soccer, basketball and volleyball players (Bonza et al., 2009).

In badminton it is known that shoulder pain is common and affects sports performance (Fahlström et al., 2006). Imbalance in shoulder strength and a large acromio-humeral distance seems to be associated with a higher risk to develop shoulder pain in badminton players (Couppé et al., 2014; Chambers & Altchek, 2013). In wrestling fewer studies have been performed with the focus on shoulder pain compared to badminton. The knowledge about what consequences wrestlers suffer from their shoulder pain and how it affects their performance is not extensive. A direct comparison between badminton and wrestling, where the shoulder loading is of different character, has not been made.

The prevalence and the severity of injuries should be studied with the aim to prevent sports injuries (Van Mechelen, 1997). Therefore, comparing two sports with different injury mechanisms to the shoulder; repetitive overhead motion in badminton, and twisting, leverage and other direct forces for the wrestlers' shoulder could result in interesting findings.

The aim of this study was to study painful conditions in the shoulders among badminton players and wrestlers, to describe them and make a comparison between both sports.

MATERIALS AND METHODS

Participants

Testing was offered to badminton players and wrestlers in a local badminton club and a local wrestling club in Sweden, during competitions, training camps and practice sessions. All athletes tested were warmed up and ready to compete. The participants filled in a questionnaire, that has previously been used on badminton players, handball players and flatwater kayakers (Fahlström et al., 2006; Myklebust et al., 2013; Johansson et al., 2016).

Materials and procedures

The questionnaire included questions about basic characteristics, such as age, length, weight and dominant hand, training habits in badminton/wrestling and other shoulder loading activities, such as strength training. There were also questions about prevalence of shoulder pain connected with badminton or wrestling, and questions about the onset and course of pain. The participants registered their shoulder pain on a scale between 0-100 mm (VAS), where 0 mm equals no pain and 100 mm equals maximum pain (Aicher et al., 2012). There were also questions whether the pain affected the practice of sports, activities of daily life and sleep. Those who had sought medical advice for their shoulder pain specified who they consulted (doctor, physiotherapist or other category) and what diagnose and/or what treatment they had received. Those who at some point (previous or present) had suffered from shoulder pain marked the location of their pain in a figure.

Then the shoulder mobility and strength of all participants were tested with Constant Score (Roy et al., 2010), a method usable to assess shoulder function (Constant & Murley, 1987). Constant Score contains a subjective and an objective part. The subjective part gives a maximum of 35 points and the objective part 65 points, which gives a total score of maximum 100 points for a trouble-free shoulder. In the subjective part participants were asked about the level of pain they experienced from the shoulder during daily activities, maximum pain resulted in 0 points and no pain in 15 points. The subjective part also included scoring concerning work ability, restricted leisure activities, disturbed sleep and at what level of elevation it was possible to work without shoulder pain. The objective part of Constant Score consisted of a test of pain free range of motion and muscular strength in the shoulders. Range of motion was tested in four directions: flexion, abduction, internal rotation and external rotation. Flexion and abduction were tested while sitting down and internal- and external rotation while standing up. The results for the mobility tests were translated into scoring points. Full pain-free mobility in one of the directions resulted in 10 points, while restricted or painful mobility resulted in point deduction.

Muscular strength was assessed with an Isobex dynamometer (Medical Device Solutions AG, Burgdorf, Switzerland). The dynamometer was attached to a table while the participant stood up with the torso in basic anatomical position and 90° flexion and 30° horizontal abduction in the shoulder, extended elbow and the back of hand facing upwards. A band between the wrist and the dynamometer was applied and the participant elevated the arm with maximum force for five seconds. The test was performed three times on each shoulder. The mean value of the three attempts was registered and used for calculations. All testing was conducted by two persons who had been trained together in conducting the tests and therefore the tests were performed and judged similarly. Muscular strength was translated from kg to points and each completed 0.5 kg was translated into one point. A maximum score of 25 points could be obtained from the strength test, hence a strength ≥12.5 kg resulted in the maximum number of points.

Ethics

All participants received written and verbal information about the study and provided written consent. The intervention did not put the participants at risk. The study had received ethical approval by the Regional Ethics Board in Umeå, Sweden, Dnr 09-148M.

Statistical analysis

IBM SPSS Statistics 28 was used for all calculations. Mean, median and standard deviation was used for describing the data. Mann-Whitney test was used to calculate differences between groups for continuous variables. Chi-Square test was used for categorical variables. A p-value ≤ 0.05 was considered to be statistically significant. Effect size was calculated for Mann-Whitney test (r) and Chi-Square test (φ).

RESULTS

123 athletes were asked to participate in the study of which 119 (97%) accepted. Sixty-three of the participants (53%) were badminton players (50 male, 13 female) and 56 of the participants (47%) were wrestlers (32 male, 24 female).

Basic characteristics of the participants are shown in Table 1. The male participants were older, had a higher BMI, were stronger and had a higher total Constant Score in both shoulders than the females. Apart from the difference in shoulder strength between male and female, the only difference in strength of same-sex participants was between male badminton players and male wrestlers in the dominant shoulder [15.8±4.4, 16 points vs 17.9±4.9, 18 points (p=0.035, r=0.23)].

Previous or on-going shoulder pain was reported by 29 (46%) of the badminton players - 24 (48%) male and 5 (38%) female and by 30 (54%) of the wrestlers - 20 (63%) male and 10 (42%) female.

Table 1.
Basic characteristics for the 119 participating athletes

Variable	Badminton players (n=63) (mean±SD, median)	Wrestlers (n=56) (mean±SD, median)	p-value*	Effect size (r)
Age (years)	25.7±12.3, 20.0	18.6±6.8, 16.0	<0.001	0.40
Time active in badminton/wrestling (years)	9.0±6.7, 7.0	9.6±5.9, 8.5	0.203	0.12
Badminton/wrestling per week (h)	5.0±2.3, 5.0	5.7±2.1, 5.0	0.070	0.17
Other shoulder training per week (h)	1.3±1.2, 1.0	2.8±2.5, 2.0	<0.001	0.40
Total shoulder training per week (h)	6.3±2.6, 6.0	8.5±3.7, 8.0	<0.001	0.36
Strength dominant shoulder (points)	14.6±4.7, 14.0	15.1±5.4, 15.0	0.584	0.05
Strength non-dominant shoulder (points)	14.3±4.9, 14.0	14.3±5.2, 13.5	0.900	0.01
Total Constant Score dominant side (points)	83.4±8.7, 85.0	84.6±7.8, 84.5	0.604	0.05
Total Constant Score non-dominant side (points)	87.9±6.0, 89.0	83.0±11.3, 86.0	0.005	0.26

* p-value: significant differences for values lower than 0.05.

A comparison of differences between badminton players with previous or on-going pain and other badminton players can be seen in Table 2. There were no differences in shoulder strength or mobility between the two groups of badminton players.

Table 2.
Comparison of significant differences between badminton players with on-going or previous pain and other badminton players

Variable	Badminton players with on-going or previous pain (n=29) (mean±SD, median)	Other badminton players (n=34) (mean±SD, median)	p-value*	Effect size (r)
Age (years)	28.8±13.0, 23.0	23.1±11.1, 18.0	0.046	0.25
Time active in badminton (years)	11.6±7.6, 10.0	6.7±4.9, 5.8	0.004	0.36
Total Constant Score dominant side (points)	78.1±8.6, 78.0	88.0±5.7, 88.0	<0.001	0.56

A comparison of differences between wrestlers with ongoing or previous pain and other wrestlers can be seen in Table 3.

Table 3.
Comparison of significant differences between wrestlers with ongoing or previous pain and other wrestlers

Variable	Wrestlers with ongoing or previous pain (n=30) (mean±SD, median)	Other wrestlers (n=26) (mean±SD, median)	p-value*	Effect size (r)
Age (years)	20.6±8.5, 17.0	16.4±2.6, 15.0	0.007	0.36
Time active in wrestling (years)	11.1±7.1, 10.0	7.8±3.6, 6.5	0.035	0.28
Other shoulder training per week (h)	3.4±2.9, 2.0	2.1±1.9, 1.8	0.005	0.38
Abduction in non-dominant shoulder (points)	9.2±1.6, 10.0	9.9±0.4, 10.0	0.035	0.28
Internal rotation in dominant shoulder (points)	7.8±1.8, 8.0	8.8±1.5, 10.0	0.028	0.29
Internal rotation in non-dominant shoulder (points)	8.3±1.9, 8.0	9.4±1.2, 10.0	0.011	0.34
Total Constant Score dominant side (points)	81.5±8.0, 82.5	88.0±6.0, 89.0	0.002	0.41
Total Constant Score non-dominant side (points)	78.8±13.5, 80.5	87.7±5.5, 87.0	0.003	0.40

* p-value: significant differences for values lower than 0.05.

In badminton players the shoulder pain was located to subacromial structures in the dominant shoulder, while the distribution of shoulder pain in wrestlers was widespread and included both dominant and non-dominant side on various locations, (Figures 1a and 1b).

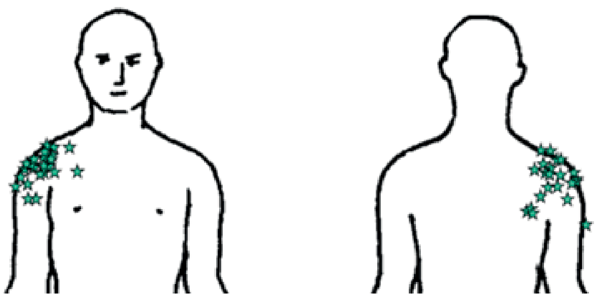

Figure 1a. Localization of pain in 29 badminton players, both with ongoing (n=3) and previous (n=26) shoulder pain.

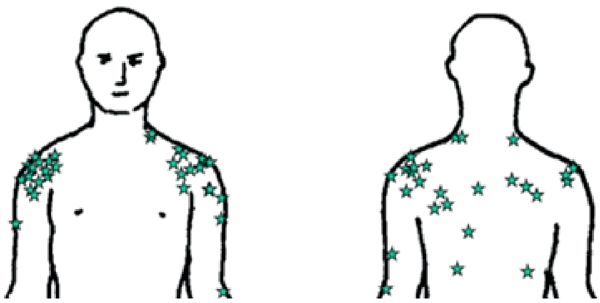

Figure 1b. Localization of pain in 30 wrestlers, both with on-going (n=18) and previous (n=12) shoulder pain.

In Figure 1a and 1b the right side represents dominant side and the left side non-dominant side. Each participant may have marked more than one location for pain.

On-going shoulder pain was more frequent in wrestlers; 18 of the wrestlers (32%) had ongoing shoulder pain, while three badminton players (5%) had ongoing shoulder pain ($p=<0.001$, φ-0.36). Ongoing shoulder pain was registered by 14 (44%) of the male wrestlers, compared to three (6%) of the male badminton players ($p=<0.001$, $\varphi=-0.45$). More male than female wrestlers had ongoing shoulder pain, [14 (44%) vs 4 (17%), ($p=0.032$, $\varphi=0.29$)].

A comparison of differences between male wrestlers with ongoing pain and other male wrestlers can be seen in Table 4. Male wrestlers with ongoing shoulder pain had a higher body mass index compared to male wrestlers without ongoing shoulder pain [25.2±2.6, 25 kg/m^2 vs 23±2.3, 23 kg/m^2 ($p=0.011$, $r=0.44$)]. Similar differences as those presented in Table 4 could be seen comparing female wrestlers with ongoing pain and other female wrestlers, except for body mass index, where female wrestlers with ongoing pain had a lower body mass index compared to pain-free female wrestlers [19.4±2, 18.9 kg/m^2 vs 21.7±2.1, 22.2 kg/m^2 ($p=0.045$, $r=0.41$)].

No significant differences were found between badminton players and wrestlers with ongoing or previous pain regarding type of debut of pain (sudden or gradual). Also, no differences between the sports whether the pain affected competition and training habits were found.

Eight of the male wrestlers with ongoing pain (57%) had experienced a sudden onset of pain, while for female wrestlers none had experienced a sudden onset of pain ($p=0.055$, $\varphi=0.48$). Furthermore, seven (50%) of the male wrestlers with ongoing pain were forced to change their training- or competition habits, while for female wrestlers with ongoing pain there were none ($p=0.070$, $\varphi=0.43$). Four of the male wrestlers with ongoing pain (29%) experienced that their pain affected activities of daily life, while for female wrestlers with ongoing pain, one (25%) experienced affected activities of daily life ($p=0.888$, $\varphi=0.033$). Disturbed sleep due to ongoing pain was experienced by four of the male wrestlers (29%), and by one of the female wrestlers (25%) ($p=0.888$, $\varphi=0.033$). Looking at wrestlers with ongoing pain, eight male wrestlers (57%) had sought medical advice, while no female wrestlers had done so ($p=0.043$, $\varphi=0.48$).

DISCUSSION

The aim of this study was to study painful conditions in the shoulders among badminton players and wrestlers, to describe them and make a comparison between both sports.

Previous or on-going shoulder pain was common in both studied groups of badminton players (46%) and wrestlers (63%), even though more wrestlers than badminton players were found to suffer from on-going shoulder pain. Previous studies performed on competitive and recreational badminton players have shown that shoulder pain is a common problem with about 30% of players suffering from on-going shoulder pain (Fahlström et al., 2006; Fahlström & Söderman, 2007). Surprisingly few badminton players in this study (5%) suffered from on-going shoulder pain. This might be because they were relatively young and did not practice as much as the players in the previous studies. The badminton players' prevalence of shoulder pain in this study is comparable to the prevalence of shoulder pain in 9-12% among people aged 19-44 years old in the normal population (Urwin et al., 1998).

However, the localization of shoulder pain was very similar among the badminton players in this study and those in previous studies (Fahlström et al., 2006; Fahlström & Söderman, 2007), which indicates that the type and mechanism of injury is of a similar character. If this study had been conducted on badminton players who practiced more and competed at a higher level, it is likely that the prevalence of on-going shoulder pain would have been more similar to what has been found in previous studies.

Table 4.
Differences between male wrestlers with ongoing pain and other male wrestlers

Variable	Male wrestlers with ongoing pain (n=14) (mean±SD, median)	Other male wrestlers (n=18) (mean±SD, median)	p-value*	Effect size (r)
Age (years)	24.1±10.8, 19.0	16.9±3.4, 15.5	0.008	0.47
Body Mass Index (score)	25.2±2.6, 25.0	23.0±2.3, 23.0	0.011	0.44
Time active in wrestling (years)	13.6±8.2, 12.5	7.9±4.9, 6.0	0.010	0.45
Internal rotation in non-dominant shoulder (points)	7.3±2.0, 8.0	8.9±1.6, 10.0	0.027	0.41
Total Constant Score non-dominant side (points)	75.3±18.2, 80.5	88.4±7.8, 89.0	0.020	0.41

* p-value: significant differences for values lower than 0.05.

The prevalence of on-going pain was especially high among male wrestlers, where 44% suffered from on-going pain. Despite the on-going pain, the wrestlers were still participating in competitions and training sessions. Wrestling with on-going shoulder pain seems likely to inhibit the performance of the wrestler and may force them to utilize different techniques compared to if they weren't suffering from shoulder pain. This might contribute to the development of other injuries.

The male and female wrestlers in this study perform different styles of wrestling, the male Greco-Roman wrestling and the female Freestyle wrestling. In Greco-Roman wrestling it is only allowed to grapple the opponent from waist and above, while in Freestyle it is also allowed to grapple the opponent's legs. A previous study that compared the injuries of the two wrestling styles during a 2006 US national junior tournament, found that the overall injury rate was higher in Freestyle wrestling (7.0 injuries/1000 athlete-matches) than in Greco-Roman wrestling (4.6 injuries/1000 athlete-matches). Knee injuries were more common in freestyle while elbow and head/face/neck injuries were more common in Greco-Roman wrestling. Shoulder injuries in Greco-Roman wrestlers were found to be caused from being driven into the mat (70%) and by other physical contacts (30%) (Yard & Comstock, 2008).

Looking at the localization of pain, wrestlers had a more widespread localization than badminton players. This difference in localization of pain indicates that the shoulder loading within badminton and wrestling are of different characters, and that different mechanisms are responsible for causing shoulder pain in badminton players and wrestlers. This gives better insight in participants shoulder pain and is a strength of this study.

Male wrestlers with on-going pain had a higher BMI than other male wrestlers, while female wrestlers with on-going pain had a lower BMI than other female wrestlers. Perhaps in Greco-Roman wrestling, having a higher BMI (being relatively heavier) is a factor that increases the load on the shoulders that might result in pain. For the female wrestlers with pain, having a lower BMI might be related to less stabilizing musculature for the shoulder. No female wrestler in this study with on-going pain had experienced a sudden debut of pain, that might indicate that different mechanisms of injury occur in Greco-Roman and Freestyle wrestling.

In this study eight (57%) of the male wrestlers (who performed Greco-Roman wrestling) with on-going shoulder pain had experienced a sudden debut of their pain. Taking this together with the mechanisms of shoulder injuries found earlier by Yard & Comstock (2008) into consideration, it seems likely that many Greco-Roman wrestlers with shoulder pain have a sudden debut of their pain due to direct trauma.

Wrestlers with on-going or previous pain had lower scores in several directions of shoulder mobility compared to other wrestlers. (Table 3). This may be due to them suffering from shoulder pain during the testing (those with ongoing pain), or it may be because they, due to decreased mobility, were more susceptible to acquiring shoulder pain. It is generally not known if it is beneficial for wrestlers regarding shoulder pain and injuries to have a flexible or a more rigid shoulder. One previous study, however, showed that wrestlers with at least one positive test for general ligamentous laxity had only half the number of shoulder injuries compared to the other wrestlers in that study (Pasque & Hewett, 2000). Comparatively, for badminton players it is known that instability in the shoulder and an imbalance in shoulder strength for internal- and external rotation may contribute to painful conditions (Couppé et al., 2014; Chambers & Altchek, 2013; Stausholm et al., 2021).

Wrestlers seemed to suffer from more severe consequences from their shoulder pain compared to badminton players. Male wrestlers also seemed to suffer from more severe consequences of their pain compared to female wrestlers. For wrestling, the different prevalence of pain for male and female wrestlers and its consequences might be related to the difference in wrestling styles by male and female wrestlers.

Although this study was performed on badminton players and wrestlers, similar shoulder problems can be expected in athletes who participate in other types of sports with shoulder loading of similar character.

Constant Score is an established method to assess shoulder function, it can be performed in a short amount of time, which was important in this study, since testing of each athlete was performed in a limited timeframe. The mobility and strength tests are measured in intervals that are translated into points. This does not give an exact measurement but on the other hand it is easier and quicker to conduct the tests.

CONCLUSION

The badminton players in this study had a lower prevalence of shoulder pain compared to in previous studies on badminton players. Many wrestlers in this study were suffering from shoulder pain, especially male wrestlers, of which several had experienced a sudden debut of pain. Wrestling with ongoing shoulder pain is likely to affect sports performance and could lead to development of other injuries. The badminton players had pain located to the subacromial area, while the wrestlers´ shoulder pain was of widespread location, which reflects the different loading between the two sports. The higher prevalence of ongoing shoulder pain in male than in female wrestlers indicates that the risk of injuries to the shoulder is higher in Greco-Roman than Freestyle wrestling.

Injury registration and analysis is valuable to gain more knowledge about injuries in sports with different shoulder loading.

PRACTICAL APPLICATIONS

Even though badminton players in this study practiced relatively few hours per week, shoulder pain was still prevalent. This indicates that specific training to prevent shoulder pain could be of value even in non-elite badminton players with a lower training load. Male wrestlers in this study had a high prevalence of shoulder pain, which may be related to wrestling Greco-Roman style. Injury preventive training focusing on strength and mobility of the shoulders could be useful to prevent shoulder injuries in both sports.

DECLARATIONS

Ethics approval and consent to participate

All participants received written and verbal information about the study and provided written and verbal informed consent. The intervention did not put the participants at risk. All methods were carried out in accordance with the Declaration of Helsinki. The study and all experimental protocols had received ethical approval by the Regional Ethics Board in Umeå, Sweden, Dnr 09-148M.

Consent for publication

Not applicable.

Availability of data and material

Data is available from the corresponding author upon reasonable request.

Competing interests

The authors, Anders Sundström, Conny Tärnklev and Martin Fahlström, declare that they have no competing interests.

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Authors' contributions

AS, CT and MF planned the study. AS and CT collected the data. AS analysed the data. AS wrote the article with support from MF and CT.

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The Influence of Tennis Serve Kinematics on Ball Impact Sound and Post Impact Ball Speed and Spin

Influencia de la cinemática del servicio de tenis en el sonido del impacto de la pelota y en la velocidad y el efecto de la pelota tras el impacto

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Abstract

In this study, we examined the pressure levels of ball impact sounds during serving in tennis. Ten participants were recruited and instructed to serve from the Deuce and Advantage Courts in the Center and Wide directions. The sound pressure levels were measured and analyzed on the receiver side. High-speed cameras, motion capture, and racket excitation experiments were also conducted to assess the spin amount, initial velocity of the ball, and impact position of the racket during service. The results indicated that the ball impact sound during service is influenced by the racket's impact position, initial velocity of the ball, and spin amount of the ball. Furthermore, it was found that when the spin amount of the ball was high, the racket's impact position tended to deviate from the center, leading to a decrease in the ball impact sound. However, there was little difference in the tendencies observed in participants based on handedness or sex. These findings suggest that receivers can improve their accuracy in play by predicting the spin amount and velocity of the ball based on the ball impact sound. Additionally, servers can strive to strike the ball at the center of the racket and maintain the initial velocity of the ball, even when applying spin, to make their serves more difficult for receivers to predict. The p-value in the present experimental results is less than 0.47, and the discussion is based on results with certain significant differences.

Keywords: *tennis, serve, impact sound, ball spin, ball speed, modal analysis, motion capturing.*

Resumen

En este estudio se examinaron los niveles de presión de los sonidos del impacto de la pelota durante el servicio en tenis. Se seleccionaron diez participantes y se les indicó que sirvieran desde las canchas de deuce y advantage en las direcciones abierto y al cuerpo. Se midieron y analizaron los niveles de presión sonora en el lado del receptor. También se realizaron experimentos con cámaras de alta velocidad, captura del movimiento y excitación de la raqueta para evaluar la cantidad de efecto, la velocidad inicial de la pelota y la posición del impacto de la raqueta durante el servicio. Los resultados indicaron que el sonido del impacto de la pelota durante el servicio está influenciado por la posición del impacto de la raqueta, la velocidad inicial de la pelota y la cantidad de efecto de la pelota. Además, se observó que cuando el efecto de la pelota era alto, la posición del impacto de la raqueta tendía a desviarse del centro, lo que provocaba una disminución del sonido del impacto de la pelota. Sin embargo, no hubo grandes diferencias en las tendencias observadas en los participantes en función de su lateralidad o sexo. Estos resultados sugieren que los receptores pueden mejorar su precisión en el juego prediciendo la cantidad de efecto y la velocidad de la pelota basándose en el sonido del impacto. Adicionalmente, los servidores pueden esforzarse por golpear la pelota en el centro de la raqueta y mantener la velocidad inicial de la pelota, incluso cuando aplican efectos, para que sus servicios sean más difíciles de predecir para los receptores. El valor p en los resultados experimentales es inferior a 0,47 y la discusión se basa en resultados con ciertas diferencias significativas.

Palabras clave: *tenis, servicio, sonido de impacto, efecto de la pelota, velocidad de la pelota, análisis modal, captura de movimiento.*

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INTRODUCTION

The study of the sound produced during ball impacts in various ball sports has a lengthy history, with numerous investigations leveraging the modal analysis of vibrations and assessments of auditory impressions. Key contributions to this field include the investigations by Roberts et al (2001, 2006). on golf clubs, research by D. A. Russell (2017) on bats used in baseball and softball, and detailed studies on tennis rackets by G.H. Banwell et al. (2012, 2014). These studies span a range of sports and equipment employed within each domain, marking a robust domain of inquiry. More recent studies have focused intensively on the specific sounds produced in these contexts, with research covering table tennis (Klein et al, 2021), soccer, and volleyball (Sors et al., 2017; Camponogara et al., 2024); the distinctive sounds of golf shots (Roberts et al., 2005) and badminton (Zhu, 2013; Arianto et al., 2017); and further investigations into tennis (Bower & Cross, 2003; Cañal-Bruland et al., 2018). These research efforts have examined the various ways athletes utilize sound information, the psychological benefits of auditory feedback, and the impact of sound on the accuracy and quality of play. Particularly in tennis, studies have shown that the intensity of a racket-ball impact sound can influence players' predictions of ball trajectory, revealing a significant correlation between auditory cues and precision of play (Cañal-Bruland et al., 2018).

In this study, we extend previous research by empirically investigating the relationship between the sounds produced during tennis serves and players' performance accuracy, with a special focus on the sounds emitted during the service. Our initial experiments aimed to identify any correlation between the sound produced at the moment of service and the subsequent direction of the service. We then investigated the reasons for the variations in these sounds depending on the direction of the service. The study involved ten participants, each asked to perform multiple serves directed towards both wide and central court positions, while the resulting sounds were recorded and analyzed from the perspective of the serve's receiver. Further analytical efforts included vibrational testing of the tennis rackets and examination of their modal vibrations and natural frequencies to explore the potential causes of the observed acoustic phenomena. To enhance our understanding of how the direction of the serve influences the resulting sound, we employed high-speed cameras and motion-capture systems to analyze the trajectories of the rackets. This comprehensive approach not only deepens our understanding of acoustic effects in tennis serves but also provides insights into how auditory information can be strategically utilized to enhance athletic performance.

Our study complements and extends the existing research on visual anticipation and auditory information by focusing specifically on the acoustic properties of ball-impact noise during tennis serves. Our findings provide a new perspective on how differences in sound pressure levels influence visual anticipation, and contribute to the development of specific training methods aimed at improving sports performance.

Research on the impact of auditory information on visual anticipation in tennis suggests that the intensity of racket-ball-contact sounds systematically biases the estimation of ball speed, thereby influencing anticipatory judgment. Here, we examined whether the effect of auditory information on visual anticipation is dependent on sport-specific context in two separate experiments. In Experiment 1, participants watched short videos of tennis rallies occluded at the moment of racket-ball contact. The racket-ball contact sounds of the final shot were either present or absent. Participants performed different tasks in two counterbalanced blocks: in one block, they estimated the ball's speed, and in the other block, they indicated the ball's landing location. The results showed that Participants estimated longer ball flight trajectories and higher ball speeds in the sound-present condition than in the sound-absent condition. To probe whether this effect was dependent on sport-specific context, Experiment 2 introduced an abstract (i.e., context-free) version of the previous stimuli. Based on the ball locations in the original videos used in Experiment 1, we rendered new videos that displayed only circular movements against a blank background. The sine tones replaced the original racket-ball contact sounds. The results indicated that sound presence had no impact on location anticipation judgments. However, similar to the results of Experiment 1, the object speed was judged to be higher when the final sound was present. Together, these findings suggest that the impact of auditory information on anticipation does not seem to be driven by sound alone but is moderated by contextual information (Murphy et al., 2016).

The impact of auditory information on visual anticipation has been a subject of significant research. For instance, arguments in favor of context dependency are based on recent research on visual anticipation (e.g., Murphy et al., 2016) and anticipatory gaze behaviors (e.g., Goettker et al., 2021), indicating that contextual information can be used to successfully predict the future location of a ball in tennis or a puck in hockey. Conversely, arguments in favor of context independence stem from research showing that the synchronous presentation of audiovisual stimuli, without any additional context information, may cause an illusory increase in perceived object speed (Meyerhoff et al., 2022), which in turn may account for the reported effects of auditory information on anticipatory judgments in sports (for example, Cañal-Bruland et al., 2018; Müller et al., 2019).

To test competing hypotheses, participants watched tennis rally videos where racket-ball contact sounds were either present or absent (Experiment 1) or context-free videos with only circular movements and sine tones (Experiment 2). The results from Experiment 1 showed that racket-ball contact sounds influenced judgments of ball flight trajectory and speed. In contrast, Experiment 2 showed that sound presence did not affect location anticipation but influenced speed perception. These findings emphasize the role of context in sports anticipation.

Research shows that racket-ball contact sound intensity influences ball speed estimation and anticipation judgments. Two experiments tested the effect of auditory information on visual anticipation. In Experiment 1, the participants estimated longer flight trajectories and higher ball speeds when sound was present. Experiment 2 used context-free videos and showed that sound had no effect on location judgments but did influence speed perception. These findings suggest that the role of sound in anticipation is moderated by the context.

Together, the results of previous studies and our current study provide evidence against the purely context-independent effect of auditory information on location anticipation. Instead, they support a context-dependent effect, aligning with findings on the impact of contextual information on visual anticipation (Murphy et al., 2016; Goettker et al., 2021; Cañal-Bruland et al., 2022). The aim of this study is to investigate how auditory cues during tennis serves influence players' anticipation of ball trajectory and speed, depending on the context. We hypothesize that auditory cues will have a significant effect on speed estimation, but this effect will be moderated by the presence or absence of contextual information. These findings have practical implications for training protocols in sports, emphasizing the importance of multisensory integration and context-specific training in enhancing anticipatory skills.

EXPERIMENTAL SETUP AND PROCEDURE

Participants

The measurements were conducted in the outdoor tennis courts of the university to which the authors belong. A total of ten participants, comprising nine male and one female individuals were included in this study. Participants were selected from the University's students with tennis experience. One male participant was left-handed. Their ages ranged from 20 to 24 years, heights from 160 to 178 cm, weights from 50 to 70 kg, and years of tennis experience from 1 to 10 years. These individuals will be referred to as Participants A through J, with Participant I being left-handed and Participant J being female. The experiments in the study were conducted in accordance with ethical guidelines. Prior to the commencement of the experiment, approval was obtained from the Ethics Review Subcommittee of the "Research for Human Subjects" section at author's University. Informed consent was obtained from all participants prior to their involvement in the study.

Ball Impact sounds

The primary focus of this study was the sounds produced during service. The impact sounds were measured using a microphone (PCB Inc., 130F20) and data logger (Keyence Corp., NR-500/-CA04). The direction of the stroke, the impact position of the racket, and the landing spot of the ball were recorded using a high-speed camera (CASIO Corp., EX-100F). The balls utilized were AUSTRALIAN OPEN (DUNLOP Corp.), and the rackets were VCORE100 (Yonex Corp.) with standard gut tension (52.5 pounds).

The arrangement of the participants and equipment in the tennis court is shown in Figure 1. Microphones were placed on both sides of each participant, and high-speed cameras were positioned in front of and behind them. The data logger and other equipment were strategically placed behind the participants to prevent any interference with their services.

Participants initially served two balls from the deuce court (indicated by the black dashed line in Figure 1) to the center of the court, and the impact sounds were measured. They then served two balls, each from the ad court to the center, the deuce court to near the edge of the court (hereinafter referred to as "wide"), and the ad court to wide. Similar measurements were performed for each condition. Any service that did not land within the designated area was considered invalid and was not included in the analysis. The sampling time for the measurements was approximately 30 s with a sampling rate of 100 kHz. The impact sounds were analyzed using a frequency analysis. In this study, high-speed cameras were used to measure the amount of spin and speed of the ball. Measurements were taken using a Photron Nova S9 high-speed camera paired with a Nikon AF-S NIKKOR 50 mm f/1.8G lens. The frame rate was set to 1000 fps, and the pixel resolution of the captured images was 1024×1024 pixels. Measurements of the impact position and trajectory of the ball were conducted using a high-speed camera, and the impact position, spin amount, and speed were calculated from these images.

It is important to note that in Figure 1, when participants served from the Advantage Court, the position of the receiver was mirrored to reflect this change. However, the position of camera 1 remained unchanged. This ensured consistency in capturing the serve dynamics, while accurately representing the adjusted position of the receiver.

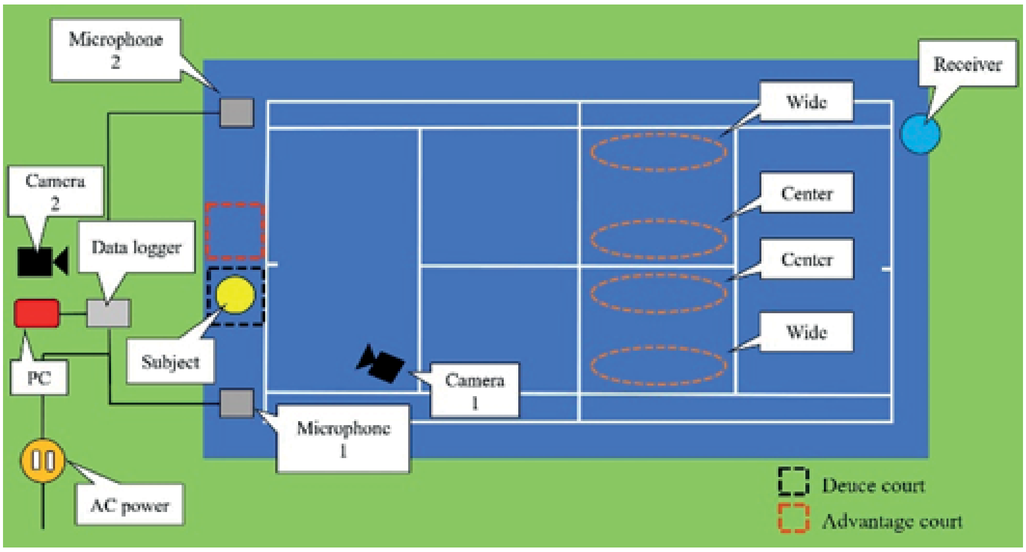

Figure 1. Experiment setup in the tennis court, showing the arrangement when participants serve from the advantage court. The receiver's position is mirrored, while Camera 1 remains unchanged.

Racket Vibration Modes

An impact hammer (PCB Inc., 086C03) was used to excite the rackets. As shown in Figure 2(a), a vibration accelerometer (PCB Inc., 352C41, 2.8 g) was affixed to the frame of the racket to quantify the vibration acceleration generated during excitation. Ten sensors were deployed and positioned at locations 1-10 on the frame, as illustrated in the figure. The positions of excitation by the hammer, as depicted in Figure 2(b), were the center of the racket face (1), right edge (2), intermediate position at 45 ° (3), end position at 45 ° (4), intermediate position at -45 ° (5), and end position at -45 ° (6). A data logger (Keyence Corp., NR-500/-CA04) was employed to capture the signals from the vibration accelerometers with a sampling time of approximately 10 s and a sampling rate of 100 kHz. The acquired vibration acceleration data and CAD data of the tennis racket, generated through shape measurement, were imported into the operational modal analysis software (Vibrant Technology Inc., ME'scopeVES) for vibration mode analysis. The acquisition of the racket shape data essential for vibration mode analysis was performed using a 3D texturing system (Steinbichler, COMET L3D 8M). The racket was mounted on a turntable and a white spray was applied to enhance the reflectivity of the laser for measurement. Based on the measured data, a 3D CAD model was created in STL format. Because of the limited scanning area accessible to the camera's light, the racket was scanned in sections, strings, and other parts separately and then merged to produce a comprehensive CAD model of the entire racket. The CAD data contained minor imperfections that were smoothed using software. Moreover, owing to the considerable number of contact points in the STL, the contact points from the measurement data were compressed and thinned to approximately 10%, resulting in approximately 314,376 contact points for the entire racket.

Racket Trajectory

Measurements for this study were conducted with a single participant, referred to as Man A participated in the experiment. The research utilized four OptiTrack Flex3 motion capture cameras and OptiTrack Motive control software to track the participants' movements during the service and create accompanying videos. The sampling frequency for this motion capture is 100 Hz. Data measured with OptiTrack Motive control software is smoothed or low pass filtered. Motion capture was not done with other experiments. The x-axis was defined as the forward and backward directions, the y-axis as the vertical direction, and the z-axis as the left-right direction. The trajectory of the tennis racket during serve was measured by tracking the movement of the reflective markers attached to the racket with the cameras.

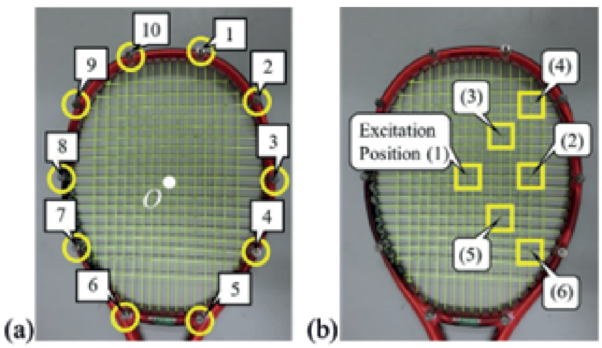

Figure 2. Photographs of (a) measurement positions and (b) excitation positions

RESULTS

Ball Impact Sounds

Figures 3 and 4 present the frequency analysis results for the ball-impact sounds measured for participant A. The horizontal axis represents the frequency in Hz, while the vertical axis represents the sound pressure in dB, with values normalized to the minimum audible sound pressure of 2×10^{-5} Pa. Figure 3 depicts the results from the Deuce Court, and Figure 4 represents the Advantage Court. Each figure also includes photographs illustrating the ball impact positions, specifically during serves directed towards the center. The results are presented as representative examples of the findings observed across all participants. Detailed discussions of the measurement results for individual participants are provided in Section 3.4.

From both figures, particularly Figure 3 from the Deuce court, a difference in sound pressure between serves to the Center and Wide is observed, particularly at approximately 1000 Hz. However, this trend is less pronounced in the Advantage Court, where the sound pressure near 1000 Hz tends to be higher for the service-directed Wide. Furthermore, the serve speeds were approximately 120 km/h to the center and approximately 100 km/h to the Wide on the Deuce court, and approximately 105 km/h to the center and 115 km/h to the Wide on the Advantage court. The spin rates were approximately 1500 rpm to the center and 3000 rpm to the Wide on the Deuce court, and approximately 2000 rpm to the center and 2500 rpm to the Wide on the Advantage court. Additionally, from Figure 3, it can be observed that serves towards the center direction on the Deuce court are struck at the central position of the racket, whereas from Figure 4, it is evident that serves towards the center direction on the Advantage court are struck at the upper right position of the racket.

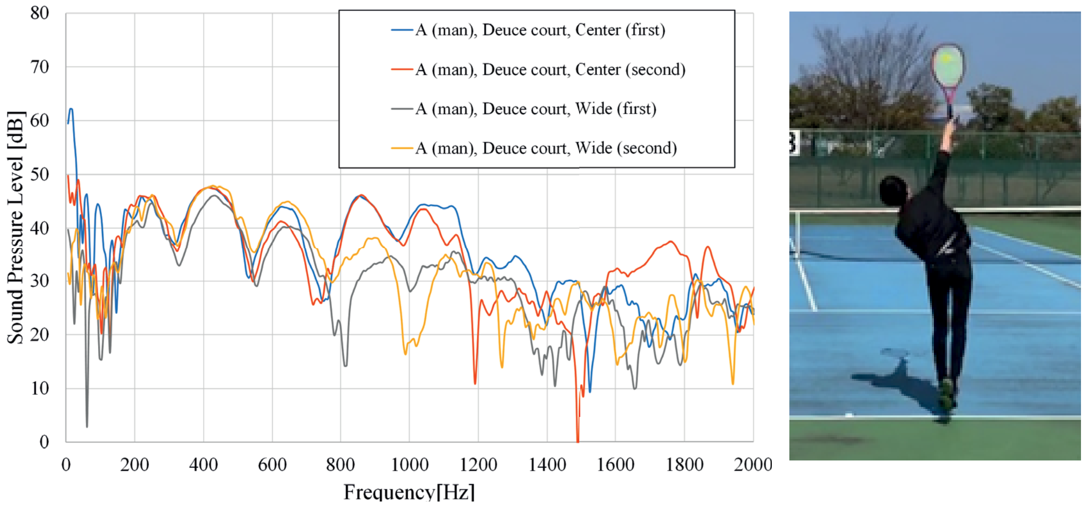

Figure 3. Measured sound pressure and ball impact position when the ball direction was center (Participant A, Deuce court).

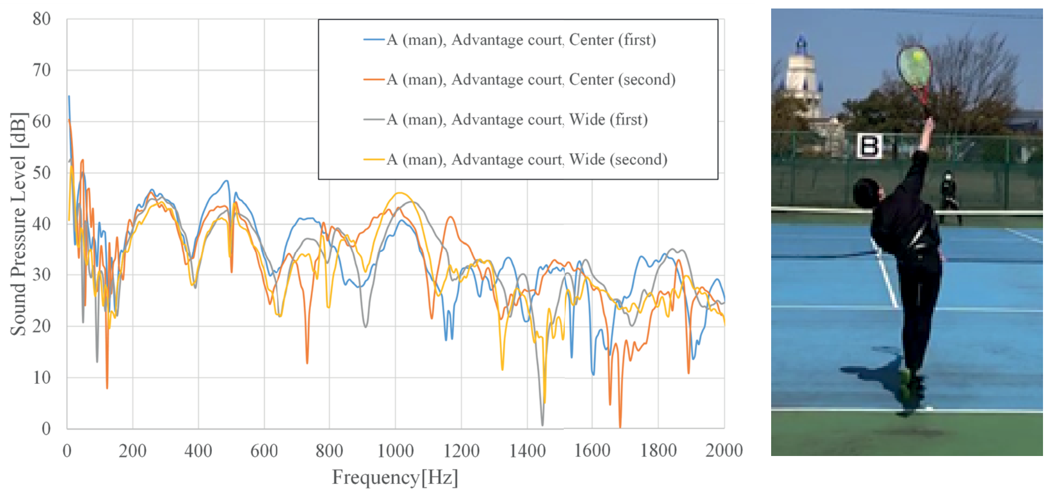

Figure 4. Measured sound pressure level and ball impact position when the ball direction was center (Participant A, Advantage court).

Racket Vibration Modes

Figure 5 presents the findings of the frequency analysis of the vibration acceleration at various measurement points when the racket was excited at positions (1) and (3). Figure 5(a) and 5(b) correspond to the excitation positions (1) and (3), respectively. With reference to Figure 5, it is essential to acknowledge that the sensor numbers depicted in the legend denote the specific measurement positions shown in Figure 2(b). As observed in Figure 5, a significant vibration acceleration was detected at 1130 Hz in both Figure 5(a) and (b) at a frequency of approximately 1000 Hz, where differences were observed in Figures 3 and 4. Additionally, in Figure 5(a), a notable vibration acceleration was seen at 1020 Hz, and in Figure 5(b), a notable vibration acceleration was seen at 1040 Hz.

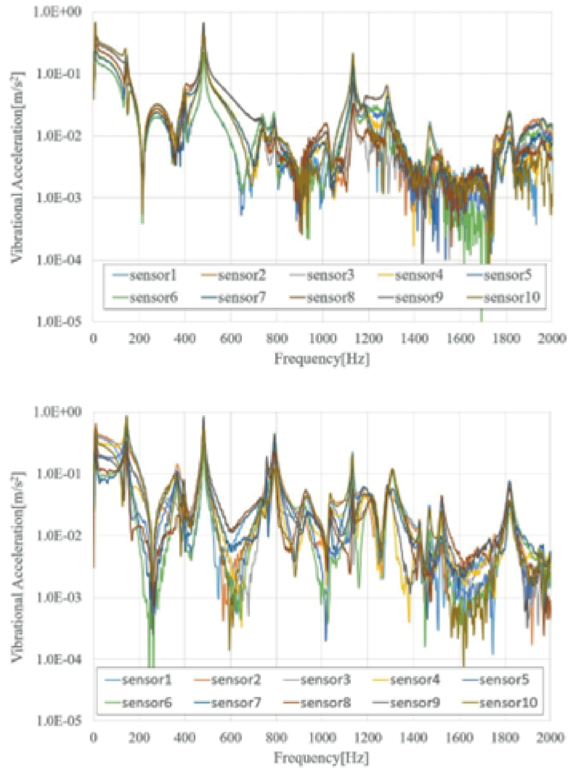

Figure 5. Frequency analysis results of vibration acceleration at each measurement location during racket excitation: (a) Excitation position (1) and (b) excitation position (3).

Figure 6 shows the results of visualizing the vibration of the racket at these frequencies. Figure 6(a) depicts the vibration at 1020 Hz for excitation position (1), and Figure 6(b) depicts the vibration at 1040 Hz for excitation position (3). As depicted in Figure 6, it is evident that for the excitation position (1), the vibration acceleration was higher on the frame on either side of the excitation point (measurement positions 3 and 8). Conversely, for excitation position (3), the frame at the upper position (measurement position 10) exhibited increased vibration acceleration. Therefore, it became apparent that differences in the excitation positions resulted in variations in the frame vibration frequencies and locations. Furthermore, the excitation of the racket at other positions demonstrated peaks in the vibration acceleration near 1000 and 1130 Hz. The aforementioned findings indicate that the vibration acceleration per unit excitation force (1 N) per frame is lower when vibrating position (3) is stimulated in comparison to vibrating position (1). Consequently, it is inferred that vibration acceleration at 1130 Hz occurs regardless of the excitation position. Additionally, the vibration at a frequency of 1000 Hz varies depending on the excitation position, exhibiting similar trends between positions (1) and (2), whereas positions (3), (4), (5), and (6) display an increased vibration acceleration at measurement positions 3 and 9 in a specific vibration mode.

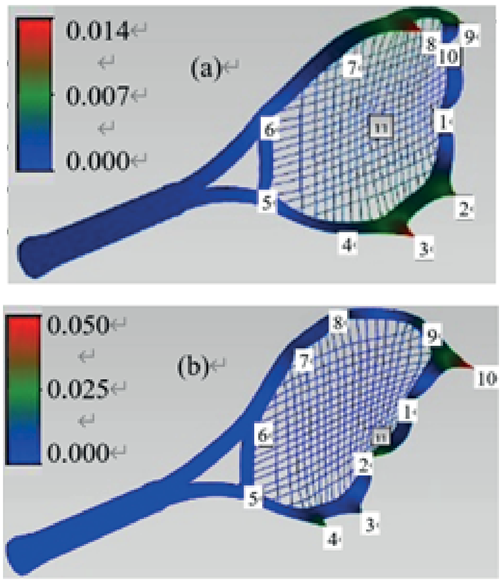

Figure 6. Results of modal analysis in (a) excitation position (1) at 1,020 Hz and (b) excitation position (3) at 1,040Hz. The red arrows in the diagram indicate the excitation positions.

Racket Trajectory

Figure 7 displays the results of measuring the trajectory of the racket while serving, using Participant A's data as a representative example. As shown in Figure 7(a), when the ball is struck at the center position of the racket (as indicated by (1) in Figure 2(b)), and in Figure 7(b), when the ball is struck 45 °upward and to the right of the center of the racket (as indicated by (3) in Figure 2(b)), the trajectories represent the tip of the racket (red), center (green), base (cyan), left end (yellow), and right end (pink), respectively. A comparison of the two trajectories indicates that there is greater variation in the forward-backward and left-right directions when the ball is struck 45 °upward and to the right from the center of the racket. This suggests that the striking surface of the racket (the side with the strings) rotates around the grip of the racket as its central axis.

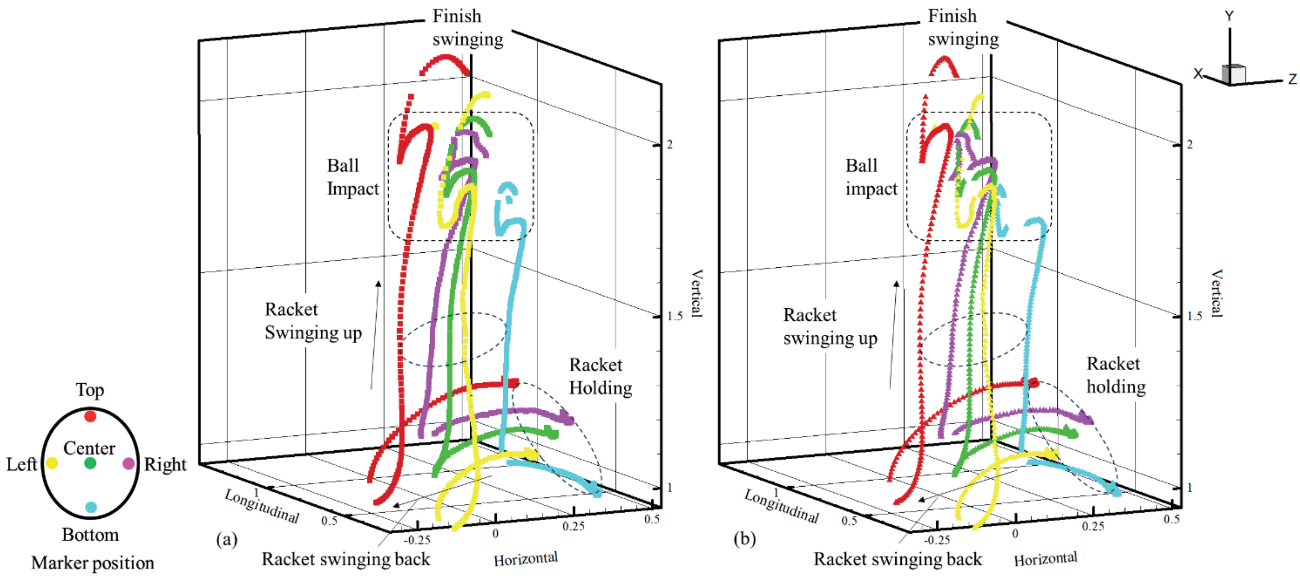

Figure 7. Results of racket trajectory in (a) ball impact position is center of the racket (impact position (1) in Fig. 2) and (b) 45 degrees upward and to the right from the center of the racket (impact position (3) in Fig. 2).

Relationship between tennis serve kinematics on ball impact sound

Based on the findings in Sections 3.1–3.3, it was observed that an increase in the spin amount of the ball during a player's serve was accompanied by a decrease in ball speed and a shift in the impact position of the racket away from its center. Additionally, changes in the sound pressure and frequency at approximately 1000 Hz were noted. To further validate these observations, data from additional participants were used as a reference.

The connection between the ball's spin amount and the impact position during each subject's serve is shown in Figure 8. Table 1 shows the average values and standard deviations of the ball spin rate and impact position for each player. This figure encompasses all measurement data from 10 participants who served twice each from the Deuce and Advantage courts in both the Wide and Center directions, resulting in 80 data points for the analysis. The horizontal axis of Figure 8 represents the amount of spin, while the vertical axis indicates the distance from the origin O, which is the center of the racket, to the impact position. The blue circles in the figure represent the outcomes when serving from the Deuce court in the center direction, the orange circles indicate the results when serving from the Deuce court in the wide direction, the gray circles show the outcomes when serving from the Advantage court in the center direction, and the yellow circles represent the results when serving from the Advantage court in the wide direction. Figure 8 shows that for the majority of the subjects, there was a tendency for the impact position to move away from the center of the racket as the spin amount on the ball increased. Note that since there is only one left-handed player and one female player, no conclusions can be drawn regarding the relationship between handedness or gender and these results.

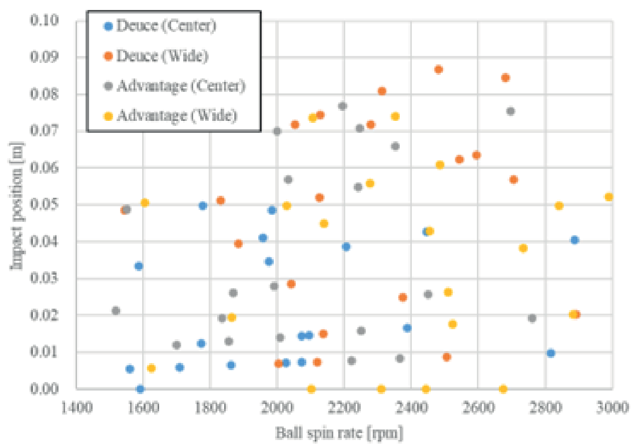

Figure 8. Relationship between ball spin rate and ball's impact position

Using all the data shown in Figure 8, the correlation between the ball spin rate and the distance of the ball impact position was found to be 0.21, indicating a slightly positive correlation, although not a strong one. Additionally, when calculating the correlation coefficients using the data from Deuce (Center), Deuce (Wide), Advantage (Center), and Advantage (Wide) Serve, the results were 0.047, 0.151, 0.222, and 0.035, respectively. This indicates that when serving from the Advantage Court, an increase in spin rate resulted in the ball impact position deviating more from the center of the racket. Finally, Table 2 shows the correlation coefficients between ball spin rate and ball impact position for each participant. As can be seen from Table 2, the correlation coefficients for Participant F and Participant H are low or negative, indicating a different trend from the other participants. However, for the other eight participants, a consistent positive correlation was observed between ball spin rate and ball impact position.

Table 1.
Average values and standard deviations of the ball spin rate and impact position for each player.

	Ball spin rate (rpm)		Impact position (m)	
	Average	Deviation	Average	Deviation
Participant A	2079	252	0.0465	0.0238
Participant B	2024	303	0.0225	0.0143
Participant C	2311	346	0.0332	0.0279
Participant D	2605	279	0.0447	0.0250
Participant E	2116	351	0.0296	0.0201
Participant F	1940	331	0.0349	0.0391
Participant G	1995	125	0.0267	0.0183
Participant H	2356	428	0.0418	0.0269
Participant I (Left-handed)	2428	259	0.0538	0.0298
Participant J (Female)	2020	282	0.0326	0.0201

Table 2.
Correlations between ball spin rate and impact position for each player

Participant A	0.56
Participant B	0.59
Participant C	0.60
Participant D	0.82
Participant E	0.70
Participant F	-0.14
Participant G	0.62
Participant H	0.12
Participant I (Left-handed)	0.64
Participant J (Female)	0.58

Figure 9 depicts the relationship between the spin amount of the ball and the initial velocity of the ball during service. Table 3 shows the average values and standard deviations of the ball spin rate and impact position for each player. The meaning of each symbol's color is the same as that shown in Figure 8. In addition, the total number of plots was the same as that shown in Figure 8. From this figure, it can be observed that as the spin amount of the ball increases, there is a tendency for the initial velocity of the ball at the time of serving to decrease for most participants. The correlation between the ball spin rate and initial velocity was found to be -0.90. Although this result pertains only to the ten participants in this study, it suggests that an increase in the ball spin rate may lead to a decrease in the initial velocity of the serve.

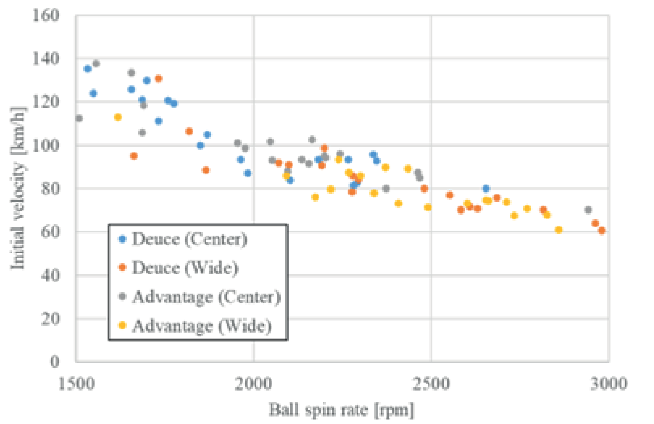

Figure 9. Relationship between ball spin rate and initial velocity

Table 3.
Average values and standard deviations of the initial velocity for each player

	Initial velocity (km/h)	
	Average	Deviation
Participant A	91.0	18.2
Participant B	89.4	25.3
Participant C	85.6	15.4
Participant D	89.3	14.5
Participant E	94.2	15.3
Participant F	96.2	24.2
Participant G	89.3	12.8
Participant H	87.6	18.6
Participant I (Left-handed)	97.4	17.9
Participant J (Female)	96.0	13.6

Figure 10 illustrates the relationship between the ball spin amount and sound pressure of the ball impact sound. Table 4 shows the average values and standard deviations of sound pressure level for each player. The colors of the symbols and the total number of plots are the same as those in Figure 8. Additionally, the ball impact sound was represented by the partial O.A. value of the sound corrected with the A-characteristic in the range of 1000-1200 Hz. From this figure, it can be observed that as the spin amount of the ball increased, the ball impact sound tended to decrease. The correlation between the ball spin rate and sound pressure level was – -0.88, suggesting that an increase in the ball spin rate may lead to a decrease in the sound pressure level.

Based on these findings, it is clear that the sound produced during a serving while impact the ball varies depending on the position of the racket, initial velocity of the ball, and amount of spin on the ball. Furthermore, it was observed that when the spin on the ball was high, the impact position of the racket tended to deviate from the center of the racket, resulting in a decrease in the ball impact sound. Moreover, these trends were observed to be independent of handedness or sex differences, as all participants demonstrated similar tendencies.

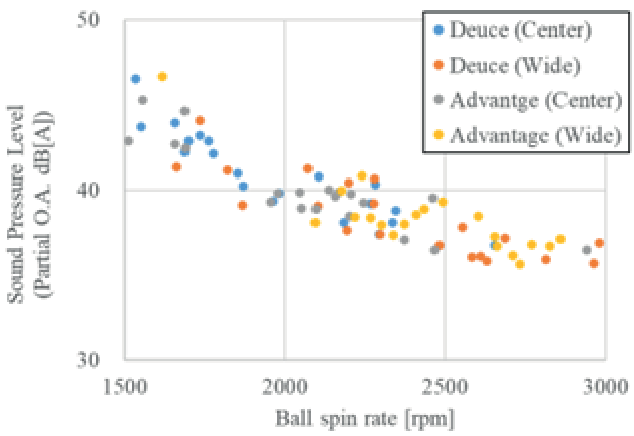

Figure 10. Relationship between the ball spin rate and the sound pressure level.

Table 4.
Average values and standard deviations of sound pressure level for each player.

	Sound Pressure Level (Partial O.A. [dB])	
	Average	**Deviation**
Participant A	39.0	2.2
Participant B	39.5	2.9
Participant C	38.6	2.0
Participant D	38.8	1.5
Participant E	39.9	2.7
Participant F	39.9	3.2
Participant G	39.2	2.3
Participant H	38.7	2.5
Participant I (Left-handed)	40.1	3.4
Participant J (Female)	40.5	1.5

These findings suggest that receivers can enhance the accuracy of their play during a serve by predicting the spin amount and velocity of the ball based on the ball impact sound. Furthermore, servers can increase the difficulty of their servers for receivers to predict by aiming for the center of the racket and maintaining the initial velocity of the ball, even when applying a spin. These results indicate that the relationship between the sound of impact and the accuracy of predicting a player's movements, as demonstrated in other studies (Sors et al., 2017; Camponogara et al, 2024), also exists during tennis serves, indicating the possibility of predicting the characteristics of serves based on impact sound.

While it is generally known that increasing the initial speed of a serve can be achieved by impacting the ball towards the upper part of the racket (closer to the tip), our findings suggest that if players can increase the initial speed of the serve while impacting the ball at the center of the racket, it would be an effective technique. This approach could provide an additional advantage by making the serve more difficult for the receiver to predict based on the sound alone.

The study also found that the trends observed remained consistent when the tension of the strings was set at 60 pounds and 42.5 pounds; however, there was a slight difference of approximately 100 Hz in the frequency of the generated sound. This suggests that the quality of the striking sound may vary based on string tension. The examination of 64 serves performed by right-handed male participants revealed that the average spin rates for serves from the Deuce court to the Center direction were 1917 rpm, from the Deuce court to the Wide direction were 2482 rpm, from the Advantage court to the Center direction were 2074 rpm, and from the Advantage court to the Wide direction were 2532 rpm. The results indicate that the spin rate tends to decrease when serving in the central direction and increases when serving in a wide direction.

DISCUSSION

The findings of this study provide new insights into the acoustic properties of tennis serves and their effects on player performance. Specifically, we observed that an increase in the spin amount of the ball during serve is associated with a decrease in ball speed and a shift in the racket's impact position away from its center. Additionally, changes in sound pressure and frequency at approximately 1000 Hz were noted. These observations align with existing research on the role of auditory information in visual anticipation, particularly studies by Cañal-Bruland et al. (2020), Murphy et al. (2018), and Goettker et al. (2021), which highlight the importance of sound in predicting the trajectory and speed of a ball.

Comparison with previous research

Previous research has demonstrated that auditory cues, such as the sound of racket-ball contact, can significantly influence players' ball trajectory and speed predictions. For instance, Cañal-Bruland et al. (2022) showed that the intensity of racket-ball-contact sounds systematically biases estimates of ball speed, thereby affecting anticipatory judgment. Similarly, Meyerhoff et al. (2022) found that the synchronous presentation of audiovisual stimuli could cause an illusory increase in perceived object speed, thereby influencing players' anticipatory judgments. Our study extends these findings by showing that the specific acoustic properties of serves, such as sound pressure and frequency changes associated with increased ball spin, can further refine players' anticipatory skills. The observation that higher spin rates are linked to lower sound pressure and frequency supports the notion that auditory information is a critical component of effective visual anticipation in tennis.

In recent years, several studies have investigated the role of auditory information in sports performance, particularly in relation to how sound impacts athletes' anticipatory skills. For example, study by Cañal-Bruland et al. (2018) demonstrated how auditory cues, such as the sound of ball impact, can significantly enhance visual anticipation in fast-paced sports. This finding complements the work of Goettker et al. (2021), who showed that contextual factors, like ball trajectory and speed, play a critical role in how auditory and visual cues are integrated during high-speed movements. Similarly, Murphy et al. (2016) emphasized the importance of contextual auditory information in perceptual-cognitive tasks, suggesting that auditory cues, when combined with temporal constraints, can improve an athlete's ability to predict and respond quickly. Also, studies by Murphy et al. (2018) and Goettker et al. (2021) found that auditory cues, such as the sound of ball impact, can significantly influence a player's ability to predict ball trajectory and speed. These findings align with our results, which suggest that the intensity of racket-ball impact sounds affects both speed estimation and anticipatory judgment. However, while previous studies primarily focused on the general influence of sound, our research adds nuance by exploring how contextual factors, such as spin and ball trajectory, moderate these auditory effects.

Consideration of context-dependency

Murphy et al. (2016, 2018) and Goettker et al. (2021) argued that the impact of auditory information on visual anticipation is context-dependent. They suggested that contextual information, such as the visual and auditory environment of a tennis match, enhances players' ability to accurately predict ball trajectories. Our study supports this view, showing that the changes in sound properties related to ball spin and speed are crucial for making accurate predictions during serve. However, our findings also indicate that these auditory cues are effective regardless of the player's handedness or gender, suggesting that fundamental auditory processing mechanisms are robust across different player demographics. This aligns with previous research indicating that the integration of the auditory system with visual cues is a generalizable phenomenon in sports anticipation.

Limitations

While our study offers new findings, it is not without limitations. The sample size was relatively small compared to other studies in human sciences. Future research should aim to include a larger and more diverse participant pool to enhance the generalizability of the findings. Additionally, investigating the impact of various playing surfaces and environmental conditions on the acoustic properties of serves could provide a more comprehensive understanding of the role of auditory information in tennis. The p-value in the present experimental results is less than 0.47, and the discussion is based on results with certain significant differences.

CONCLUSIONS

In this study, we explored the acoustic properties of ball impact sounds in tennis by focusing on the serves. Our findings indicate that the direction of the serve, deviation of the racket from the center of the court, spin amount, and initial velocity of the ball all influence the differences in sound pressure levels. Some of the measured data showed consistency and coherence, suggesting that these findings may be applicable to a broader population. Additionally, it was demonstrated that a high spin amount on the ball tends to cause the racket to diverge from the center, leading to a reduction in ball impact sound. This implies that receivers can potentially improve the precision of their returns by estimating the spin and velocity of the ball based on ball impact sound. While it is generally recommended that servers impact the ball slightly above the center of the racket to increase the initial velocity, our study suggests that impact the ball at the center without reducing its initial velocity can make it more difficult for receivers to predict the serve.

These findings have practical implications for training protocols in tennis and other ball sports. Coaches can use this information to develop drills that enhance players' sensitivity to auditory cues, thereby improving anticipatory skills. For instance, training sessions could include exercises that focus on recognizing and reacting to different sound patterns associated with various service spins and speeds. Furthermore, servers can use this knowledge to make their serves less predictable by maintaining a high ball speed while applying significant spin, thus reducing the auditory cues available to the receiver. This strategic use of sound can make it more challenging for opponents to anticipate and return serves effectively.

Further research is needed to explore the impact of different court surfaces and environmental conditions on ball-impact sounds. Additionally, expanding the participant pool to include a wider range of skill levels and age groups would help to validate and generalize these findings.

CONFLICT OF INTERESTS

The authors have no conflict of interests to declare that are relevant to the content of this research.

FUNDING

No funding was received for this study.

ETHICAL APPROVAL

The experiments described above were conducted in accordance with ethical guidelines. Prior to the commencement of the experiment, approval was obtained from the Ethics Review Subcommittee of the "Research for Human Subjects" section at author's University. Informed consent was obtained from all participants prior to their involvement in the study.

CONSENT TO PARTICIPATE

Consent to participate in this study has been obtained from the participants.

CONSENT TO PUBLISH

Consent to publish has also been obtained from the participants.

DATA AVAILABILITY STATEMENTS

The author confirms that all data generated or analysed during this study are included in this published article. A portion of the data that support the findings of this study, which are not shown in this paper, are available from the author upon reasonable request.

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Invisible Wounds: The Cumulative Impact of Mental Injury and Positive Punishment in Junior Racket Sports - A Critical Analysis*

Heridas invisibles: el impacto acumulativo de las lesiones mentales y los castigos positivos en los deportes de raqueta juveniles – Un análisis crítico

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Abstract

This article investigates the combined impact of stress and the use of discipline in youth racket sports like badminton, tennis, squash and table tennis. It sheds light on how pressures, often underestimated or misjudged, can build up over time, significantly impacting an athlete's performance and overall well-being. The article identifies the progression from stress to mental health issues that can leave lasting psychological scars. Furthermore, it touches upon how criticism from coaches or parents can worsen these issues potentially leading to feelings of anxiety, burnout or depression. The article stresses the significance of detection, communication and bringing awareness proactive support for mental health to prevent lasting harm and promote healthier growth, in athletes.

Keywords: *mental injury, mental health, junior athlete, coaching style.*

Resumen

Este artículo investiga el impacto combinado del estrés y el uso de la disciplina en deportes de raqueta juveniles como el bádminton, el tenis, el *squash* y el tenis de mesa. Los resultados clarifican cómo las presiones, a menudo subestimadas o juzgadas erróneamente, pueden acumularse con el tiempo y afectar significativamente el rendimiento y el bienestar general del deportista. Este artículo identifica la progresión del estrés a problemas de salud mental que pueden dejar cicatrices psicológicas duraderas. Además, se aborda el modo en que las críticas de entrenadores o padres pueden agravar estos problemas y provocar sentimientos de ansiedad, *burnout* o depresión. El artículo subraya la importancia de la detección, la comunicación y la concienciación del apoyo proactivo a la salud mental para prevenir daños duraderos y promover un crecimiento más saludable en los deportistas.

Palabras clave: *lesión mental, salud mental, atleta joven, estilo de entrenamiento.*

* Short communication.

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INTRODUCTION

In sports, such as badminton, tennis, squash and table tennis, the welfare of athletes holds significance to their physical well-being. Mental strains in these sports can exert impacts on athletes to physical ailments. While physical injuries are typically identified and addressed promptly mental strains often evade detection or misinterpretation. These strains tend to manifest over time due to issues that accumulate. Detecting strains poses a challenge owing to their nature and can significantly affect an athlete's performance and overall wellness in the long term.

Mental injuries in sports typically result from a buildup of stressors and emotional strains than a single traumatic event for junior players. The pressure to excel meets expectations. Handling criticism can become overwhelming for young athletes over time. This accumulation of stressors can lead to stress, anxiety, depression and other psychological difficulties (Tutte-Vallarino et al., 2022).

The danger with injuries lies in their tendency to be overlooked and untreated. Because emotional disturbances do not show signs, like injuries they are frequently overlooked or brushed off as minor concerns. Consequently, these psychological issues continue to accumulate, worsening the damage and increasing complexity. It is crucial to acknowledge the impact of factors on sports injuries underscoring how mental injuries are often disregarded due to their lack of symptoms. This oversight can lead to issues over time potentially resulting in severe psychological repercussions if left unattended (Hammond et al., 2013; Ogundele, 2018; Wiese-Bjornstal, 2010).

When these mental issues begin to show up they are often already deeply rooted in the athlete's mind, which can make them hard to recognize and deal with. If untreated stress escalates into health issues it can lead to lasting emotional scars that are tough to overcome (Gustafsson et al. 2011; Rice et al., 2016). The lack of symptoms in these conditions may result in them being underreported. Not receiving adequate treatment potentially causes a progression towards more severe mental health issues, among athletes (Oforeh et al., 2023; Raglin, 2001).

THE IMPACT OF POSITIVE PUNISHMENT ON AGGRAVATING MENTAL INJURIES

Coaches and parents sometimes resort to using feedback like criticism or constant nagging following a player's performance, which can have effects on the mental resilience, focus and confidence of athletes. Continuously criticizing athletes after games or victories can lead to psychological harm. Consistent negative feedback may create a mindset where success becomes associated with negativity leading to conflict and stress. This pattern could potentially result in "learned helplessness", where players believe that no matter how well they perform they will always receive criticism.

This kind of reinforcement can exacerbate existing strain. Contribute to intricate psychological complexities. Apart from affecting their performance in competitions athletes might struggle with reduced concentration levels, lower motivation or exhibit signs of anxiety, burnout and possibly depression. Sadly, these symptoms are often mistaken for issues, than being acknowledged as signals of an underlying mental challenge (Martín-Rodríguez et al., 2024)

A real-life example from the world of tennis highlights the consequences of coaching practices. Andre Agassi, a tennis player, faced critical coaching from his father Mike Agassi throughout his career. Despite Andre's accomplishments, which include winning eight Grand Slam titles, he faced pressure and criticism that ultimately caused him to harbor deep resentment towards tennis. This led to periods of rebellion, burnout and a waning passion for the sport. This scenario reflects the struggles experienced by players in racket sports who despite their victories or strong performances are constantly scrutinized for their errors. Such continuous criticism can result in feelings of inadequacy and frustration to what Andre went through. If left unattended these emotions can snowball into challenges that affect long term performance.

To prevent strain and reduce the impact of positive punishment on young athletes it is essential to take proactive measures. The first crucial step is acknowledging injuries as serious issues that demand attention just like physical injuries do. Coaches, parents and sports organizations need to be attuned to the signs of stress and act preemptively to address them. Establishing a nurturing environment is vital in averting injuries from accumulating. Coaches should aim for a balance between offering feedback and providing reinforcement while focusing on an athletes' strengths rather than solely pointing out their mistakes. This approach does not boost a players' self-assurance. Also cultivates a healthier bond with sport.

Encouraging and recognizing accomplishments along with offering guidance play a role in promoting mental well-being and athletic success over the long term (Purcell et al., 2022; Vella et al., 2011). It is important for coaches and mentors to focus on developing their communication skills to deliver feedback in a manner. Giving feedback laden with negativity or emotional intensity adopting an understanding approach is key. Positive communication nurtures bonds between coaches and athletes boosts motivation levels and leads to performance results (Smith et al., 2007; Vella et al., 2011). Conversely feedback delivered with emotions can trigger heightened anxiety levels, self-esteem levels and impede an athletes' progress (Gould et al., 2002). Consistently using language or negative attitudes in communication can form a negative pattern that persists over time. This recurring use of communication does not become ingrained as a habitual behavior but also contributes to the buildup of mental strain in athletes (Gustafsson et al. 2011; Hammond et al., 2013).

Furthermore, offering health assistance for athletes is crucial. This involves providing access to sports psychologists training in skills and fostering an atmosphere where athletes feel at ease discussing their mental health struggles. Taking care of issues on and offering continuous assistance can help prevent these issues from becoming deeply ingrained making it easier to address and manage them (Weiß et al., 2024; Wiese-Bjornstal, 2010).

IN SUMMARY

Mental challenges in sports that are compounded by the repercussions of punishment present a significant but often underestimated problem with lasting effects on athletes. These challenges develop gradually over time due to turmoil often slipping under the radar and being disregarded. As they build up, they become more intricate and harder to pinpoint, ultimately affecting the athletes' performance and overall well-being. Preventing hurdles and lessening the impact of punishment demands a joint effort, from coaches, parents and sports institutions to establish a nurturing and harmonious setting that values the mental and emotional well-being of young athletes. By doing we can assist racquet sports players in enjoying their sport, boosting their self-assurance and reaching their full potential.

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Impact Evaluation Planning and Socio-Educational Legacy through Volunteering. A Narrative Review associated with the 2021 Badminton World Championships

Planificación de la evaluación de impacto y legado socioeducativo a través del voluntariado. Una revisión narrativa asociada al Campeonato Mundial de Bádminton 2021

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Abstract

This article examines the gap in the literature on the planning and evaluation of socio-educational impact and legacy through volunteering at sport events. The existing scientific literature on impact and legacy planning of sport events focuses on economic impact. Sport events not only have an economic impact, but are also a key tool for fostering social cohesion, inclusion and the development of personal and professional skills in volunteers. The literature review for this study included eleven articles focusing on the impact of sport events of different dimensions on the socio-educational area through volunteering. Through rigorous planning and proper impact assessment, it is possible to maximize these benefits and ensure a lasting legacy in host communities. The study proposes the creation of BEAT, Badminton Events Assessment Tool, a comprehensive tool to plan and measure socio-educational impact in a structured way, facilitating the collection of key indicators before, during and after the event.

Keywords: *Socio-educational impact, volunteering, planning, legacy, evaluation.*

Resumen

Este artículo examina el vacío existente en la literatura sobre la planificación y evaluación del impacto socioeducativo y el legado a través del voluntariado en eventos deportivos. La literatura científica existente sobre la planificación del impacto y el legado de los acontecimientos deportivos se centra en el impacto económico. Los eventos deportivos no sólo tienen un impacto económico, sino que también son una herramienta clave para fomentar la cohesión social, la inclusión y el desarrollo de habilidades personales y profesionales en los voluntarios. La revisión bibliográfica para este estudio incluyó once artículos centrados en el impacto de eventos deportivos de diferentes dimensiones en el ámbito socioeducativo a través del voluntariado. Mediante una planificación rigurosa y una evaluación adecuada del impacto, es posible maximizar estos beneficios y garantizar un legado duradero en las comunidades de acogida. El estudio propone la creación de BEAT, Badminton Events Assessment Tool, una herramienta integral para planificar y medir el impacto socioeducativo de forma estructurada, facilitando la recogida de indicadores clave antes, durante y después del evento.

Palabras clave: *impacto socioeducativo, voluntariado, planificación, legado, evaluación.*

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INTRODUCTION

Both the sports and tourism industries have developed continuously and rapidly since the 1960s. When they intersected, they resulted in a new field, sports tourism, which integrates one of the most widespread social phenomena and one of the largest industries in the world. Sports tourism is understood as a phenomenon that relates the direct and indirect benefits of tourists travelling to actively participate in and/or attend a sporting event (Fernández et al., 2023). In recent years, sporting events have become increasingly relevant not only as entertainment spectacles, but also as catalysts for social change and community development. These competitions have the potential to have a profound impact on host communities, positively affecting economic, social and educational outcomes (Schnitzer et al., 2021). Beyond tangible benefits, such as improving infrastructure or boosting tourism, sport events can leave an intangible legacy that includes promoting social cohesion, developing human capital and strengthening community participation (Preuss, 2004; Malchrowicz-Mośko & Rozmiarek, 2017).

The concept of legacy, as defined by Preuss (2007), implies planned and unplanned consequences that endure beyond the event, affecting various areas such as the economy, environment, politics and society. However, the lack of efficient planning can lead to considerable challenges, such as corruption and misuse of resources (Dolles & Soderman, 2010; Leopkey & Ellis, 2019). Hence the importance of a clear strategy that considers both short-term leverage, image enhancements and regional promotion to ensure long-term positive impact (O'Brien & Chalip, 2007).

At the socio-educational level, sport events have the potential to generate lasting change by fostering education and personal development, although these aspects are often underestimated. A thorough impact assessment and good legacy planning in this area are essential to ensure that tangible and intangible benefits are not limited to economic, but also include the enhancement of human and social capital (Sánchez-Sáez et al., 2020). As organisers and partners seek to justify the value of an event, the integration of a socio-educational approach can generate lasting effects in the community and contribute to holistic development (Fonseca et al., 2022; Association of Summer Olympic International Federations [ASOIF], 2021).

Historical and recent evidence suggests that sport generates social and educational benefits in a number of areas, such as improved health, reduced crime, educational advancement and increased subjective well-being (Davies et al., 2019). These positive impacts are closely linked to the planning and objectives set prior to organising a sporting event. To maximise socio-educational impact, it is essential that events have a clear vision, well-defined mechanisms and concrete goals that explain how these effects will be realised (ASOIF, 2021).

In addition to the direct benefits that sport events bring to participants and spectators, they also contribute to the development and strengthening of sport organisations. The resources used to run these events can be harnessed to improve the provision of sport, health and wellbeing in communities. Indeed, sport events act as catalysts to increase participation in sport activities, inspiring both individuals and organisations, which directly contributes to the creation of social value through sport (Davies et al., 2019). This makes sport a strategic investment to address social and educational issues, as detailed in recent studies (Sanatkhah, 2021).

Volunteering, which is often a key component in the organisation of these events, plays a central role in creating this legacy. Volunteers not only support competitions logistically, but also gain organisational, leadership and teamwork skills that they can transfer to other areas of their lives (Cuskelly et al., 2006). Furthermore, volunteering promotes important civic values such as commitment, fairness and solidarity, contributing to the social cohesion of the communities involved (Koutrou et al., 2016).

However, in order to maximise the benefits of sport events in terms of socio-educational impact, proper planning that considers both the evaluation of immediate legacy and long-term impact is essential. This includes the development of tools to objectively measure the effects of volunteering on skills development and social cohesion in host communities (ASOIF, 2021).

This paper analyses the planning and evaluation of the socio-educational impact of volunteering in sport events, with a specific focus on the Badminton World Championships 2021 held in Huelva where a study of the different areas of impact was carried out where a socio-educational impact assessment focused on volunteering was necessary, but was not finally carried out due to the need for a simple tool that provides a correct view of the impact.

Through a review of the literature and the use of validated measurement tools, we explore how volunteering can contribute to the lasting legacy of these events and how strategic planning can ensure that the social benefits transcend the duration of the competition.

METHOD

For this study, a review of relevant literature was conducted using academic databases such as Web of Science, Google Scholar and Scopus from which eleven articles, one conference paper and the Association of Summer Olympic International Federations (ASOIF) handbook (2021) were selected. The selection of articles focused on research addressing the social and educational impact of volunteering in sport events, as well as studies exploring the motivations and outcomes of volunteering in similar contexts. Specific case studies were included on international mega sporting events such as the Summer Olympics, Winter Olympics, Super Bowl, medium-scale events such as the Pan American Youth Games, and regional community events. We also considered the main scales and measurement instruments developed to assess the motivation and impact of volunteering in each of the studies, such as the Volunteer Motivation Scale for International Sporting Events (VMS-ISE), proposed by Bang et al (2008) and subsequently modified by Bang & Chelladurai (2009), the Volunteer Functions Inventory (VFI), developed by Clary et al. (1998), the Olympic Volunteer Motivation Scale (OVMS), developed by Giannoulakis et al. in 2008, the Special Event Volunteer Motivation Scale (SEVMS) conducted by Farrel et al, (1998), in addition to the common indicators proposed by ASOIF (2021).

Relevant information extracted from the articles searched and used for the literature review is attached in Table 1 below. Here you can find the author(s), the event at which the study is conducted, the method of study, what is studied and the scale used.

RESULTS AND DISCUSSION

The analysis reveals that volunteering at sport events generates multiple benefits, both at the individual and community level. On a personal level, volunteers acquire key competencies such as organisational skills, teamwork and leadership, which can enhance their employability and their ability to integrate into community life (Bang et al., 2008). In addition, participation in sporting events fosters important values such as respect, fairness and social engagement.

At the community level, volunteering contributes to the strengthening of social capital, promoting inclusion and cohesion within host communities (Zhou & Pappous, 2024). Sport events provide a unique platform for people from different backgrounds to interact, creating an environment of collaboration and mutual support. This interaction not only benefits the volunteers, but also enhances the perception of the event within the community, increasing its legitimacy and long-term impact.

A key aspect emerging from this review is the need to create a comprehensive tool for planning and evaluating the impact and socio-educational legacy of sport events. Despite the recognition of the benefits of volunteering at such events, there is a clear lack of standardised methodologies to effectively measure short and long-term impact. Currently, while surveys and post-event analysis are used, these approaches are often limited and do not adequately capture the long-term effects and the experience of volunteers in terms of personal and professional growth (ASOIF, 2021). Without a clear and consistent methodology to measure these impacts, organisers and policy makers miss the opportunity to generate valuable data that could improve the planning of future events and justify investments in social and human capital development.

As a result, the creation of the BEAT 'Badminton Events Assessment Tool' is proposed for the planning and evaluation of the impact and legacy of Badminton sport events.

The creation of such a tool would enable organisers and stakeholders to:

- Define clear objectives: events should set specific goals related to community development, social inclusion and cohesion, which can then be objectively evaluated.
- Monitor progress in real time: During the event, it would be possible to record key performance indicators (KPIs), such as the number of volunteers, hours worked and the diversity of participants according to specific demographic groups (youth, minorities, unemployed).
- Assessing post-event impact: This tool would allow not only to measure the immediate success of the event, but also to assess the lasting legacy, such as volunteer retention, skills development gained and effects on social cohesion and community well-being.

The Volunteer Motivation Scale for International Sporting Events (VMS-ISE) (Bang et al., 2009) and the Special Event Volunteer Motivation Scale (SEVMS) (Farrell et al., 1998) are validated scales that could be integrated into this tool to assess volunteer motivation and satisfaction more specifically. Also, the incorporation of pre- and post-event surveys would allow organisers to better understand how the event has influenced the community and what aspects require adjustment in addition to common indicators proposed by ASOIF (2021).

An important finding is that volunteer satisfaction and motivation are strongly linked to the perceived tangible impact their participation has on the community (Bang & Ross, 2009). Volunteers who feel that their work is meaningful and contributes directly to the success of the event are more likely to continue to participate in future events and to maintain a long-term commitment to volunteering.

There is a need for a model to follow with hybrid methodologies and tools to obtain quantitative and qualitative information that allows for proper planning before, during and after the event while being a useful and realistic tool from the point of view of available resources but can provide insight and measurement of the success of the event in terms of social, educational and community impact, and contribute to establishing a positive, sustainable and lasting legacy.

Table 1.
Details of the 12 reviewed research papers examining the evaluation of socio-educative impacts of sport event volunteers.

Author (Year/ No. of authors)	Event	Method	Key concepts/variables	Key measurement model/scale
ASOIF (2021)	Olympic Games	Total planned no. of volunteers	Actual no. of volunteers No. of volunteers from target segments of local population Average no. of hours volunteering per person	Common Indicators
Bańbuła (2021)	Sports volunteers who participated in the AZS Warszawa and AZS Kraków volunteer program. (Poland)	Quantitative Online Survey	Volunteer motivation	Volunteer Functions Inventory Clary et al.'s (1998)
Giulianotti et al., (2021)	The global Sport for Development and Peace (SDP): DP user groups, NGO personnel, volunteers, local leaders, and in-country stakeholders and policymakers	Fieldwork: participant observation, consultation and formal and informal interview	The complex positioning, roles, statuses, and experiences of volunteers: antinomies and liminality of volunteering	not specified model
Koutrou et al., (2016)	London 2012 Olympic Games volunteers	Quantitative and qualitative online survey incorporating a series of open-endedand closed-type questions	The participantswere asked to indicate their level of current volunteering engagement and whether volunteering atthe Games had an impact on their current volunteering levels.	Not specified model
Koutrou and Kohe (2021)	United Kingdom'sregional grassroots football communities.	Openended online survey and discussion groups	Connections between the shared ideas that help build volunteerism, educational opportunities and capacities for volunteer action	Spatial theory
Koutrou and Pappous (2016)	London 2012 Olympic Games volunteers.	Quantitative survey	volunteering experience in other contexts, motivation and intentions of volunteers to continue volunteering	Modified version of the VMS-ISE developed by Bang et al. (2009) and Olympic Volunteer Motivation Scale (OVMS) from Giannoulakis et al. (2008)
Legg and Karner (2021)	Volunteers at the local, regional and national levels in USA.	Qualitative Semi-structured interviews and Narrative inquiry	Volunteer experience Experience being a person of color, or from a diverse population, and a volunteer	Four-layersystem 8personal, interpersonal, organisational and community impacts)
Loaiza and Mejía (2023)	Juegos Panamericanos Juveniles Bogotá	Quantitative survey	Motivation	VMS-ISE Bang et al. (2009)
Miller et al., (2021)	Small-scale sporting event in a small city.	Quantitative survey	Volunteer motivation and satisfaction	Special Event Volunteer Motivation Scale (SEVMS) Farrell et al. (1998)
Otto et al. (2022)	Football Bowl Association's (FBA) executive directors and their volunteers	Online Quantitative survey	Psychological meaningfulness, psychological safety, and psychological availability and motivation	May et al.'s (2004) scale. Shuckand et al. 's engagement scale (2017) A modified version of the VMS-ISE Bang et al., (2009). Items from SEVMS Scale from Farrell et al. (1998) to assess purposive motivation
Teixeira et al., (2023)	Rio 2026 Olympic Games volunteers.	Online Quantitative survey	Volunteer experience, motivation and perception	modified version of the VMS-ISE developed by Bang et al. (2009)
VanSickle et al., (2015)	2012 Super Bowl	Quantitative survey	Motivation, Satisfaction	A modified version of the VMS-ISE Bang and Ross' (2009)
Wollebæk et al., (2014)	2010 FIS Nordic World Ski Champioship	Quantitative survey	Motivation	Motivation but not specified model

The development of such a robust tool would not only support effective event planning, but also ensure that socio-educational benefits are accurately measured and maximised, contributing to the creation of a positive, sustainable and replicable legacy for future large-scale sporting competitions and facilitating the comparison of events in different contexts, providing quantitative and qualitative data that would serve to adjust and improve future volunteering programmes by providing an equal and 360° view of all impacts (Figure 1) and legacies of a sporting event without focusing only on the economic impact.

BADMINTON EVENTS ASSESSMENT TOOL				
ECONOMIC	IMAGE	SPORT	SOCIO-EDUCATIONAL	ENVIROMENTAL
Inputs	**Inputs**	**Inputs**	**Inputs**	**Inputs**
Spectators Participants Organiser Exp. Infrastructure	Transmission Social Media Press Live Experience	Results Development Participation	Volunteers (Inclusion and Diversity) Education, skills development and transmission of values Motivation and satisfaction Activation	Promotion Transport Waste Energy
Outputs	**Outputs**	**Outputs**	**Outputs**	**Outputs**
Direct Economic impact Gross Domestic Product Trade Deals	Brand Value Value of New Visitors	Investment on Grassroots Investment on Spaces Residents Inspired for Sport	Benefits for Residents (skills development, employability) Social cohesion, community and wellbeing Volunteer loyalty	Net Carbon Footprint Waste Management Renewables Energy

Figure 1. Impact's dimensions measured for a Badminton Event

CONCLUSION

The benefits of sport as a cultural manifestation, its social potential as an instrument to improve the health and education of the people, its political importance, and its growing economic impact demand more and more attention every day (Quirante et al., 2024).

Volunteering at sporting events represents an invaluable opportunity to bring about positive change in host communities. Through proper planning and ongoing evaluation, the socio-educational impact of volunteering can be maximised, ensuring a lasting legacy that transcends the sporting arena. However, in order to achieve these objectives efficiently, it is essential to develop a comprehensive tool to plan and evaluate impact and legacy in a structured and objective manner.

Such a tool should not only focus on the definition of clear objectives and the collection of key performance indicators (KPIs) during the event, but also on post-event evaluation in order to measure the long-term impact in terms of social cohesion, skills development and community well-being. By incorporating validated scales such as the Volunteer Motivation Scale for International Sporting Events (VMS-ISE) (Bang et al., 2009) and the Special Event Volunteer Motivation Scale (SEVMS) (Farrell et al., 1998), indicators proposed by ASOIF (2021), organisers could gain a deeper understanding of volunteers' motivations and satisfaction, which would be key to improving their experience and encouraging their retention.

In addition, this tool would facilitate the planning of future events by providing a standardised model that could be replicated in different contexts. It would ensure that events not only achieve immediate economic impact, but also leave a sustainable and measurable social and educational legacy in local communities.

In summary, the development of a tool for socio-educational impact planning and evaluation is essential to optimise the role of volunteering in sport events, enabling them to contribute effectively to the well-being of volunteers and the cohesion and development of host communities.

Future research should follow the three-step plan for the creation of the tool:

Before the event: Define clear quantitative and qualitative objectives, carry out recruitment and selection of volunteers. During the event, training and development of values is necessary, as well as monitoring of participation and performance. Finally, after the event, evaluate personal development, the impact on social cohesion and well-being, and attempt to retain and build volunteer loyalty.

Always defining the inputs, outputs and hybrid measurement instruments throughout the evaluation process to get the right feedback. Finally, we should follow up with longitudinal studies to further analyse the long-term impact on volunteer participation and community well-being (Koutrou et al., 2016).

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Badminton racket deflection, comparison between rigid versus flexible according to different strokes

Deflexión de la raqueta de bádminton: comparación entre rígida y flexible en diferentes golpes

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Abstract

Badminton shuttlecock generate the highest projectile velocity among all sports. To deliver a powerful stroke, the design of a badminton racket is primordial, especially the deflection on the shaft. The purpose of the study was to analyse the gain of racket deflection compares with a rigid racket during four different strokes. Eight national and international standard badminton players participated in this study and performed a drop, a clear, a smash and a full smash. Six reflective markers were affixed to the racket and were recorded with Vicon cameras capture system set. Results showed racket deflection increased racket head velocity by shaft deflection by +13.2% during a full smash and a typical time around 60 ms during which the player accelerates the racket head. The gain obtained between head velocity related to the handle by +74% during a full smash. The deflection is caused by the relation between player ability, racket mass repartition and stiffness properties of the shaft. Finding suggest players should choose a racket with their badminton stroke pattern, especially the timing of the preparation phase before the impact with the shuttlecock to obtain the higher deflection and the best energy restitution during the impact.

Keywords: *performance, equipment, biomechanic, sport science, technology.*

Resumen

El volante de bádminton genera la mayor velocidad de proyectil de todos los deportes. Para realizar un golpe potente, el diseño de una raqueta de bádminton es primordial, especialmente la deflexión en la varilla. El objetivo del estudio fue analizar la ganancia de deflexión de una raqueta flexible en comparación con una raqueta rígida durante cuatro golpes diferentes. Ocho jugadores de bádminton de nivel nacional e internacional participaron en este estudio y realizaron un drop, un clear, un smash y un full smash. Se colocaron seis marcadores reflectivos en la raqueta y se grabaron con el sistema de captura de cámaras Vicon. Los resultados mostraron que la deflexión de la raqueta aumenta la velocidad de la cabeza de la raqueta por la deflexión de la varilla en un +13,2 % durante un full smash y un tiempo típico de alrededor de 60 ms durante el cual el jugador acelera la cabeza de la raqueta. La ganancia obtenida entre la velocidad de la cabeza se relacionó con el mango en un +74 % durante el full smash. La deflexión se debe a la relación entre la habilidad del jugador, la distribución de la masa de la raqueta y las propiedades de rigidez de la varilla. Los resultados sugieren que los jugadores deberían elegir una raqueta que se ajuste a su patrón de golpeo en bádminton, especialmente al momento de la fase de preparación antes del impacto con el volante, para obtener la mayor deflexión y la mejor restitución de energía durante el impacto.

Palabras clave: *rendimiento, equipamiento, biomecánica, ciencia del deporte, tecnología.*

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INTRODUCTION

Shuttlecock generate highest projectile velocity among all sports (Phomsoupha & Laffaye, 2015) and has recorded at 157 m/s by the Indian Satwiksairaj Rankireddy (Guinness World Record, 2023). The speed is depended of the player expertise level whereas the shuttlecock velocity ranged from 24.4 to 81.6 m/s (Phomsoupha & Laffaye, 2014). Several studies have investigated power strokes as clear and smash to explain the general stroke pattern (Rambely et al., 2005; Tsai, Chang, et al., 2000; Tsai, Huang, et al., 2000). To produce the maximum velocity at the shuttlecock, players add velocity through a sequential proximo-distal joint action (Tsai, Chang, et al., 2000). Specifically, for an overhead stroke, players quickly stretch their forearm during the eccentric phase (lateral rotation of the shoulder and radio-ulnar supination), followed by a rapid concentric action (medial rotation the shoulder and radio-ulnar pronation) (Waddell & Gowitzke, 2000).

To deliver a powerful stroke, the design of a badminton racket is primordial. To simplify, a racket is composed of a rigid handle and a flexible shaft (Kwan, Skipper Andersen, et al., 2010). Although tennis racket technology has received much research interest focusing mainly on the mass properties and geometry of racket rather than their deflection (Cross & Bower, 2006). However, few studies have been conducted on the design of badminton rackets (Hsieh et al., 2004). Nowadays, the innovation has a great influence on badminton rackets by making them light (Singh & Yogesh, 2010). Golf club shaft has a similar pattern with badminton racket shaft. Unfortunately, the golf shaft is loaded with a heavy club head mass at the tip, permitted to increase the shaft deflection (Phomsoupha et al., 2015a).

It is therefore important to examine the deflection behaviour of the badminton racket to increase the racket head velocity during a stroke as a clear or a smash. Consequently, racket deflection plays an important role in increasing racket head velocity (Phomsoupha & Laffaye, 2015). Indeed, the badminton racket is subjected to significant dynamic effect (Kwan, Cheng, et al., 2010). Furthermore, the mechanism of the racket deflection influences the terminal velocity of the racket head (Rasmussen et al., 2010). Small differences in racket design have an influence on dynamics properties (Hsieh et al., 2004; Kwan, de Zee, et al., 2008), by modifying stiffness and mass properties (Kwan, de Zee, et al., 2008; Kwan & Rasmussen, 2011; Montagny, 2003). To the best of our knowledge, no study has investigated the benefits offered by the deflection between a rigid racket and a racket head velocity during different strokes.

Thus, the purpose of the present study was to analyse the gain of racket deflection compares with a rigid racket during four different strokes (drop, clear, smash and full smash) performed by elite badminton players.

METHODS

Participants

Eight participants realised in this study (age 23.3 ± 3.1 years; body mass 76.3 ± 8.3 kg; height 179.2 ± 8.3 mm; amount of training undergone 16.1 ± 4.5 years) with national and international experience participated in this study. All participants were healthy and in good physical condition and reported no injuries at the time of the study. They were fully informed about the protocol before participating in this study and they signed an informed consent form. Ethical approval was granted by the university Human Ethics Committee and followed principles of the Declaration of Helsinki.

Design & Procedures

After a general warm-up of 10 minutes, participants were allowed to perform as many practice movements as needed to familiarize themselves with the testing requirement under coached supervision. The racket used during the test was identical for all participants (Yonex Astrox 88D Pro; 88g; 680 mm). Four conditions were included during each session slow compared as a drop, medium compared as a clear, fast compared as a smash and very fast compared as a full smash. Each condition was repeated 10 times within a counter-balance order. The timing of stroke is obtained by the beginning of the movement (acceleration phase) and the impact between the racket with the shuttlecock (figure 1). A shuttlecock is attached to the duct ceiling by using a wire and adjusted from the participant.

Analysis

The experimental setup consisted of a nine-camera Vicon V8i motion capture system set at a frequency of 500 Hz (Vicon Peak, Oxford, UK). For kinematic analysis, six reflective markers of 14 mm in diameter were affixed to specific anatomical landmarks (Plug-In Gait Marker Set, Vicon Peak) for each participant. The markers were fixed to the dominant side, as follows: (a) angulus acromialis; (b) medial and lateral humeral epicondyles; (c) radial and ulnar styloid processes; and (d) 2nd metacarpal heads, as recommended by the International Society of Biomechanics (Wu et al., 2005).

The global x-axis was defined in the anteroposterior, the z-axis vertically and the y-axis laterally, whereas the xy-plane was identical to the court. The orientation of the humerus, radius, ulna and hand segments was determined by the longitudinal z-axis, the mediolateral y-axis, and the perpendicular anteroposterior x-axis, as described in detail by (Wu et al., 2005). All calculations were performed using Matlab R2023a software (The Math Works Inc, Natick, MA, USA). Only the arm holding the racket was analysed.

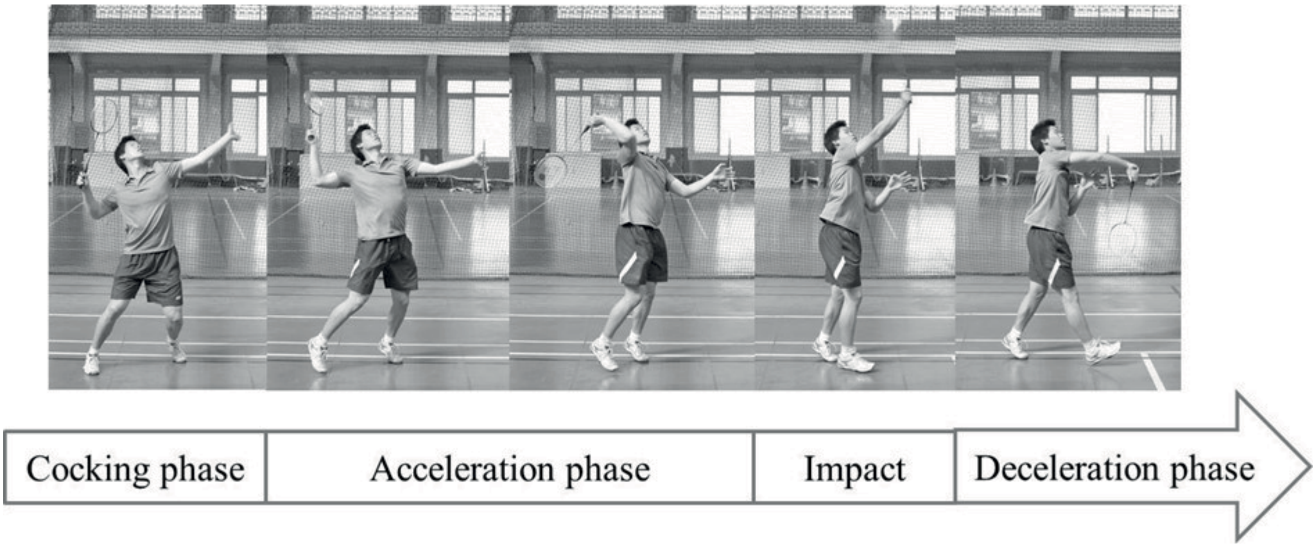

Figure 1. Different phases during a badminton stroke

Six reflective markers were affixed to the racket, as proposed by Kwan et al. (2008b) in their model: (e) racket handle, bottom and top of the handle; (f) racket shaft, top of the shaft; and (g) racket head, left, right and top of the head (figure 2). To calculate the joint positions, a 3D model (Plug-In Gait Marker Set, Vicon Peak) was used by David et al. (1991). The reflective markers placed on the racket weighed 1.2 - 2.4 g each, increasing total mass by 12.4 g (14%). Static and dynamic calibrations were conducted to set up the global reference system and calibration volume. The accuracy of 3D calibration was 0.2 mm.

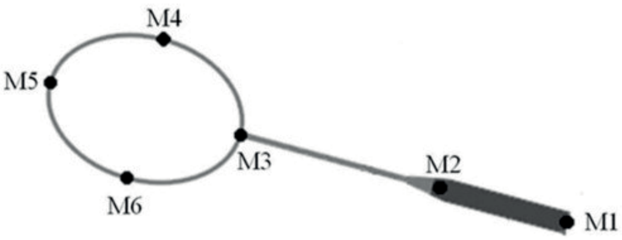

Figure 2. Reflective markers affixed to the racket

To compare the racket head velocity to a virtual stiff racket velocity, a virtual marker was built using the two markers on the racket handle. This new marker is at the same position as the marker on the top of the head when the racket is not deflected but stay aligned with the handle when it is accelerated, allowing to create a virtual stiff racket. Deflection is obtained by calculating the distance between the real marker and the virtual marker.

The kinematics data was calculated by Vicon Nexus 1.8 software (Vicon Motion System Limited, Oxford, UK). Racket deflection was calculated between the head racket real marker and the head racket virtual marker on the global system.

Statistical analysis

All statistical analyses were performed using Statistica 10 software (StatSoft Inc., Tulsa, OK). Mean and standard deviations of the variables were calculated for descriptive statistics. Assumptions of normality were verified using the Shapiro-Wilk W Test. Groups of variables were used for statistical analysis: (a) velocity between handle, shaft and head racket (m/s); (b) maximal velocity (m/s) (head and virtual marker); (c) maximal racket deflection (mm); and (d) wrist acceleration (m/s^2). Where the ANOVA was significant, a Bonferroni post hoc test and power test ($1-\beta$) were performed. For all statistical analyses, significance was set at $p < 0.05$ and effect size (η^2) was defined as small for $\eta^2 > 0.01$; medium $\eta^2 > 0.09$; and large for $\eta^2 > 0.25$ (Cohen, 1988). Lastly, Spearman correlation coefficients were calculated to determine the relationship between selected variables.

RESULTS

Racket deflection increased each part of the racket point from the racket handle to the head of the racket ($p < 0.001$); except for the drop shot ($p > 0.05$) (Table 1). The gain obtained between the head velocity related to the handle by +39% during a drop, by +62% during a clear, by +67% during a smash and by +74% during a full smash.

Racket deflection increased racket head compared to the virtual racket ($p < 0.001$); except for the drop and the clear ($p > 0.05$) (Table 2).

All results of maximal velocity of the racket and the virtual racket, gain, maximal racket deflection and wrist acceleration were showed in Table 3.

Table 1.
Velocity on handle, shaft and head racket during four different strokes.

Conditions	Racket handle (m/s)	Racket shaft (m/s)	Racket head (m/s)	p-value*	η²*	1-β*
Drop (slow)	5.6 ± 2.7	5.8 ± 2.3	6.3 ± 1.9	> 0.05	0.199	0.527
Clear (medium)	7.9 ± 2.9	13.2 ± 3.4	20.9 ± 4.1	**< 0.001**	**0.714**	**0.989**
Smash (fast)	11.2 ± 2.3	24.2 ± 6.5	34.6 ± 3.4	**< 0.001**	**0.836**	**0.992**
Full Smash (very fast)	12.8 ± 1.7	34.6 ± 3.6	49.2 ± 5.1	**< 0.001**	**0.946**	**0.993**

* p-value: significant differences for values lower than 0.05; * η^2: Effect size; *1-β: Power-test.

Table 2.
Velocity on head racket and virtual during four different strokes.

Conditions	Racket head (m/s)	Virtual racket (m/s)	p-value*	η²*	1-β*
Drop (slow)	6.3 ± 1.9	6.2 ± 1.9	> 0.05	< 0.001	0.050
Clear (medium)	20.9 ± 4.1	18.5 ± 3.5	> 0.05	0.022	0.262
Smash (fast)	34.6 ± 3.4	31.7 ± 4.6	**< 0.001**	**0.198**	**0.984**
Full Smash (very fast)	49.2 ± 5.1	41.4 ± 4.1	**< 0.001**	**0.438**	**0.998**

* p-value: significant differences for values lower than 0.05; * η^2: Effect size; *1-β: Power-test.

Table 3.
Virtual and real racket velocity, deflection racket, wrist velocity and acceleration during four different strokes.

Condition	Drop (slow)	Clear (medium)	Smash (fast)	Full smash (very fast)	p-value*	η²*	1-β*
Maximal velocity racket head (m/s)	6.3 ± 1.9	20.9 ± 4.1	34.6 ± 3.4	49.2 ± 5.1	**< 0.001**	**0.921**	**0.975**
Maximal velocity virtual head racket (m/s)	6.2 ± 1.9	18.5 ± 3.5	31.7 ± 4.6	41.4 ± 4.1	**< 0.001**	**0.931**	**0.984**
Gain (%)	0.2	3.8	6.3	13.2	**< 0.001**	**0.828**	**0.993**
Maximal racket deflection (cm)	0.8 ± 0.3	2.6 ± 0.6	4.6 ± 0.8	8.4 ± 1.2	**< 0.001**	**0.832**	**0.952**
Wrist acceleration (m/s²)	3.4 ± 0.7	10.2 ± 4.8	15.6 ± 0.8	23.1 ± 1.5	**< 0.001**	**0.607**	**0.931**
Timing (ms)	73.7 ± 5.4	64.8 ± 2.8	60.1 ± 2.7	58.5 ± 3.1	**< 0.001**	**0.665**	**0.954**

* p-value: significant differences for values lower than 0.05; * η^2: Effect size; *1-β: Power-test.

A strong correlation was found between maximal racket deflection and gain obtained by the deflection ($r = 0.933$; $p > 0.001$) (figure 3), and maximal deflection and maximal racket velocity ($r = 0.954$; $p < 0.001$) (figure 4).

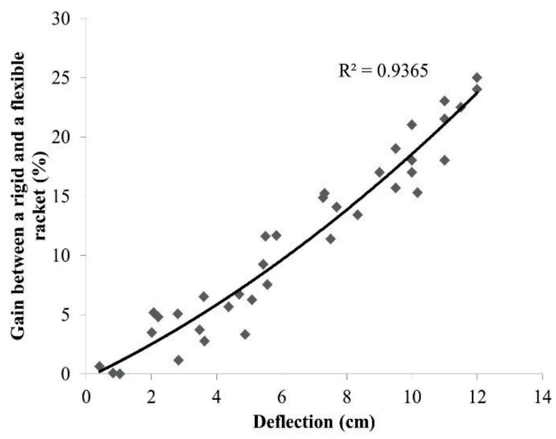

Figure 3. Correlation between rigid and flexible racket and deflection ($p > 0.001$)

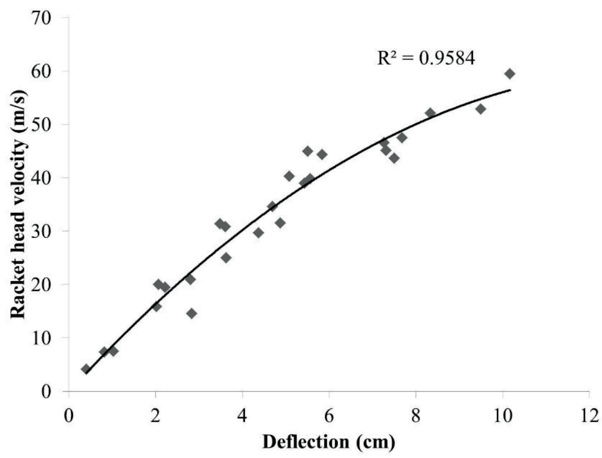

Figure 4. Correlation between racket head velocity and deflection ($p > 0.001$)

DISCUSSION

The aim of the study was to analyse to compare the velocity gain of the racket deflection compared with a rigid one during four different strokes (drop, clear, smash and full smash) performed by elite badminton players. In this experimentation, we compared the gain obtained from a flexible racket with a rigid racket (a virtual stiff racket) to analyse the gain on racket velocity. Simulate a new marker allows to be a new useful tool for analysing stroke dynamics with a flexible racket. Starting from this virtual stiff racket, information about the deflection during a stroke was extracted and could be compared between the type of stroke and players.

The average values of the flexible racket head velocity (44.3 ± 17.6 m/s) are very similar to the experimentally obtained values reported from 40 m/s to 50 m/s during a smash in previous study (Kwan, Skipper Andersen, et al., 2010). The maximal head racket velocity was obtained during a full smash stroke (49.2 ± 5.1 m/s). However, these values are higher than those found in other study with 37.5 m/s (Rambely et al., 2005). This difference could be due to a lower sampling rate (50 Hz) on their study.

Racket deflection showed a significant change in racket head velocity and was influenced by shaft deflection by +13.2% during a full smash. Assuming consistent stroke condition, it has been estimated that this could lead to an increase in racket head velocity of approximately +24% during a full smash (Phomsoupha et al., 2015). A rigid racket showed lower velocity than flexible one according to the kind of strokes, except for the drop and clear where there is a low deflection (Table 2). A totally rigid racket produces a slightly highest velocity at head than handle during a translation movement due to the lever effect (Kwan, de Zee, et al., 2008), however, the head velocity could be increased during a rotational movement. The racket properties have a great influence during a stroke and and particularly the racket's deflection by providing about 4-6% through the elastic energy (Kwan & Rasmussen, 2010).

Maximum deflection of the racket head in our study ranged between 4.1 and 102.2 mm during a drop to a full smash, which is higher than the values found in earlier studies, where deflection ranged from 38.5 to 56.2 mm for a smash (Kwan, Skipper Andersen, et al., 2010). This disparity can be explained, firstly, by differences in racket properties in our study; the racket used was more flexible. In addition, our study was performed with human players and they realised a complete stroke, whereas the earlier study used a rotational actuator with a rotational movement. In addition, by storing and releasing more strain energy with a greater flexibility, this results in a higher racket velocity (Phomsoupha et al., 2015). A similar pattern has found with golf club, the effect of deflection amplified club head speed (Worobets & Stefanyshyn, 2012). The correlation between racket head velocity and the gain showed the influence of elastic deformation to increase the final velocity (figure 4). It seems to be important to obtain a high deformation to produce a high velocity to transfer it to the shuttlecock.

To obtain the maximum benefit from deflection, impact between the racket and the shuttlecock should occur when racket deflection returns to its original position (± 0.05 s). In this way, the maximal advantage of racket elasticity can be obtained at the contact with the shuttlecock (Kwan & Rasmussen, 2010). For a given player, lighter strokes as drop shot were characterized by a lower deflection peak and a hard stroke as smash by a high deflection peak. The peak deflection and timing values are depending of each player (Table 3). A maximal head velocity is generated that is higher than the maximal velocity of the handle, due to the elastic deformation.

Additionally, our study showed different acceleration phase according to the type of strokes. The optimal timing is obtained during a smash (60.1 ± 2.7) and a full smash (58.5 ± 3.1 ms). The timing seems to be constant whereas the peak deflection is depending of the players. The consistency of impact timing in all strokes indicates that players coordinate their stroke to allow the benefit from the deflection (Kwan & Rasmussen, 2010). Furthermore, Phomsoupha et al. (2015) showed expert have better used the deflection than novices by the fact the typical time during which the player accelerates the racket head is around 60 ms and could theoretically increase by +80% racket head velocity. Thus, players take advantage of the elastic effect of deflection to increase the racket velocity during the acceleration phase (Kwan, de Zee, et al., 2008; Smith et al., 1996).

The drop showed the lowest racket head velocity as compared of the full smash. To produce the power needed, players take advantage of adding velocity with a sequential proximo-distal joint action. The rapid sequence constituted a stretch-shorten cycle to increase the efficiency of the force production. Higher force is generated by a high acceleration of the wrist (Phomsoupha & Laffaye, 2014). When the arm, especially at the end of the wrist movement, is accelerated, the head moves with a delay, resulting in a deflection of the shaft due to elastic deformation (Phomsoupha et al., 2015). Thus, elastic energy stored in racket deflection during the acceleration phase contribute to increase racket head velocity. A greater flexibility increases the capacity of the racket to store and to release more strain energy (Phomsoupha et al., 2015).

Additionally, our study showed different acceleration phase according to the type of strokes. The optimal timing is obtained during a smash (60.1 ± 2.7) and a full smash (58.5 ± 3.1 ms). Phomsoupha et al. (2015) showed typical time to obtained the optimal value predicted by their model is about 60 ms. Thus, players take advantage of the elastic effect of deflection to increase the racket velocity during the acceleration phase (Kwan, de Zee, et al., 2008; Smith et al., 1996). To produce a badminton stroke with a minimum energy cost, players take advantage of adding velocity with a sequential proximo-distal joint action during a rotational and a translation movement (Lees, 2003; Sakurai & Ohtsuki, 2000). Join contribution attributed to 53% of the shuttlecock velocity during a smash output to the radio-ulnar pronation (Gowitzke & Waddell, 1977) and showed that the combination of both forearm acceleration impacts the deflection.

CONCLUSION

To conclude, the deflection is caused by the relation between player ability (stroke technique), racket mass and stiffness properties (Kwan & Rasmussen, 2010). With the increase of the shot frequency (Laffaye et al., 2015), the time to prepare the stroke (cocking phase) is decreased and the racket should rapidly stroke the incoming shuttlecock. Thus, elite players tend to select a stiff and light racket, permitted with their skill and ability to swing the racket at high speed and short acceleration times. Players have better used the racket elasticity and deflection is affected by stiffness and mass properties (Kwan, de Zee, et al., 2008). Furthermore, players should choose a racket with the best fits and their badminton stroke pattern.

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CONFLICT OF INTEREST

None.

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Perception Training Approach for Elite Badminton Players Using Visual Obstacle

Entrenamiento enfocado en la percepción para jugadores de bádminton de élite mediante obstáculos visuales

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Abstract

Badminton is a fast-paced sport that requires not only physical fitness but also strong mental skills like anticipation and quick decision-making. This study introduces a new training method called "One-Way Mirror Perceptual Training", which uses a one-way mirror to block players' view of their opponent, forcing them to rely on their perception and reaction skills instead of visual cues. Twenty male badminton players aged 13-25 were divided into two groups: an experimental group that received the special training for six weeks and a control group that continued with regular practice. The training focused on improving agility, reaction time, coordination, and accuracy. Performance was measured before and after the training using tests like the Four Corner Run Test (FCRT) and agility drills. The experimental group showed significant improvement, with faster reaction times, better movement, and higher performance scores, while the control group had little change. These results suggest that the One-Way Mirror Perceptual Training helps players improve their mental and physical skills, making them more prepared for high-level competition. This study highlights the importance of including perceptual training in badminton and suggests that similar methods could be useful in other fast-paced sports.

Keywords: *Badminton, perceptual training, one-way mirror, anticipation, visual obstacle, sports performance.*

Resumen

El bádminton es un deporte de ritmo rápido que requiere no solo de una buena condición física, sino también de habilidades mentales sólidas, como la anticipación y la rapidez en la toma de decisiones. Este estudio introduce un nuevo método de entrenamiento denominado «Entrenamiento perceptivo con espejo unidireccional», el cual utiliza un espejo unidireccional para bloquear la visión de los jugadores de su oponente para así obligarlos a confiar en sus habilidades de percepción y reacción en lugar de en las referencias visuales. Veinte jugadores hombres de bádminton de entre 13 y 25 años fueron divididos en dos grupos: un grupo experimental que recibió el entrenamiento especial durante seis semanas y un grupo de control que continuó con la práctica habitual. El entrenamiento se centró en mejorar la agilidad, el tiempo de reacción, la coordinación y la precisión. El rendimiento se midió antes y después del entrenamiento mediante pruebas como el Four Corner Run Test (FCRT) y ejercicios de agilidad. El grupo experimental mostró una mejora significativa con tiempos de reacción más rápidos, mejores movimientos y puntuaciones de rendimiento más altas, mientras que el grupo de control apenas experimentó cambios. Estos resultados sugieren que el entrenamiento perceptivo con espejo unidireccional ayuda a los jugadores a mejorar sus habilidades mentales y físicas, y los prepara mejor para la competición de alto nivel. Este estudio destaca la importancia de incluir el entrenamiento perceptivo en el bádminton y sugiere que métodos similares podrían ser útiles en otros deportes de ritmo rápido.

Palabras clave: *bádminton, entrenamiento perceptivo, espejo unidireccional, anticipación, obstáculo visual, rendimiento deportivo.*

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INTRODUCTION

Badminton is widely recognized as one of the most unique and fast-paced racket sports in the world, characterized by its high speed and demanding nature (Kamruddin & Mannan, 2019; Kumar et al., 2023). While physical fitness is a fundamental aspect of success in badminton, it is not the sole determinant. Success in this sport also requires a significant degree of mental agility and strategic thinking (Green & Bavelier, 2008). Players must possess the ability to anticipate the opponent's next move and accurately place the shuttle in response (Kızılet et al., 2024). This mental aspect of the game is as crucial as physical fitness, making it essential for players to cultivate a well-rounded skill set. (Hagemann et al., 2006)

In badminton, players are required to master multi-dimensional competencies, where perceptual abilities are just as important as physical ones (Caserta et al., 2007). To enhance these perceptual skills, players need to develop unconventional perception and anticipation abilities. This goes beyond traditional physical training, requiring specialized brain stimulation and cognitive exercises that are particularly relevant in racket sports (Cece et al., 2020). These perceptual competencies enable players to process visual information quickly, make rapid decisions, and respond effectively during gameplay.

In a typical badminton match, a player's ability to react effectively to their opponent's movements is crucial (Sivamani et al., 2022). For instance, when Player A executes a jump to smash the shuttlecock near the front service line, Player B instinctively anticipates the attack and prepares to defend, often reacting with a sense of urgency or even fear. However, if Player A unexpectedly performs a drop shot instead of a smash, Player B may struggle to respond quickly, leading to a potential loss of the point.

This dynamic changes significantly when a visual obstacle, such as a one-way mirror screen, is introduced. In this scenario, Player B cannot see Player A's movements, which forces them to rely solely on their perceptual and anticipatory skills rather than visual cues. Without the ability to see Player A's actions, Player B may feel less intimidated or anxious, allowing them to focus more on responding to the shuttle's trajectory rather than the opponent's presence. Consequently, Player B might be better prepared for a drop shot, despite the absence of visual information about Player A's movements.

Developing these advanced perceptual skills often involves a range of training methods designed to enhance Global Motion Perception (GMP). Such methods include long-term ball training, sports vision training, stroboscopic training, and visual reaction exercises. Additionally, tools like the Bassin anticipation timer and inertial measurement units (IMU) play a significant role in refining these skills (Russo & Ottoboni, 2019; Kızılet et al, 2024). These techniques are essential for improving vision, reaction time, perception, anticipation, and decision-making across various sports, with a specific focus on enhancing the cognitive aspects of athletic performance.

In the present study, introduce an innovative approach known as visual obstacle one-way mirror screen perceptual training for badminton players. This method is designed to elevate players' perceptual cognitive skills, particularly in the areas of anticipation and rapid decision-making. By utilizing this training, players can better understand and predict their opponent's actions, enabling them to respond swiftly and effectively in competitive scenarios. This approach aims to sharpen a player's ability to counteract the opponent's strategies, thus enhancing their overall performance on the court. (Appelbaum & Erickson, 2018; Broadbent et al., 2015; Russo & Ottoboni, 2019; Farrow, 2013). This can lead to better performance in tournaments and, ultimately, to success at the elite level.

METHOD

Participants

A total of 20 male badminton players were selected for this study. Among these participants, 10 players were randomly assigned to the experimental group, while the remaining 10 players constituted the control group. All participants were from the state of Haryana, India, with an age range between 13 - 25 years. All participants were state-level elite players, training for an average of 15 hours per week in badminton-specific training. Each participant had a minimum of 3-5 years of experience in competitive badminton.

Procedure

In this study, a specialized training setup was employed to assess and enhance the perceptual and cognitive skills of badminton players. The setup involved the use of a one-way mirror screen strategically placed at the midpoint of the badminton court. This screen created a unique visual barrier between the server (feeder) and the receiver (participant). The one-way mirror allowed the server, who could be one of up to five coaches, to have a clear view of the participant's court side and movements, while the participant was unable to see the server's side of the court. This setup was crucial for isolating the participant's perceptual skills, forcing them to rely on anticipation and reaction rather than visual cues from the server. Participants in the experimental group underwent one-way mirror screen training for 3 hours per week.

Variables and Training

The experimental group underwent 42 days of One-Way Mirror Screen training, while the control group did not participate in this specific training. Instead, the control group continued with their regular gameplay practice, which was considered a limitation in assessing the impact of the training. During the training sessions, the feeder served the shuttle to various designated positions on the participant's side of the court, which were randomly numbered as 1, 2, 3, or 4. The participant's task was to return the shuttle to a specific target area predetermined by the coach. This target area remained consistent throughout the session, ensuring that the participant focused on precision and accuracy in their returns. The number of successful returns to the designated target area was recorded as a scoring metric figure 1 shows perceptional training platform. Additionally, the time taken by the participant to complete each return and complete cycle was carefully noted, providing a measure of the participant's reaction time and decision-making speed. The variables assessed in this study included agility, reaction time, anticipation, neuromuscular coordination, eye-hand coordination, speed play, and accuracy. Agility was assessed using the T-test, reaction time with a reaction timer, anticipation with anticipation drills, neuromuscular coordination with coordination exercises, eye-hand coordination using hand-eye coordination tasks, speed play with sprint tests, and accuracy with target hitting drills.

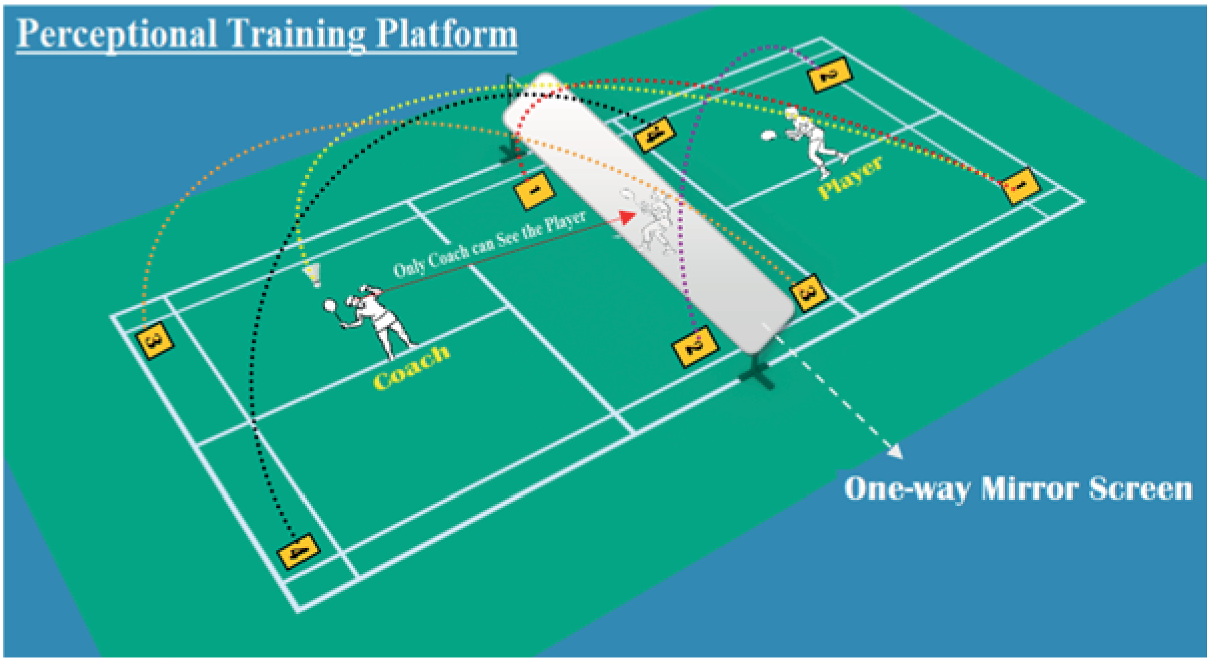

Figure 1. The Visual Obstacle tool as a "One-way Mirror Screen" in the perceptual training platform used for during training and assessment.

The Perceptual Training Approach incorporated in this study involved an X-shaped four-corner training pattern. This pattern required the participant to cover multiple areas of the court, enhancing their agility and spatial awareness while also improving their ability to anticipate the shuttle's trajectory. The combination of these elements aimed to sharpen the player's cognitive processing and quick decision-making under conditions that simulated the unpredictability of real match scenarios.

The effectiveness of the training program was rigorously evaluated by comparing the players' performance before and after the intervention. Pre-training and post-training assessments, consisting of the best of 3 trials, were conducted, and the best timing from these trials was calculated for this study, with particular attention paid to improvements in the accuracy of shuttle returns, the speed of decision-making, and overall court coverage. Further assessment of the training impact on the off-court test was conducted using an agility T-test. The data collected provided valuable insights into the impact of the One-Way Mirror Perceptual Training on the participants' ability to anticipate and respond to game situations, ultimately contributing to enhanced performance on the badminton court.

RESULTS

The paired t-test analysis reveals significant differences in the performance of the experimental and control groups. For the experimental group, the mean agility score improved from 11.14 seconds (pre-test) to 10.11 seconds (post-test), with a mean difference of

1.03 seconds. The t ratio of 10.88, which is more than the table value of 2.26 at a 0.05 significance level, and a p-value of 1.75 (below 0.05) indicate a statistically significant improvement due to the training. The control group showed a small change in mean agility scores, from 11.13 seconds (pre-test) to 11.12 seconds (post-test), with a mean difference of only 0.009 seconds. The t ratio of 1.71, which is below the table value, and a p-value of 0.12 (above 0.05) suggest no significant change in performance. Figure 2 shows the performance of the experimental and control groups for agility.

Table 1.
Paired t-test for Experimental and control group (Agility T-Test)

Groups	Test	Mean	N	Std. Dev	SEM	DM	t ratio
Experi-mental	Agility Pre-test	11.14	10	0.55	0.17	1.03	10.88*
	Agility Post-test	10.11	10	0.49	0.15		
Control	Agility Pre-test	11.13	10	0.56	0.17	0.09	1.71
	Agility Post-test	11.12	10	0.56	0.18		

Note: Significance level at 0.05

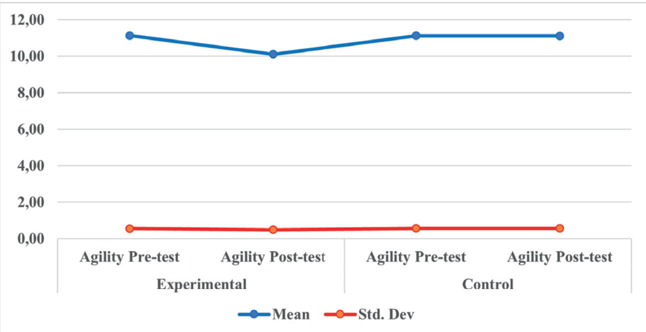

Figure 2. Performance of the experimental and control groups for agility

Table 2.
Four Corner Run Test (FCRT)

Groups	Test	Mean	N	Std. Dev	SEM	Mean Differ-ence	t ratio
Experi-mental	FCRT Pre-test	10.968	10	0.690	0.218	1.224	6.968*
	FCRT Post-test	9.744	10	0.673	0.213		
Control	FCRT Pre-test	10.917	10	0.643	0.203	0.071	1.578
	FCRT Post-test	10.846	10	0.647	0.204		

Note: Significance level at 0.05

In the Four Corner Run Test (FCRT), the experimental group showed a significant improvement between the pre-test and post-test, with the mean score decreasing from 10.968 to 9.744. The calculated t ratio of 6.968 is significantly higher than the table value of 2.262 at a 0.05 significance level with 9 degrees of freedom, indicating statistical significance ($p < 0.05$). The control group showed a small change, with pre-test and post-test means of 10.917 and 10.846, respectively. The t ratio for the control group was 1.578, which is below the table value of 2.262, suggesting that the difference is not statistically significant ($p > 0.05$). These results highlights that the training significantly improved the experimental group's FCRT, while in the control group, there were no significant changes. Figure 3 shows performance of the four-corner run test (FCRT) timing.

Table 3.
Performance Score (PS)

Groups	Test	Mean	N	Std. Dev	SEM	Mean Difference	t ratio
Experi-mental	PS Pre-test	94	10	11.734	3.711	15	6.708*
	PS Post-test	109	10	7.378	2.333		
Control	PS Pre-test	93	10	8.234	2.604	2	0.802
	PS Post-test	91	10	7.378	2.333		

Significance level at 0.05

In the Performance Score (PS) test, the experimental group showed a significant performance improvement, with the mean score increasing from 94 in the pre-test to 109 in the post-test. This significant improvement, reflected by a mean difference of 15 and a t ratio of 6.708, is more than the table value of 2.262 at a 0.05 significance level with 9 degrees of freedom, indicating statistical significance ($p < 0.05$). The control group showed a slight decline in scores, with pre-test and post-test means of 93 and 91, respectively. The mean difference of 2 and a t ratio of 0.802 are below the table value of 2.262, suggesting that the observed change is not statistically significant ($p > 0.05$). These results highlight that the training significantly improved the experimental group's performance scores, while in the control group, there were no significant changes. Figure 4 shows performance score (PS) for 4 corners.

The 4-corner assessment showed that right-handed players moved more quickly to the right-side corners, both front and back, compared to the left-side corners. The mean time to reach the right-side corners was significantly lower than the time to reach the left-side corners, indicating a potential area for targeted training to balance their movement efficiency across all directions.

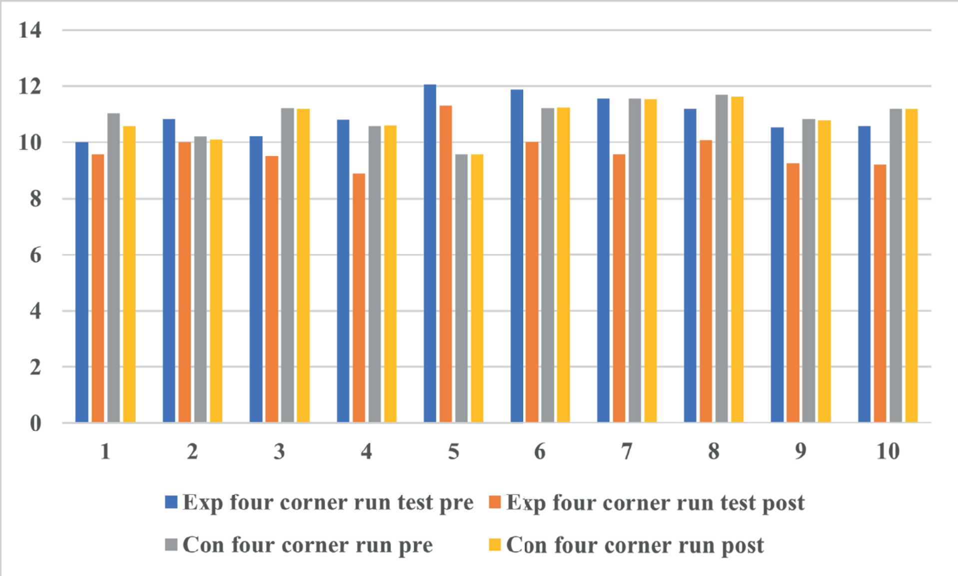

Figure 3. Performance of the Four Corner Run Test (FCRT) timing.

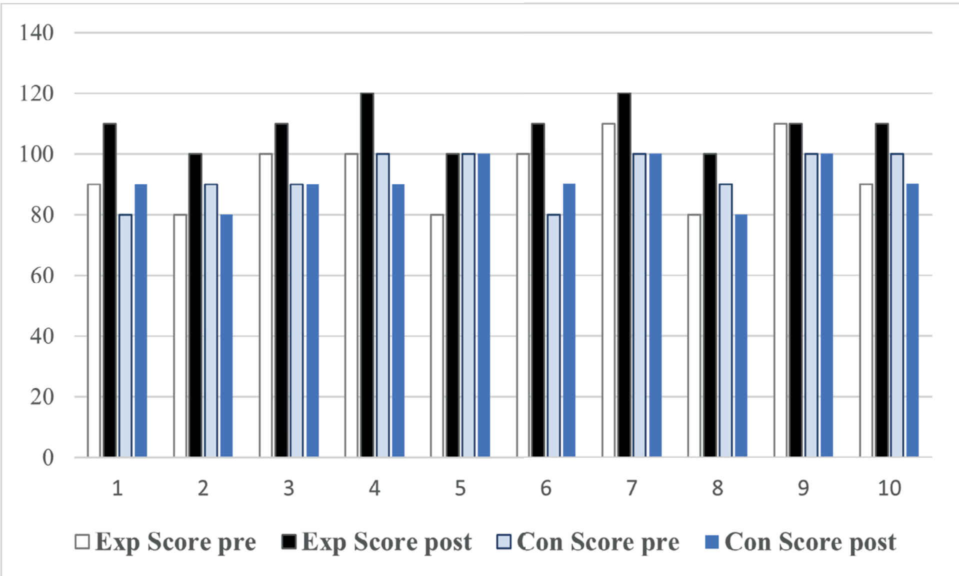

Figure 4. Performance Score (PS) for 4 corners.

DISCUSSION

The findings of this study offer valuable insights into the role of perceptual training in enhancing badminton performance. The implementation of the One-Way Mirror Screen as a training tool has shown considerable potential in developing critical skills that are essential for competitive play. This research demonstrates that incorporating visual obstacle training can significantly boost a player's agility (Kızılet et al, 2024), allowing them to move more efficiently and react swiftly to their opponent's actions.

In addition to physical agility, the study reveals that perceptual training markedly improves players' ability to anticipate their opponent's next move. Anticipation is a key element in badminton, where the speed of play demands rapid decision-making (Kızılet et al, 2024). The enhancement of this skill suggests that players who engage in such training may gain a strategic edge, being better prepared to counteract their opponent's strategies (Loffing et al., 2015).

The study also indicates a positive impact on neuromuscular coordination, which is crucial for executing precise movements and maintaining control during high-intensity rallies (Cece et al., 2020). The improvement in this area suggests that the training method used not only benefits perceptual abilities but also translates into more effective physical execution on the court.

Another significant aspect highlighted by the research is the enhancement of visual tracking and eye-hand coordination (Faber et al., 2019; Vickers, 2011). These improvements are fundamental to a player's ability to follow the shuttle's trajectory accurately and respond with precision (Russo & Ottoboni, 2019). The findings suggest that visual obstacle training could be particularly effective in honing these skills, which are often the difference between success and failure in high-stakes matches. (Williams et al., 2003; Hassan El-Gezawi, 2015).

The study also emphasizes the role of speed and accuracy, two elements that are intrinsically linked in badminton. The improvements observed in these areas further support the notion that perceptual training is an effective approach for developing a comprehensive skill set in players (Russo & Ottoboni, 2019).

The six-week training program utilizing the One-Way Mirror Screen had a significant impact on the performance of the experimental group compared to the control group (Farrow, 2013). Participants who underwent this specialized training demonstrated notable improvements in agility, reaction time, and decision-making, outperforming those who did not receive the intervention (Hopwood et al., 2011)

The One-Way Mirror Screen proved to be an effective tool in challenging and enhancing the players' perceptual and cognitive abilities, leading to superior performance outcomes. The training program also improved the players' ability to anticipate their opponent's moves and react quickly, suggesting that operating with limited visual information sharpened their focus and court awareness (Poliszczuk & Mosakowska, 2009). These findings highlight the potential of the One-Way Mirror Screen as an innovative addition to traditional training regimens, emphasizing the importance of perceptual training in developing the mental (Gobet, 2000) and physical coordination essential for success in badminton.

Overall, this study not only supports the integration of perceptual training into badminton practice but also opens the door for further exploration into how these methods can be applied across different sports (Appelbaum & Erickson, 2018). The promising results suggest that future research should continue to explore innovative training techniques that challenge traditional approaches, thereby contributing to the evolution of sports performance training (Roberts et al., 2019).

CONCLUSION

This research significantly contributes to the understanding of the effectiveness of perceptual training programs in badminton. The introduction of visual obstacle training, specifically using the One-Way Mirror Screen, has demonstrated notable improvements in several key areas of badminton performance. The study highlights that such training enhances agility, reaction time, and anticipation, all critical components for success in a fast-paced sport such as badminton. Additionally, the training positively impacts nerve stimulation and neuromuscular coordination, further refining the players' ability to respond swiftly and accurately during gameplay. The 4-corner assessment shows that right-handed players move to the right-side corners, both front and back, very quickly, but they move slowly and struggle to the left-side corners compared to the right. Hence, the study suggests that future research should more focus on left side as well as all directions of player movement. Moreover, the research underscores the importance of eye-hand coordination, speed play, visual tracking, and accuracy, all of which are crucial for high-level badminton performance. The findings suggest that incorporating perceptual training into regular practice routines can lead to significant advancements in these areas, ultimately improving overall player performance on the court. The positive outcomes observed in this study may serve as a foundation for future research, encouraging the exploration of similar training techniques in other sports and contexts, thereby further advancing the science of athletic performance enhancement.

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