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Pickleball Flight Dynamics

Dinámica de vuelo en pickleball

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Abstract

This paper considers the flight dynamics of the ball in the sport of pickleball. Various simplifications are introduced according to the features of the game. These simplifications and some approximations enable straightforward coding to study aspects of the game such as the trajectory of the ball and its velocity. In turn, strategic questions may be addressed that have not been previously considered. In particular, our primary research question involves the preference between playing with the wind versus against the wind. It is demonstrated that playing against the wind is often preferable than playing with the wind.

Keywords: *Pickleball, projectile motion, strategy.*

Resumen

Este artículo estudia la dinámica de vuelo de la pelota en el deporte del pickleball. Se introducen diversas simplificaciones en función de las características del juego, las cuales, junto con algunas aproximaciones, permiten una codificación sencilla para estudiar aspectos del juego como la trayectoria de la pelota y su velocidad. A su vez, se pueden abordar cuestiones estratégicas que no se habían considerado anteriormente. En concreto, la pregunta principal de investigación tiene que ver con la preferencia entre jugar con el viento o contra el viento. Se demuestra que jugar contra el viento es a menudo preferible en comparación a jugar con el viento.

Palabras clave: *pickleball, movimiento de proyectiles, estrategia.*

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INTRODUCTION

Pickleball is a relatively new sport. It was invented in 1985, and in recent years its popularity has taken off. Pickleball was the fastest growing sport from 2022 to 2023 in the United States with over 8.9 million participants (Sports & Fitness Industry Association, 2024). According to a 2023 report from the Association of Pickleball Players (APP), nearly 50 million Americans have played pickleball at least once in the previous year (https://www.theapp.global). The game is popular across wide age cohorts at the recreational level. Pickleball also has various professional leagues and tours including Major League Pickleball (MLP).

Despite the popularity of the sport, there has been little quantitative research on pickleball. Gill & Swartz (2019) consider the impact of strong and weak links on success in doubles pickleball. It is the intention of this paper to add to the sparse literature with a specific aim of gaining a better understanding of pickleball flight dynamics. Albert et al. (2017) consider problems in sports analytics across major sports.

The topic of projectile motion has a long and well-studied history (Lubarda & Lubarda, 2022) The details are complex, especially when considerations are given to the impact of air resistance and wind. Projectile motion models typically involve special functions and differential equations. Such work is important to serious investigations such as ballistics. In sport, Chudinov (2022) considers issues of approximate projectile motion in the sports of golf, tennis and badminton. However, there does not seem to be any literature on pickleball flight dynamics; this paper attempts to provide some initial insights on this topic.

In the problem considered here, we take features of the sport of pickleball into account. This, together with additional assumptions simplifies our projectile motion model. The final model is straightforward to code so that various investigations involving pickleball may be undertaken. In particular, we look at the impact of the wind in pickleball. Pickleball is often played outdoors where the choice of ends, and understanding how to play in the wind become issues of strategy. Our primary research question involves the preference between playing with the wind versus playing against the wind where it is demonstrated that playing against the wind is preferable in many contexts. This problem in pickleball strategy does not seem to have been previously addressed.

In Section 2, we provide a description of the relevant details of the pickleball court, and features of interest. We also define the relevant input variables to the projectile motion model. In Section 3, the basics of the pickleball motion model are described. In particular, we explain how features and strategies in the sport allow us to calculate input variables that are not immediately available. In Section 4, we look at various pickleball applications. In particular, we investigate pickleball trajectory and pickleball velocity under various conditions. We then discuss a question of strategy in terms of whether it is better to play against the wind or with the wind. The work indicates that a strategic advantage is often conferred when playing against the wind. We conclude with a short discussion in Section 5. Details regarding modelling and simulations are left to the Appendix.

PROBLEM FORMULATION

Figure 1 provides the relevant details of the pickleball court and features of interest. The pickleball court is 44 feet long which is divided into two equal halves by a net. The net is 3 feet tall at the ends although this detail is not important for our motion model.

In Figure 1, a launch point is depicted on the left side of the court. This is the location from which the player of interest strikes the pickleball. The location is marked x_0 feet from the left endline and serves as an input variable for our investigation. We have the constraint $x_0 \in (0, 15)$ feet where we note that the 15-foot mark denotes the beginning of the non-volley zone (i.e. the closest point to the net that the player should approach). The player strikes the ball at height y_0. We consider $y_0 \in (1, 3)$ feet as a range for the height at which the pickleball is struck. Although the pickleball can be struck from higher heights, this range corresponds to the situation where the ball is hit in an upwards trajectory. Further, the ball is struck at launch angle θ. For our purposes, we consider $\theta \in (10°, 30°)$. An angle larger than 30° either represents a lob shot or a mishit, two shots that are not relevant to this investigation.

In Figure 1, we also depict the opponent (i.e. the point of interest) on the right side of the court whose horizontal position is given by z_0 feet from the left endline. Later, we are interested in the opponent's ability to hit the struck ball. Since the opponent is not advised to stand in his non-volley zone, we have the constraint $z_0 \in (29, 44)$.

There are two quantities that are relevant to our investigation that are not depicted in Figure 1. First, the wind is a characteristic of interest. We make the assumption that the wind blows in a strictly horizontal direction. Our personal experiences in pickleball suggest that playing in winds which are less than 10 mph is largely inconsequential. On the other hand, playing in wind speeds exceeding 20 mph is extreme and is a situation that many players avoid. Therefore, we are interested in wind velocities w (i.e. speed and direction) in the intermediate intervals (-20, -10) mph and (10, 20) mph.

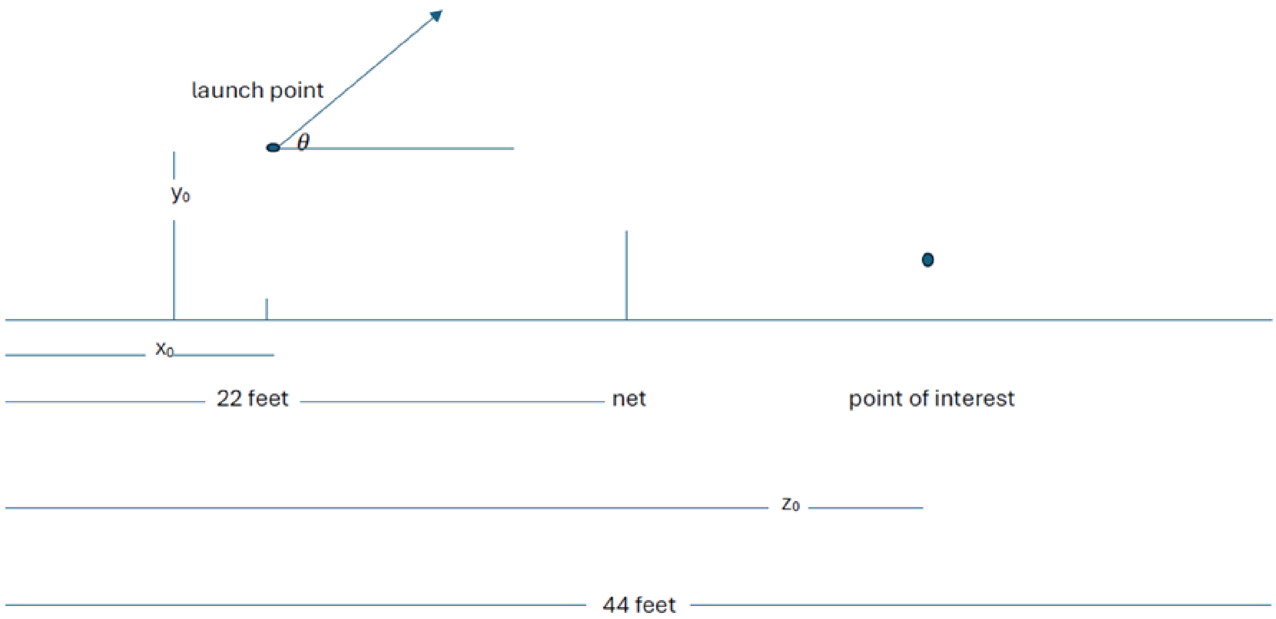

Figure 1. Configuration of the court and the variables related to the flight of the pickleball.

Second, we require the initial velocity v_0 which is velocity that the pickleball is struck at the launch point. In the related sport of tennis, the average serves in men's professional tennis (e.g. the ATP tour) is estimated at 120 mph. Unlike tennis, the pickleball paddle is rigid (without strings), and the ball is hard and compresses only negligibly. Therefore, the fastest pickleball shots reach instantaneous speeds of roughly 60 mph.

Therefore, to summarize, the input variables that are relevant to pickleball flight dynamics are (x_0, y_0, θ, z_0, w, v_0).

PICKLEBALL MOTION MODEL

This section describes the basics of the pickleball motion model. More details including the associated physics of the model are provided in the Appendix.

For this investigation, it is convenient to express the location and the speed of the pickleball in both the *x* and *y* coordinates. We denote the location and speed of the pickleball by x and x_0 in the horizontal direction, and by y and y_0 in the vertical direction.

Referring back to the discussion and the notation in Section 1, the coordinate speeds are expressed more fully as

$$x'(t,\theta,w,v_0) \text{ and } y'(t,\theta,w,v_0) \qquad (1)$$

The arguments of the speeds in (1) have common terms, namely the time from launch t, the launch angle θ, the wind velocity w and the initial velocity v_0. Of course, and as described in the Appendix, the functions in (1) also depend on the features of the pickleball (e.g. weight, size and surface) which determine the impact of air resistance. Also, the force of gravity comes into play in the vertical speed but not in the horizontal speed. In our model, we ignore the impact of spin.

In (1) we note that the speed functions depend on the launch angle θ and the initial velocity v_0. Since the initial coordinate speeds only depend on θ and v_0 through the initial coordinate speeds, using trigonometry in (1), we may replace θ and v_0 in x' by $v_0 \cos\theta$, and we may replace θ and v_0 in y' by $v_0 \sin\theta$. However, we retain the excessive notation in (1) which is helpful in future considerations.

For the coordinate locations, these are expressed more fully as

$$x(x_0, t, \theta, w, v_0) \text{ and } y'(y_0, t, \theta, w, v_0) \qquad (2)$$

The functions in (2) have the same arguments as in (1) except that the initial locations x_0 and y_0 also influence location at time *t*.

It may be noted that the relationship between location and velocity allows us to express the locations functions as $x(x_0, t, \theta, w, v_0) = x_0 + \int_0^t x'(s, \theta, w, v_0)ds$ and $y(y_0, t, \theta, w, v_0) = y_0 + \int_0^t y'(s, \theta, w, v_0)ds$. However, these expressions do not assist our development since the integrands are intractable functions.

A Pickleball Simplification

A primary interest in our research concerns the issue of playing in the wind; should you prefer to play with the wind or play against the wind?

Of course, in pickleball, there are various types of shots and these include lobs, dink shots, smashes, drops, drives, etc. For the time being, we are going to restrict our attention to drive shots.

With respect to drive shots, we simplify aspects of the motion model by considering some standard pickleball strategy. Referring to Figure 1, we assume that the player on the left-hand side of the court (i.e. the launch point) hits the ball as hard as possible such that the ball would remain in bounds if left untouched. This assumption is sensible for drive shots in pickleball. Players hit the ball hard because high speed shots pose difficulty for the opponent; in particular, the opponent has less time to react. Hitting the ball as described, means that the ball, if left untouched, would land on the endline on the right-hand side of the court. Therefore, hitting the ball in this manner may be considered optimal for drive shots in pickleball.

We denote *tb* as the hypothetical time that it would take the hard-hit ball to bounce on the right endline. Because the length of the court is 44 feet, we can express this constraint as

$$y(y_0, t_b, \theta, w, v_0) = 0, x(x_0, t_b, \theta, w, v_0) = 44 \qquad (3)$$

With equations (3), we are going to investigate various cases involving the input settings x_0, θ and w. In other words, x_0, θ and w are values that are determined in advance. Therefore, (3) represents two equations in two unknowns, *tb* and v_0. Using the model described in the Appendix and the associated numerical methods, we are able to solve for *tb* and v_0. This is particularly helpful since these are two quantities for which little is known apriori.

Having solved for v_0, we can then consider the equation

$$x(x_0,t,\theta,w,v_0) = z_0 \qquad (4)$$

for an unknown time *t*. Equation (4) addresses the time that it takes the ball from when it is struck to reach the opponent (i.e. the location of interest in Figure 1 which is z_0 feet from the left endline).

From (4), we are able to solve for *t*. When *t* is small, this means that there is little time for the opponent to react with their return shot. Therefore, the shot would be a very good shot. Consequently, for wind speeds w and $-w$, we can assess whether it is better to play with or against the wind in the context of a drive. This problem is studied in Section 4.3.

APPLICATIONS

Pickleball Trajectory

Using the motion model described in the Appendix for drive shots and the associated numerical methods, we are able to compute both the horizontal location $x(x_0, t, \theta, w, v_0)$ and the vertical location $y(y_0, t, \theta, w, v_0)$ given the input variables. The resulting (x, y) coordinates taken over a sequence of times *t* allow us to produce trajectory plots. Note that our code allows us to do this over any set of input variables.

In Figure 2, we provide plots for input values x_0 = 11 feet (which corresponds to the middle of the left court), y_0 = 3 feet (which is a typical height from where the ball is hit) and θ = 20 degrees (which is a typical launch angle). Four plots are provided; for wind speeds w = -10 mph, w = 0 mph (no wind), w = 10 mph and w = 15 mph. The initial velocity input v_0 is evaluated according to the optimality conditions (3) described in Section 3.1.

In Figure 2, we observe that the trajectories for wind speeds w = 0, 10, 15 mph do not differ greatly. However, when playing against the wind (i.e. w = -10 mph), the pickleball flight has greater curvature with a higher arc. It appears that the pickleball (which is light) gets held up by the wind. Towards the end of the path when playing against the wind, the pickleball is moving more in a downward vertical direction than horizontally.

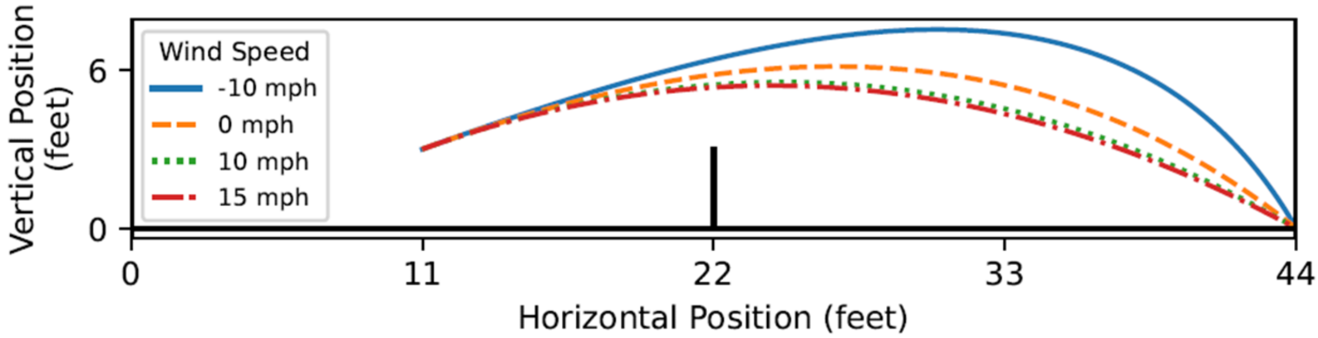

Figure 2. Trajectory of an optimally hit drive shot in four wind conditions w = -10 mph, w = 0 mph, w = 10 mph and w = 15 mph. Other input values are set at x_0 = 11 feet, y_0 = 3 feet and θ = 20 degrees.

Pickleball Velocity

We now consider an exercise with the same input values as given in Section 4.1. However, this time we calculate the velocity functions $x_0(t, \theta, w, v_0)$ and $y_0(t, \theta, w, v_0)$. We evaluate the coordinate velocities x' and y' for increasing times t. Then, the overall speed v is calculated via $v = [(x')^2 + (y')^2]^{1/2}$. In Figure 3, we plot v versus the horizontal location x under the wind conditions w = -10 mph, w = 0 mph, w = 10 mph and w = 15 mph.

In Figure 3, we again observe that the condition of playing against wind (i.e. w = -10 mph) is significantly different from the other three cases. For example, the initial velocity v_0 is greatest when playing against the wind. This is necessary in order for the shot to reach the right endline. When playing against the wind, we also observe greater initial deceleration (i.e. the slope of the velocity curve is steeper). On the other hand, when playing with the wind, the ball maintains a similar velocity throughout its path. Under all four wind conditions, we see that the pickleball speed is similar (approximately 24 mph) at the horizontal position 27 feet. The 27-foot position is close to the boundary of the non-volley zone (NVZ) on the right-hand side of the court. From a playing perspective, this is interesting since the NVZ boundary is widely regarded as being the most strategic position.

Strategy - Playing in the Wind

Here we return to the primary strategic question: is it better to play with the wind or against the wind?

As mentioned at the beginning of Section 3.1, there are various shots in pickleball. Some shots are infrequent (e.g. lob shots). Smash shots are also less common than other shots, although it is apparent that a trailing wind makes smash shots even faster (i.e. more difficult to handle). Alternatively, some shots are not greatly affected by the wind. For example, dink shots are soft shots taken close to the net; consequently, they are not in the air for long periods of time. A case could be made that it is preferable to play against the wind when hitting the common drop shot. Against the wind, a player needs to worry less about \popping up” their drop shot and having it smashed back. The drop shot will be pushed down by the wind. Therefore, before endorsing playing against the wind over playing with the wind, we need to look at the common drive shot.

We now consider the merits of playing against the wind versus playing with the wind in the context of drive shots. For drive shots, we assume that the player of interest has played optimally in the sense that the ball is hit hard enough to bounce on the right endline should it be left untouched.

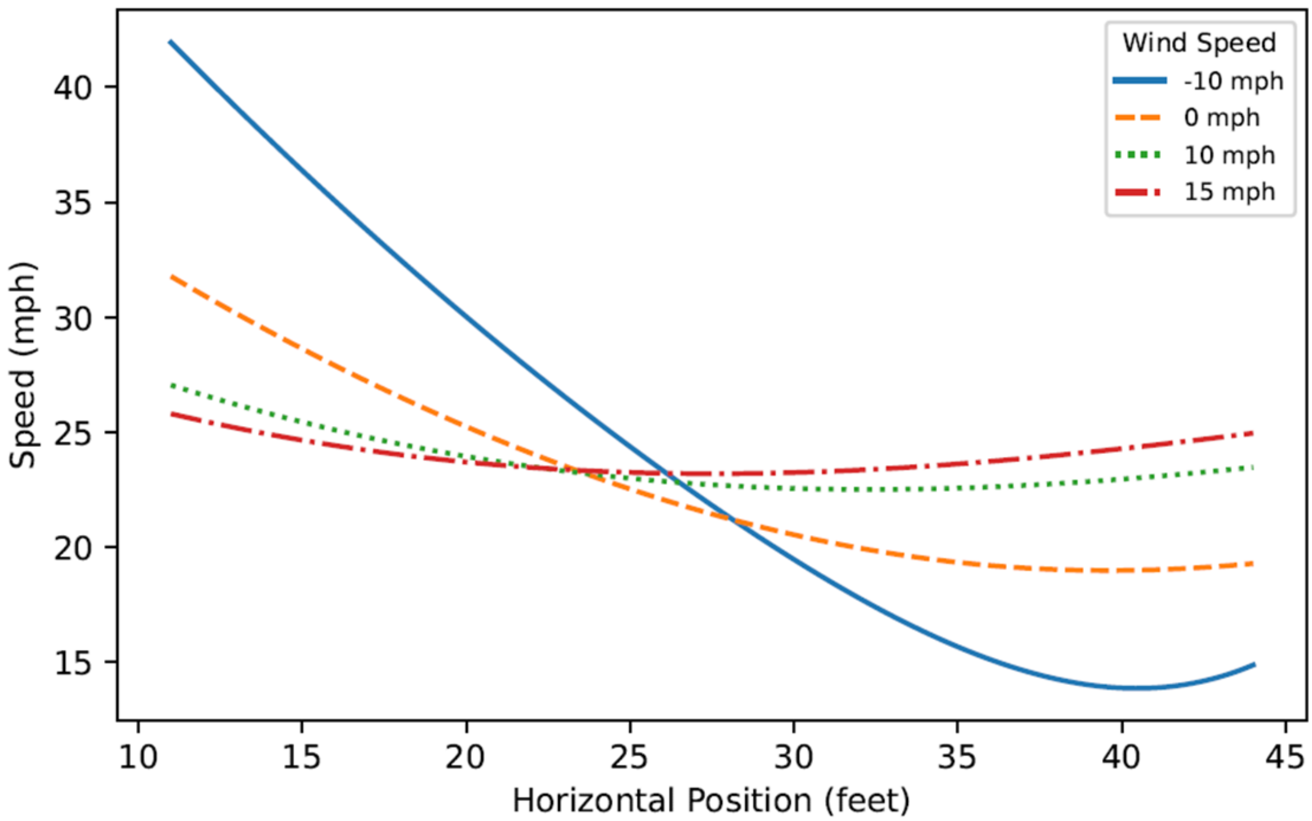

Figure 3. Speed of an optimally hit drive shot in four wind conditions, w = -10 mph, w = 0 mph, w = 10 mph and w = 15 mph plotted against the horizontal location. Other input values are set at x_0 = 11 feet, y_0 = 3 feet and θ = 20 degrees.

We use the general approach described in Section 3.1 to evaluate the time that it takes the ball to reach the opponent (i.e. point of interest in Figure 1). If it takes less time to reach the opponent playing with the wind, then playing with the wind is preferred. If it takes less time to reach the opponent playing against the wind, then playing against the wind is preferred. We calculate time differences under the following conditions: x_0 = 0, 11, 15 feet (corresponding to endline, mid-court and non-volley zone) for the player executing the shot, z_0 = 29, 33, 44 feet (corresponding to non-volley zone, mid-court and endline) for the opponent, launch angle θ = 20 degrees and launch height y_0 = 3 feet.

Letting t_w denote the time in seconds that it takes the ball to reach the opponent with an assisting wind $w \geq 0$, we consider the excess time difference $D_w = t_w - t_{-w}$ that it takes for the ball to reach the opponent when playing with the wind compared to when playing against the wind. This is evaluated for the wind conditions w = 10 mph, w = 15 mph and w = 20 mph. Table 1 provides the results. We note that the time difference results in Table 1 are not greatly sensitive to minor modifications in the values of θ and y_0.

Table 1.
Excess time difference in seconds Dw that it takes the drive shot to reach the opponent when playing with the wind compared to when playing against the wind where w is recorded in mph.

x_0	z_0	D_{10}	D_{15}	D_{20}
0	29	0.097	0.200	0.346
0	33	0.056	0.166	0.348
0	44	-0.302	-0.490	0.089
11	29	0.082	0.150	0.242
11	33	0.058	0.133	0.255
11	44	-0.230	-0.375	-0.568
15	29	0.075	0.131	0.203
15	33	0.059	0.124	0.223
15	44	-0.203	-0.332	-0.505

Note. The calculations are carried out using 9 combinations of x_0 and z_0, and using typical settings θ = 20 degrees and y_0 = 3 feet.

From Table 1, we observe that most of the D_w entries are positive. This suggests that there is a competitive advantage to playing against the wind when hitting the common drive shot. The ball reaches the opponent faster and there is less time for the opponent to react when playing against the wind. The only situations where D_w is negative correspond to the setting z_0 = 44 feet (i.e. the opponent is located on the right endline). This is noteworthy since it is generally accepted pickleball strategy to approach the non-volley zone, and not sit back at the right endline.

It is also interesting to look at the row with input settings x_0 = 15 feet and z_0 = 29 feet. This corresponds to the common situation where both players have approached the non-volley zone and are as close as possible. Here, we see that as the wind w increases, D_w increases. That is, the advantage of playing against the wind becomes greater as the wind blows harder. In fact, this same phenomenon is observed in all situations in Table 1 whenever $z_0 \neq 44$ feet.

DISCUSSION

This paper appears to be the first serious investigation of flight dynamics in the sport of pickleball. Our main contribution is one of strategy; we argue that playing against wind is generally preferable to playing with the wind. Previously, there appeared to be no consensus opinion on the preference. The work is based on a detailed physical model that takes into account relevant inputs including air resistance and wind. Python code is provided in a Github page (see the Appendix) that allows researchers to graph pickleball trajectories and velocities under various conditions.

Although the results provided in this paper correspond to our intuition and were derived from existing knowledge of projectile motion, it would be good to verify some of the results against video taken from pickleball matches. In future research, it may also be useful to consider additional wind environments such as crosswinds.

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REFERENCES

Albert, J., Glickman, M. E., Swartz, T. B., & Koning, R. H. (Eds.). (2017). *Handbook of statistical methods and analyses in sports*. Crc Press.

Chudinov, P. (2022). Projectile motion in a medium with quadratic drag at constant horizontal wind. *arXiv preprint arXiv:2206.02397*. https://doi.org/10.48550/arXiv.2206.02397

Dormand, J. R., & Prince, P. J. (1980). A family of embedded Runge-Kutta formulae. *Journal of computational and applied mathematics*, *6*(1), 19-26. https://doi.org/10.1016/0771-050X(80)90013-3

Gill, P. S., & Swartz, T. B. (2019). A characterization of the degree of weak and strong links in doubles sports. *Journal of Quantitative Analysis in Sports, 15*(2), 155-162. https://doi.org/10.1515/jqas-2018-0080

Lubarda, M. V., & Lubarda, V. A. (2022). A review of the analysis of wind-influenced projectile motion in the presence of linear and nonlinear drag force. *Archive of Applied Mechanics, 92*(7), 1997-2017. https://doi.org/10.1007/s00419-022-02173-7

Munson, B. R., Young, D. F., & Okiishi, T. H. (1997). *Fundamentals of Fluid Mechanics* (3rd. ed). John Wiley & Sons Inc.

Rossmann, J., & Rau, A. (2007). An experimental study of Wiffle ball aerodynamics. *American Journal of Physics, 75*(12), 1099-1105. https://doi.org/10.1119/1.2787013

Sports & Fitness Industry Association (2024). *2023 Sports, Fitness, and Leisure Activities Topline Participation Report*. https://sfia.users.membersuite.com/shop/store/f147b189-00ce-c703-0f83-0b450aa46a95/detail

Virtanen, P., Gommers, R., Oliphant, T. E., Haberland, M., Reddy, T., Cournapeau, D., Burovski, E., Peterson, P., Weckesser, W., Bright, J., van der Walt, S. J., Brett, M., Wilson, J., Millman K. J., Mayorov, N., Nelson, A. R. J., Jones, E., Kern, R.,Larson, E., Carey, C. J., Polat, I., Feng, Y., Moore, E. W., van der Plas, J., Laxalde, D., Perktold, J., Cimrman, R., Henriksen, I., Quintero, E. A., Harris, C. R., Archibald, A. M., Ribeiro, A. H., Pedregosa, F., Van Mulbregt, P., & SciPy 1.0 Contributors. (2020). SciPy 1.0: fundamental algorithms for scientific computing in Python. *Nature methods, 17*(3), 261-272. https://doi.org/10.1038/s41592-020-0772-5

APPENDIX

This section provides details regarding the pickleball motion model. It is a projectile equation which takes into account the air resistance and wind speed. A similar model has been used by Chudinov (2022) to study the projectile motion in three other sports: badminton, tennis and golf. Before presenting the full mathematical equation, we introduce and recall previous notation related to the pickleball and its motion:

m: mass

t: flight time

(*x*, *y*): coordinates

$\vec{v} = (x', y')$: velocity

$\vec{v} = |\vec{v}|$: speed

v_0: initial speed

θ: initial launch angle

w: horizontal constant wind speed.

The equation for projectile motion follows from Newton's second law, where we only take into account the gravity and air resistance acting on the pickleball. The air resistance or the drag force is given by

$$\vec{F} = \frac{1}{2}\rho C_d A\left(\vec{v} - (w,0)\right)\left|\vec{v} - (w,0)\right| \quad (5)$$

where

- *ρ* is the density of the air,
- *A* is the cross-sectional area of the pickleball,
- $\vec{v} - (w, 0)$ is the relative velocity of the pickleball with respect to the wind,
- C_d is the drag coefficient.

The drag coefficient varies with the Reynolds number

$$R_e = \frac{\rho U D}{\mu}$$

where *U* is the pickleball speed relative to the air, *D* is the diameter of the ball, *ρ* is the air density, and *μ* is the dynamic viscosity of the atmosphere. The relation between C_d and R_e is in general a complicated nonlinear function that depends on the object shape, the object orientation, and characteristics of the air ow. Examples of C_d for a smooth cylinder and a smooth sphere are shown in Figure 4, which was taken from Munson et al. (1997).

Though the functional form of C_d can vary depending on the situation, it is roughly proportional to R_e^{-1} for low Reynolds numbers while turbulence, or irregular air motion, is minimal. At larger Reynolds numbers, when there is significant turbulence, C_d evens out to stay roughly constant. As we can see from Fig. 4, the C_d value for a smooth sphere stays on the same order of magnitude from a Reynolds number of about 10^3 onward, though with a dip around 10^5 before returning to its constant behaviour. Rougher surfaces tend to lower this threshold Reynolds number by increasing the turbulence around the sphere. Thus, we expect the holes in a pickleball to reduce the Reynolds number required to produce a roughly constant C_d to a value even lower than 10^3.

The parameters in our problem correspond to $R_e \gtrapprox. 2.5 \times 10^4$, which is well above the threshold of 103. Thus, we conclude that C_d should stay roughly constant. In terms of the exact value of this constant, since we could not find any experimental measurements of C_d for pickleballs, we approximated the C_d value by treating the pickleball as a forward-facing wiffleball and using the experimental results found by Rossmann & Rau (2007). This gave us a constant C_d of approximately 0.6 to use in Equation (5). The constant drag coefficient leads to a quadratic dependence of the drag force on the relative velocity instead of a linear one as often used in projectile equations. The full system then has the form

$$mx''(t) = \frac{1}{2}\rho C_d A(x'(t) - w)\sqrt{(x'(t) - w^2) + \left(y'(t)\right)^2},$$

$$my'(t) = g - \tfrac{1}{2}\rho C_d A(y'(t) - w)\sqrt{(x'(t) - w^2) + \left(y'(t)\right)^2}, \tag{7}$$

$$(x(0), y(0)) = (x_0, y_0), \quad (x'(0), y'(0)) = \left(x'(0), y'(0)\right) = (v_0 \cos\theta\,, v_0 \sin\theta),$$

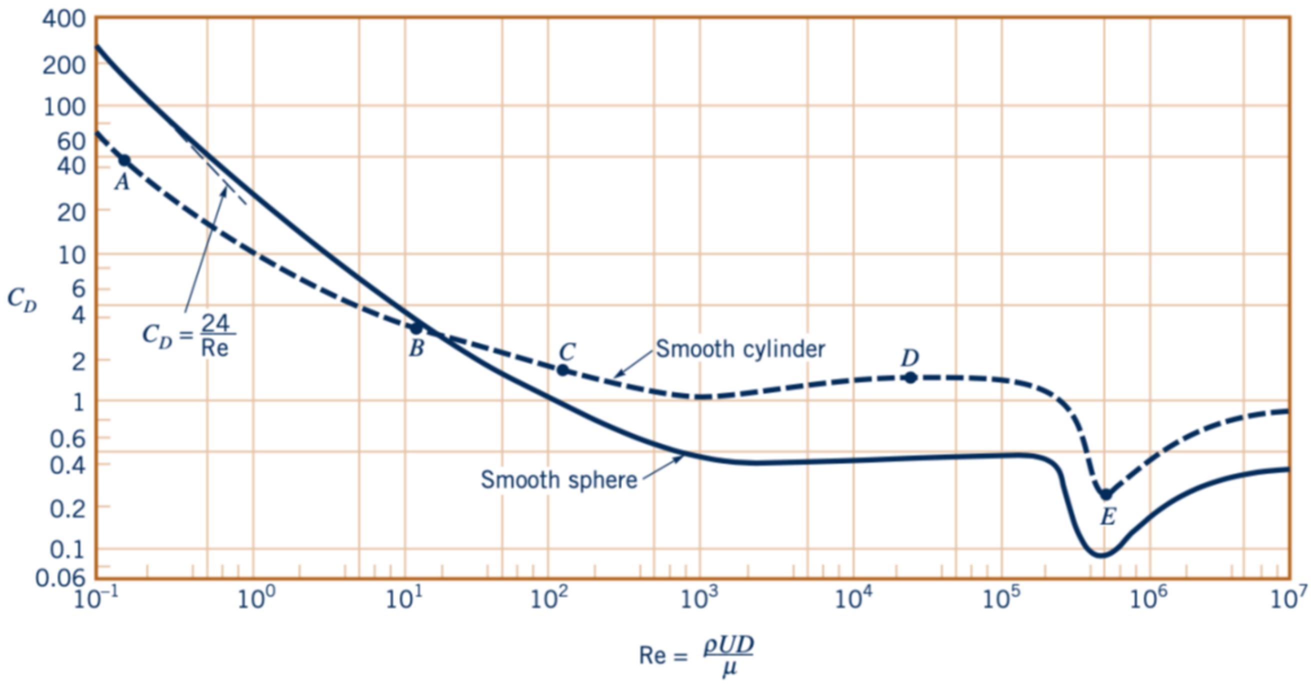

Figure 4. Examples of C_d for a smooth cylinder and a smooth sphere.
Source: Munson et al. (1997, p. 520)

where C_d is 0.6 as stated before, g is the gravitational constant 9,18 m/s², ρ is a standard atmospheric density of 1.2 kg/m³, A is a standard cross-sectional area for a pickleball of $\pi \times (37\text{ mm})^2$, m is a standard pickleball mass of 24 g, (x', y') denote the first order time derivatives which give the velocity and (x'', y'') denote the second order time derivatives which give the acceleration of the ball.

System (7) is solved numerically using the explicit Runge-Kutta method of order 5(4) provided by default in Scipy's (Virtanen et al., 2020) **solve_ivp** function (Dormand & Prince, 1980). The initial speed v_0 given implicitly by conditions in (3) are determined by using Scipy's fsolve function to numerically solve for the roots of (x – 44, y), using the $x(t)$, $y(t)$ functions we found. The Python code used to accomplish this is hosted at https://github.com/0Strategist0/Pickleball.

It should be noted that though our choice of C_d is reasonable given the data we had and seems to produce pickleball trajectories and velocities similar to what is often measured, the true C_d for a pickleball could in principle vary by roughly ±0.5 in certain conditions. We did test several such alternate C_d values, and the exact numerical values for the time differences D_w we obtained could be signifficantly different than the ones shown in this paper. However, the signs of all these time differences were preserved after varying C_d, meaning that our main conclusions about whether to play with or against the wind seem to hold regardless of the specific value of C_d. It would be interesting for future work to obtain experimental data measuring C_d at a variety of Reynolds numbers, allowing for comparison with our model and the computation of more accurate numerical results.

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DOI: 10.30827/ijrss.33250

The relationship between tennis participation and wellbeing: a survey of 2287 adults

La relación entre la participación en tenis y el bienestar: una encuesta con 2287 adultos

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Abstract

Sports participation is associated with better wellbeing in adults. Despite its popularity globally, little is known about the relationship with tennis participation and wellbeing. We conducted a survey in the United Kingdom to understand the relationship between playing tennis and wellbeing in adults. A cross-sectional survey among healthy adults aged over 18 was conducted including tennis players and non-tennis players. Information was collected on sociodemographic, frequency of playing tennis, length played tennis for and a 10 item self-rated scale on State of Mind score (scored 0-100, higher scores=greater wellbeing). Data were analysed using mean and standard deviations, Kruskal-Wallis, Mann-Whitney and chi-square tests to compare groups as well as zero-inflated negative binomial models for the main analysis. Tennis players presented 13% higher scores than their peers (69 vs. 61; p<0.001). In the main analysis, playing tennis was associated with a higher state of mind (IRR: 1.10; 95%CI: 1.07-1.13). All the categories of years playing tennis had higher state of mind compared to non-players (0-5 years: 1.11; 1.07-1.16. 5-10 years: 1.08; 1.02-1.15. >10 years: 1.10; 1.06-1.13). Only the category of >1day/week of playing tennis was associated with higher state of mind compared to the group with <1 day/week (1.08; 1.04-1.12). Tennis players that trained regularly without competing, also presented higher state of mind scores compared to those playing tennis for fun (1.07; 1.01-1.13). In conclusion, our survey suggests that playing tennis is associated with higher wellbeing. Future large scale, prospective studies are required to understand the directionality of these findings.

Keywords: *Pickleball, projectile motion, strategy.*

Resumen

La participación en deportes de adultos es asociada con un mejor bienestar. A pesar de su popularidad a nivel global, se sabe poco sobre la relación entre la participación en tenis y el bienestar. Por lo tanto, se realizó una encuesta en Reino Unido para entender la relación entre jugar tenis y el bienestar en adultos. Se completó una encuesta transversal entre adultos saludables mayores de 18 años, la cual incluyó jugadores y no jugadores de tenis. La información recolectada estuvo relacionada con la sociodemogragfía, la frecuencia con la que jugaban tenis y por cuánto tiempo habían jugado. Adicionalmente, se incluyó una escala autoevaluada de 10 elementos sobre el estado de ánimo (de 0 a 100, mayor puntaje=mayor bienestar). Se analizaron los datos usando desviaciones media y estándar y las pruebas Kruskal-Wallis, Mann-Whitney y chi-cuadrado para comparar los grupos. También se utilizaron modelos binomiales negativos inflados a cero para el análisis principal. Los jugadores de tenis tuvieron puntajes un 13 % más altos que sus contrapartes (69 vs. 61; p<0.001). En el análisis principal, jugar tenis estuvo asociado con un mejor estado de ánimo (RTI: 1,10; 95 % IC: 1,07-1,13).

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Todas las categorías de años jugando tenis tuvieron un mejor estado de ánimo en comparación a los no jugadores (0-5 años: 1,11; 1,07-1,16. 5-10 años: 1,08; 1,02-1,15. >10 años: 1,10; 1,06-1,13). Solo la categoría de >1 día/semana jugando tenis fue asociada con un mejor estado de ánimo en comparación al del grupo con <1 día/semana (1,08; 1,04-1,12). Los jugadores de tenis que entrenaron de manera regular sin competir también presentaron puntajes superiores en el estado de ánimo en comparación con los que jugaban tenis por diversión (1,07; 1,01-1,13). En conclusión, nuestra encuesta sugiere que jugar tenis está asociado con un mayor bienestar. Es necesario realizar estudios prospectivos a mayor escala para entender la direccionalidad de estos hallazgos.

Palabras clave: *tenis, deportes de raqueta, bienestar, salud mental, deporte.*

INTRODUCTION

There is an abundance of evidence that illustrates that engagement in physical activity promotes healthy ageing, reduces the risk of multiple long-term conditions and reduces the risk of a premature death (Daskalopoulou et al., 2017; Anderson & Durstine, 2019; Zhao et al., 2020). Further, physical activity engagement offers protection of cognitive decline and prevention of the onset of poor mental health or disorders (Iso-Markku et al., 2024 Schuch et al., 2018). Despite these benefits, large proportions of the population do not meet the recommended guidelines for physical activity for health (Bull et al., 2020).

Participation in sports is one way where individuals can attempt to master a sport, experience fun and often have social connection. There is good evidence that various forms of sports participation have multiple health benefits (Oja et al., 2015). A previous meta-analysis (Oja et al., 2015) investigated the health benefits of 26 sports on adults and found support that running, and football were associated with a range of physical health and fitness benefits. Substantially less research has considered the mental health and wellbeing benefits of sports participation. For instance, a recent systematic review on the mental health benefits of sports participation (Eather et al., 2023) found that there is emerging evidence for the mental health benefits of sports participation for adults but for most sports, limited conclusions could be made.

Worldwide, tennis is one of the most participated sports with an excess of 87 million people playing worldwide (International Tennis Federation [ITF], 2022). Despite the popularity of tennis, previous research is sparse on the health and wellbeing benefits of tennis participation on health and wellbeing. For instance, a previous systematic review (Eather et al., 2023) investigating all sports and mental health identified only one study that reported the wellbeing benefits of tennis. The study included 793 adults in Australia and focussed on multiple sports and suggested in their cross-sectional survey playing tennis is positive for mental health (Eime et al., 2014). An earlier systematic review on all health benefits of tennis did not identify any study that investigated the mental health benefits of tennis in the general population (Pluim et al., 2018). Despite the lack of published research, opinion pieces and media articles have repeatedly talked about the mental health benefits of tennis (Sayer, 2023).

Given the popularity of playing tennis, the potential to influence mental health and paucity of evidence to support this widely held claim, we set out to conduct a survey of tennis participation and wellbeing in adults in the United Kingdom (UK). Specifically, we sought to understand if playing to understand the potential association between playing tennis and wellbeing across genders, age groups and based on the tennis player characteristics (frequency of play and number of years playing tennis). Given the high levels of dropout from sports participation in adolescence, (Back et al., 2022) we also sought to understand how the reasons for playing tennis differed among those who dropped out of tennis during adolescence and those that did not

METHODS

A cross-sectional study design was developed, and data collected between April and June 2024. An a-priori minimum sample size of 1,000 adults was set. The survey adopted a naturalistic approach. There was not set quotient made for the number or proportion of people according to age, sex or type of tennis player. Healthy adult volunteers who were resident in the UK were invited to complete the anonymous survey via the secure survey platform Qualtrics. Participants were recruited via a snowball method online and via social media platforms (LinkedIn, X, Instagram). The inclusion criteria included people who had never played tennis or were tennis players (of any type, but not professional tennis players), residents in the UK, adults aged over 18 years of age and able to understand English. After reading the participant information sheet and people confirming they met the eligibility criteria, informed consent was taken, and University ethical approval was gained (MRA-23/24-43024). The survey was designed in line with GDPR regulations.

Sociodemographic information

Participants were asked to provide information on age (18-27, 28-43, 44-59, 60-69, 70-78, 79 and above) and gender (Male, female, non-binary or non-conforming, transgender, prefer not to say). Information on the geographic location in the UK was obtained (Regions in England: London, Northeast, Northwest, Yorkshire & Humber, West Midlands, East Midlands, East of England, South east, South West, Scotland, Wales and

Norther Ireland). For those in London, information was collected on the specific borough in London.

Wellbeing/ State of Mind measurement

An estimation of wellbeing was captured with a 10 item State of Mind measure (ASICS, 2024). The State of Mind measure asks participations to self-rate their feelings over the past month on a scale from 1-10, with 1=not at all and 10 = extremely. The 10 items include 1) felt in control; 2) felt relaxed; 3) felt content; 4) felt positive; 5) felt confident; 6) coping well with stress; 7) memory has been sharp; 8) felt calm; 9) felt focussed; 10) felt energised. Each item is weighted equally and the total for each item is added together producing a score ranging from 10 (lowest wellbeing) to 100) highest wellbeing). Whilst there is no universally agreed definition of wellbeing, it is generally considered to be a positive state of mind in life (Linton et al., 2016). A recent systematic review of 99 welbeing measures noted there is not a universally accepted or standardised tool, but the optimal measures should include a person's feelings, function and cognitive function (Linton et al., 2016). These are all factors which are included in the State of Mind Measure we used, although this has not been "validated" (there is no universally accepted and valid instrument for wellbeing).

Tennis participation

Participants were asked if they had every played tennis and those that had not were the comparison group. Tennis players were subsequently asked to rate how long they had been playing tennis (do not play tennis, 0-5 years, 6-10 years, >10 years), frequency of play (more than once a week, once a week, less than once a week) and type of player (competitive, trained regularly but do not compete, leisure player). Tennis players were also asked if they stopped playing tennis in their adolescence for any reasons. Tennis players were also asked to rate the reasons they played tennis (agree, neutral or disagree) across 15 items. The tennis players were compared to people who reported they had never played tennis.

Statistical analysis

Values were presented as medians and interquartile ranges or as relative frequencies, describing the outcomes according to the covariates. The Kruskal-Wallis test was used to assess potential differences among three or more groups, while the Mann-Whitney test was employed as a post hoc test for between-group differences and to evaluate differences between two independent groups. The chi-square test was used to detect potential differences between two groups or trends in frequencies. Zero-inflated negative binomial regression models were used considering that state of mind was zero-inflated, with a skewed distribution. Values were presented as incident risk rate, which can be interpreted as a percentage of outcome variation in case of a cross-sectional analysis. The significance level was set at $p < 0.05$. All analyses were conducted using the software Stata 18.0 (StataCorp, College Station, TX).

RESULTS

The sample was composed of 2287 participants (907 women), from which 9.8% were 18-27 years old, 30.9% were 28-43 years old, 43.9% were 44-59 years old, 12.6% were 60-69 years old, and 2.6% were 70-78 years old (Table 1). The total state of mind (SOM) score according to gender is presented in Figure 1 (panel A). Men presented with a 6% higher SOM score than women (67 vs. 63; p=0.026). Panel B from Figure 1 shows the state of mind scores according to age groups. The group aged 44-59 years (score = 66) presented higher scores than the groups aged 18-27 (score = 66) and 28-43 (score = 60), while the group aged 60-69 (score = 74) and 70-78 (score = 72) presented higher scores compared with the three younger groups.

Table 1.
Characteristics of the sample.

Variable	Category	n (%)
Gender	Male	907 (39.8)
	Female	1375 (60.3)
Age group	18-27	223 (9.8)
	28-43	705 (30.9)
	44-59	1004 (43.9)
	60-69	288 (12.6)
	70-79	64 (2.8)
Region	East Midlands	100 (4.4)
	East of England	120 (5.3)
	London	640 (28.1)
	North East	76 (3.3)
	North West	184 (8.1)
	Northern Ireland	44 (1.9)
	Scotland	100 (4.4)
	South East	416 (18.2)
	South West	260 (11.4)
	Wales	99 (4.3)
	West Midlands	136 (6.0)
	Yorkshire & Humber	76 (3.3)
	Missing	31 (1.4)

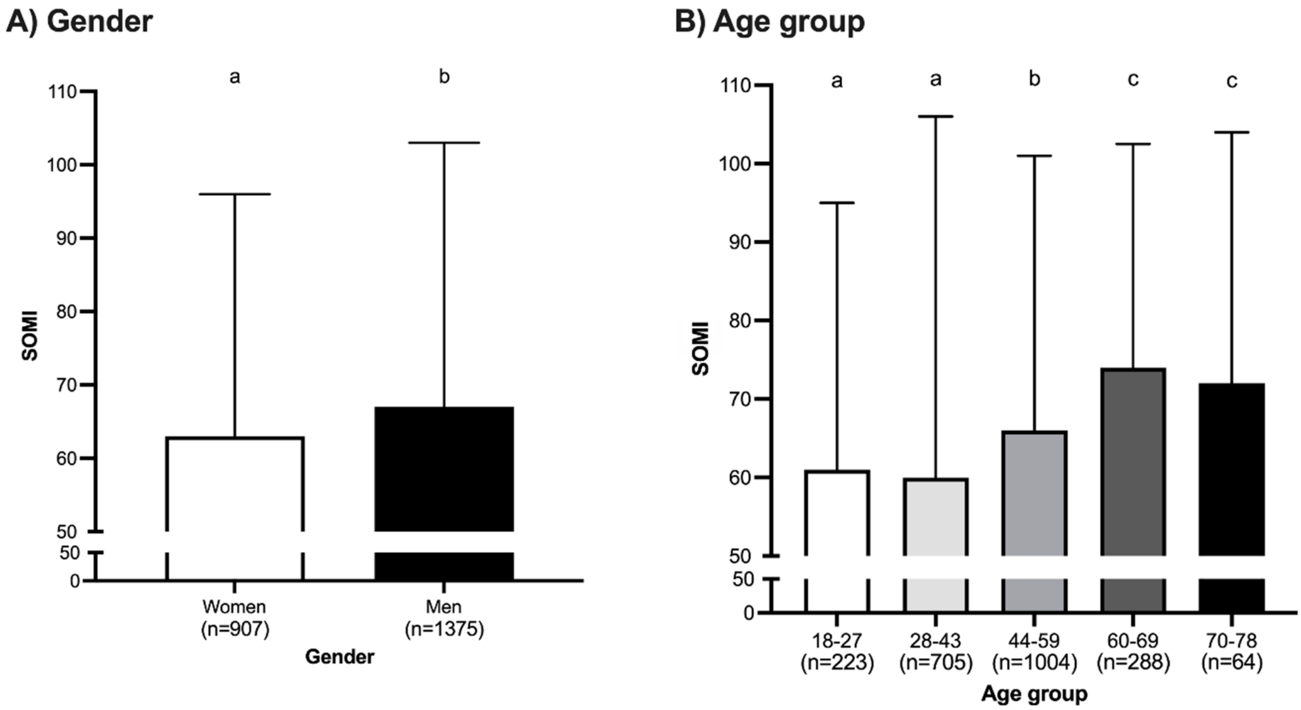

Figure 1. State of mind according to gender and age group.
Note. Different letters represent significant differences between groups.

Figure 2 shows state of mind scores according to tennis participation (panel A), frequency of playing tennis (panel B), years playing tennis (panel C), and type of tennis player (panel D). Tennis players presented 13% higher scores than their peers (69 vs. 61; p<0.001). There was a linear increase in the state of mind scores according to the frequency of tennis playing, with the group playing once a week presenting a 13% higher score than those playing less than once a week (69 vs. 61) and the group playing more than once a week (score = 71.5) presenting 4% higher scores than those playing once a week and 17% higher scores than those playing less than once a week. Considering how long the participants reported playing tennis, the groups playing tennis for 0-5 years (score = 70), 5-10 years (score = 69.5), and >10 years (score = 69) presented higher state of mind scores than those that never played tennis. Regarding the profile of tennis player, those that self-reported being a competitive tennis player (score = 71) and training regularly but not competing (score = 73.5) presented higher state of mind scores than those playing tennis for leisure (score = 64) and for fun (score = 61).

The reasons for playing tennis according to whether the participant have ever stopped playing tennis during adolescence are presented in Table 2. There was a higher frequency of agreeing that tennis makes the participant feel help, manage stress, improve self-care, enjoy playing, make or meet friends, helps optimize their routine, makes them feel part of a team, enjoy competing, and helps to stay in shape. Table 3 shows the reasons for playing tennis according to the frequency of playing tennis. There was a trend for increasing agreement according to the frequency of playing tennis for self-care, improving sleep, enjoying playing, mental wellbeing benefits, being part of the participants' life, make/meet friends, to improve routine, to be part of a team, to compete, to lose weight, to stay in shape and to make the most of the weather. The reasons for playing tennis according to whether the participants stopped playing tennis at adolescence or not are presented in Table 4. Participants that did not stop playing tennis at adolescence presented higher report agreement to feel happy, manage stress, self-care, enjoyment, make or meet friends, routine, to be social, competing and to stay in shape.

The association between playing tennis and related variables with state of mind are presented in Table 5. In the analysis adjusting for gender and age, playing tennis was associated with a 10% higher state of mind. The association was also consistent across all the categories of years playing tennis. Comparing with a frequency of playing tennis lower than weekly, only those practicing tennis at least twice a week presented higher state of mind (8%). In addition, comparing with the participants playing tennis for fun, only those training regularly but not competing presented higher state of mind (7% higher).

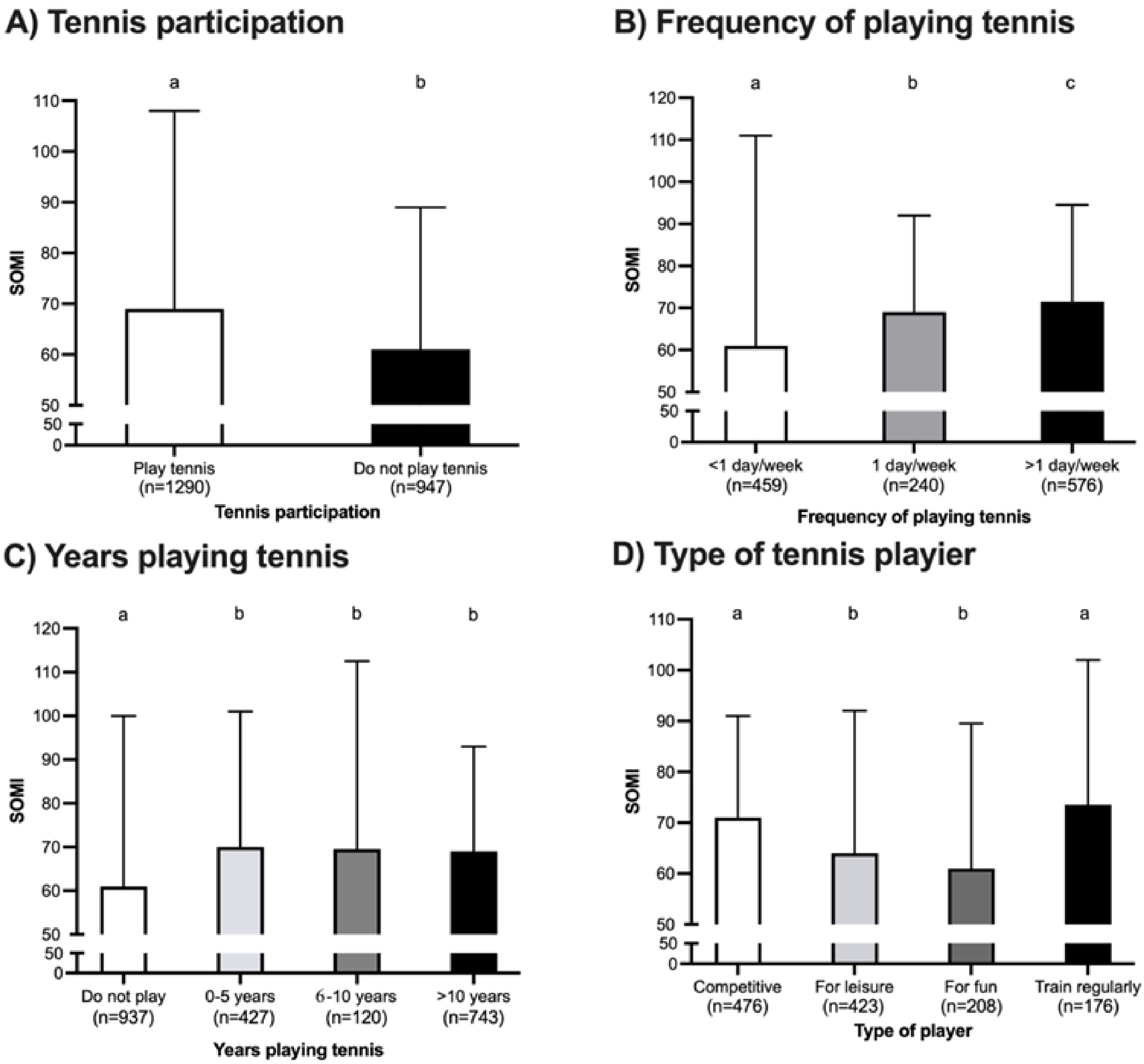

Figure 2. State of mind according to A) tennis participation, B) frequency of playing tennis, C) years playing tennis, and C) type of tennis player.
Note. Different letters represent significant differences between groups.

Table 2.
Reasons for playing tennis according to whether the participant have stopped playing tennis during adolescence

	Stopped (n=404)	Did not stop (n=771)	p
To feel happy	80.2	92.8	<0.001
To manage stress	56.4	63.4	0.021
For self-care	76.2	83.0	0.005
To improve my sleep	42.6	44.4	0.552
Because I enjoy playing	91.1	96.4	<0.001
For the physical health benefits	89.1	90.2	0.559
For the mental wellbeing benefits	81.2	82.5	0.592
Always been part of my life	48.5	51.6	0.313
To make/meet friends	54.5	64.9	<0.001
For routine & structure	45.5	54.7	0.003
To be social / part of a team	53.5	67.5	<0.001
To compete	47.5	59.4	<0.001
To lose weight	37.6	41.3	0.223
To stay in shape	72.3	81.4	<0.001
To make the most of the weather	59.4	55.3	0.186

Note. Values represent relative frequencies. p-value derived from chi-square.

Table 3.
Reasons for playing tennis according to the frequency of playing tennis

	Less than once a week (n=379)	Once a week (n=232)	More than once a week (n=556)	p
To feel happy	87.5	86.2	90.7	0.127
To manage stress	60.3	63.8	60.4	0.634
For self-care	73.9	79.3	86.3	<0.001
To improve my sleep	39.7	51.7	43.2	0.013
Because I enjoy playing	91.6	94.8	97.1	0.001
For the physical health benefits	88.5	93.1	89.9	0.179
For the mental wellbeing benefits	78.1	84.5	84.2	0.034
Always been part of my life	34.5	55.2	60.4	<0.001
To make/meet friends	43.6	70.7	69.8	<0.001
For routine & structure	30.3	53.5	65.5	<0.001
To be social / part of a team	46.7	63.8	73.4	<0.001
To compete	38.6	43.1	71.9	<0.001
To lose weight	34.5	37.9	44.6	0.006
To stay in shape	69.7	75.9	85.6	<0.001
To make the most of the weather	67.3	62.1	47.5	<0.001

Note. Values represent relative frequencies. p-value derived from chi-square for trend.

Table 4
Reasons for playing tennis according to whether the participants stopped playing tennis at adolescence

	Stopped (n=404)	Did not stop (n=771)	p
To feel happy	80.2	92.8	<0.001
To manage stress	56.4	63.4	0.021
For self-care	76.2	83.0	0.005
To improve my sleep	42.6	44.4	0.552
Because I enjoy playing	91.1	96.4	<0.001
For the physical health benefits	89.1	90.2	0.559
For the mental wellbeing benefits	81.2	82.5	0.592
Always been part of my life	48.5	51.6	0.313
To make/meet friends	54.5	64.9	<0.001
For routine & structure	45.5	54.7	0.003
To be social / part of a team	53.5	67.5	<0.001
To compete	47.5	59.4	<0.001
To lose weight	37.6	41.3	0.223
To stay in shape	72.3	81.4	<0.001
To make the most of the weather	59.4	55.3	0.186

Note. Values represent relative frequencies. p-value derived from chi-square for trend.

Table 5
Association between playing tennis and playing-related variables with state of mind

	Crude IRR (95%CI)	Adjusted IRR (95%CI)
Play tennis (Ref = no)		
No	REF	REF
Yes	1.09 (1.06-1.12)	1.10 (1.07-1.13)
Years playing tennis		
Do not play	REF	REF
0-5 years	1.08 (1.04-1.13)	1.11 (1.07-1.16)
5-10 years	1.09 (1.02-1.16)	1.08 (1.02-1.15)
>10 years	1.10 (1.06-1.13)	1.10 (1.06-1.13)
Frequency of playing tennis		
<1 day/week	REF	REF
1 day/week	1.03 (0.98-1.08)	1.02 (0.97-1.07)
>1 day/week	1.09 (1.05-1.13)	1.08 (1.04-1.12)
Type of tennis player		
Competitive	1.04 (0.99-1.10)	1.04 (0.99-1.09)
For leisure	0.97 (0.92-1.02)	0.96 (0.91-1.01)
For fun	REF	REF
Train regularly	1.08 (1.01-1.14)	1.07 (1.01-1.13)

Note. Adjusted for gender and age. Play tennis: n=2237. Years playing tennis: n=2237. Frequency of playing tennis: n=1275. Type of player: n=1283.

DISCUSSION

To the best of our knowledge, this is the largest study to attempt to understand the relationship between playing tennis and wellbeing in adults. They key findings are that participants playing tennis presented higher state of mind compared to participants that do not play tennis. This finding was consistent across all the categories of years playing tennis, while those playing at least twice a week presented higher state of mind scores compared to participants playing tennis less frequently than once a week. In addition, participants reporting training regularly presented higher state of mind compared to participants playing for fun.

This finding that playing tennis was associated with wellbeing is consistent with wider findings on sports participation and wellbeing. For instance, a recent systematic review found that playing sports in adulthood is associated with better wellbeing (Eather et al., 2023). A previous cross-sectional survey among 793 women who predominantly played tennis or netball, found a suggestion that playing tennis was associated with greater health related quality of life and life satisfaction, but no apparent dose response relationship was evident (Eime et al, 2014). Whilst it is not possible to determine this from cross sectional data, we found some evidence that the association of a positive relationship with tennis and wellbeing was relatively stable regardless of length of time people had played or frequency people played tennis for. A number of other cross-sectional surveys have investigated multiple sports and wellbeing, including tennis, but have had small numbers of people playing tennis and not sought to understand the relationship between tennis and wellbeing specifically (Gerber et al., 2014; Sorenson et al., 2024).

The reasons why playing tennis may be associated with greater wellbeing are unclear. However, this could include many of the wider neurobiological factors that have been reported from general physical activity participation such as changes in inflammation, increased released of brain derived neurotrophic factor, reductions in cortisol and possible changes in key emotional processing areas of the brain in the short and long term such as the hippocampus (Kandola et al., 2019). The psychosocial potential mechanisms how tennis influences wellbeing could include influencing social support, a key factor that wider research has shown exercise can improve mental health (Kandola et al., 2019). Tennis is a social sport, and such interactions are known to promote better mental health (Eather et al., 2023). Tennis is also a sport that requires a relative high degree of skill and participation allows people to develop a skill, overcome challenges and work towards mastering this skill (Eather et al., 2023). We found relatively consistent wellbeing associations regardless of the type of player. One previous survey among tennis professionals did not find an association with playing tennis and mental health (Spring et al., 2020) and wider literature has often found high levels of poor mental health in elite athletes (Rice et al., 2016). Our study of benefits among competitive (but no professional players) suggests that such players whose career does not depend on the outcome continues to have a favourable association with wellbeing.

The findings of a potential difference in the reasons people play tennis among those that do and do not dropout from participation in adolescence is interesting. Previous research has consistently shown that dropping out of sport at this time is high and critical. We noted a trend for a higher frequency of playing tennis and a greater endorsement of playing tennis for self-care, improving sleep, enjoying playing, mental wellbeing benefits, being part of the participants' life, make/meet friends, to improve routine, to be part of a team, to compete, to lose weight, to stay in shape and to make the most of the weather. These measures are all typically associated with greater mental health and could play a role in helping people to remain engaged in tennis.

CONCLUSION

In this large survey, we found provisional evidence of an association between tennis participation and wellbeing. The findings were evidence across all types of players and regardless of the length of time people played tennis. We found some interesting findings of potential difference in the reasons why people play tennis among those who do and do not drop out of playing tennis during the critical adolescence period.

Limitations

Whilst some novel insights have been found, it is important that these are considered in the context of the various limitations of this study. First, the study is cross sectional, and it is not possible to understand the directionality of the relationship between tennis participation and wellbeing. Future research should adopt a prospective or interventional design to understand the association between tennis participation and wellbeing and relevant moderators or mediators of this relationship. Second, the measure of wellbeing, the State of Mind score, is not a validated measure. Future research should seek to clarify the results we identified. Third, some important information from the sample was not available. For instance, information on physical health, fitness and other sociodemographic information (e.g. income) were not available. Fourth, there was some skew in the age distribution (age 44-59 was overrepresented) which could limit generalisability. Future research should seek to implement quotas to align with the general population. Finally, we did not capture and could therefore not adjust for habitual physical activity levels. Future research should seek to provide a comprehensive understanding to account for health, fitness and other variables that might influence the relationship between tennis participation and wellbeing.

REFERENCES

Anderson, E., & Durstine, J. L. (2019). Physical activity, exercise, and chronic diseases: A brief review. *Sports medicine and health science*, *1*(1), 3-10. https://doi.org/10.1016/j.smhs.2019.08.006

ASICS. (2024). *Global State of Mind Study 2024*. ASICS. https://www.asics.com/us/en-us/mk/stateofmindstudy2024

Back, J., Johnson, U., Svedberg, P., McCall, A., & Ivarsson, A. (2022). Drop-out from team sport among adolescents: A systematic review and meta-analysis of prospective studies. *Psychology of Sport and Exercise*, *61*, 102205. https://doi.org/10.1016/j.psychsport.2022.102205

Bull, F. C., Al-Ansari, S. S., Biddle, S., Borodulin, K., Buman, M. P., Cardon, G., Carty, C., Chaput, J. P., Chastin, S., Chou, R., Dempsey, P. C., DiPietro, L., Ekelund, U., Firth, J., Friedenreich, C. M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P. T., Lambert, E., Leitzmann, M., Milton, K., Ortega, F. B., Ranasinghe, C., Stamatakis, E., Tiedemann, A., Troiano, R. P., van der Ploeg, H. P., Wari, V., Willumsen, J. F. (2020). World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *British journal of sports medicine*, *54*(24), 1451-1462. https://doi.org/10.1136/bjsports-2020-102955

Daskalopoulou, C., Stubbs, B., Kralj, C., Koukounari, A., Prince, M., & Prina, A. M. (2017). Physical activity and healthy ageing: A systematic review and meta-analysis of longitudinal cohort studies. *Ageing research reviews*, *38*, 6-17. https://doi.org/10.1016/j.arr.2017.06.003

Eather, N., Wade, L., Pankowiak, A., & Eime, R. (2023). The impact of sports participation on mental health and social outcomes in adults: a systematic review and the 'Mental Health through Sport'conceptual model. *Systematic reviews, 12*(1), 102. https://doi.org/10.1136/bjsports-2014-093885

Eather, N., Wade, L., Pankowiak, A., & Eime, R. (2023). The impact of sports participation on mental health and social outcomes in adults: a systematic review and the 'Mental Health through Sport'conceptual model. *Systematic reviews, 12*(1), 102. https://doi.org/10.1186/s13643-023-02264-8

Eime, R., Harvey, J., & Payne, W. (2014). Dose-response of women's health-related quality of life (HRQoL) and life satisfaction to physical activity. *Journal of Physical Activity and Health, 11*(2), 330-338. https://doi.org/10.1123/jpah.2012-0073

Gerber, M., Brand, S., Elliot, C., Holsboer-Trachsler, E., & Pühse, U. (2014). Aerobic exercise, ball sports, dancing, and weightlifting as moderators of the relationship between stress and depressive symptoms: an exploratory cross-sectional study with Swiss university students. *Perceptual and motor skills, 119*(3), 679-697. https://doi.org/10.2466/06.PMS.119c26z4

International Tennis Federation [ITF]. (2022). *ITF GLOBAL TENNIS REPORT.* International Tennis Federation.

Iso-Markku, P., Aaltonen, S., Kujala, U. M., Halme, H. L., Phipps, D., Knittle, K., Vuoksimaa, E., & Waller, K. (2024). Physical activity and cognitive decline among older adults: a systematic review and meta-analysis. *JAMA network open, 7*(2), e2354285-e2354285. https://doi.org/10.1001/jamanetworkopen.2023.54285

Kandola, A., Ashdown-Franks, G., Hendrikse, J., Sabiston, C. M., & Stubbs, B. (2019). Physical activity and depression: Towards understanding the antidepressant mechanisms of physical activity. *Neuroscience & Biobehavioral Reviews, 107*, 525-539. https://doi.org/10.1016/j.neubiorev.2019.09.040

Linton, M. J., Dieppe, P., & Medina-Lara, A. (2016). Review of 99 self-report measures for assessing well-being in adults: exploring dimensions of well-being and developments over time. *BMJ open,* 6(7), e010641. https://doi.org/10.1136/bmjopen-2015-010641

Oja, P., Titze, S., Kokko, S., Kujala, U. M., Heinonen, A., Kelly, P., Koski, P., & Foster, C. (2015). Health benefits of different sport disciplines for adults: systematic review of observational and intervention studies with meta-analysis. *British journal of sports medicine, 49*(7), 434-440. https://doi.org/10.1136/bjsports-2014-093885

Pluim, B. M., Staal, J. B., Marks, B. L., Miller, S., & Miley, D. (2007). Health benefits of tennis. *British journal of sports medicine, 41*(11), 760-768. https://doi.org/10.1136/bjsm.2006.034967

Rice, S. M., Purcell, R., De Silva, S., Mawren, D., McGorry, P. D., & Parker, A. G. (2016). The mental health of elite athletes: A narrative systematic review. *Sports medicine, 46*, 1333-1353. https://doi.org/10.1007/s40279-016-0492-2

Sayer, A. (2023, October 21). *How Do the Health Benefits of Pickleball Compare to Tennis?* Well+Good. https://www.wellandgood.com/health-benefits-pickleball-vs-tennis/

Schuch, F. B., Vancampfort, D., Firth, J., Rosenbaum, S., Ward, P. B., Silva, E. S., Hallgren, M., Ponce De Leon, A., Dunn, A. L., Deslandes, A. C., Fleck, M. P., Carvalho, A. F., & Stubbs, B. (2018). Physical activity and incident depression: a meta-analysis of prospective cohort studies. *American Journal of Psychiatry, 175*(7), 631-648. https://doi.org/10.1176/appi.ajp.2018.17111194

Sorenson, S. C., Romano, R., Scholefield, R. M., Martin, B. E., Gordon, J. E., Azen, S. P., Schroeder, T. & Salem, G. J. (2014). Holistic life-span health outcomes among elite intercollegiate student–athletes. *Journal of athletic training, 49*(5), 684-695. https://doi.org/10.4085/1062-6050-49.3.18

Spring, K. E., Holmes, M. E., & Smith, J. W. (2020). Long-term tennis participation and health outcomes: an investigation of "lifetime" activities. *International journal of exercise science, 13*(7), 1251. https://doi.org/10.70252/BAHT9366

Zhao, M., Veeranki, S. P., Magnussen, C. G., & Xi, B. (2020). Recommended physical activity and all cause and cause specific mortality in US adults: prospective cohort study. *Bmj, 370*, 2031. https://doi.org/10.1136/bmj.m2031

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Technology-enabled reflection enhances coaching behavior in youth tennis coachess

La reflexión mediada por la tecnología mejora el comportamiento de los entrenadores de tenis juvenil

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Abstract

Sports coaches have an important role to play in the development of their participants. One way that coaches can do this effectively is to ensure their behavior is appropriate for the people they coach. Previous research has highlighted that coaches are unaware of their behavior and how this impacts their participants. This study aimed to investigate the effectiveness of technology on reflection in sports coaches and explore the influence of enhanced critical reflection on coaching behavior. The study was underpinned by theoretical frameworks on reflection. In this study, experienced and qualified tennis coaches (n=3) were video- and audio-recorded three times over nine weeks delivering sessions to youth participants (n=7). Coaches had their behavior coded using the Arizona State University Observation Inventory. After each session, coaches reflected on recordings and sent reflections to researchers. Follow-up interviews were conducted with each coach. The results showed increased self-awareness of behavior, increased quality of reflection, and enhanced coaching behavior. The study findings suggest that technology is effective in aiding reflection and coaching behavior in youth tennis coaches. From this, it is recommended that National Governing Bodies, clubs and coach developers use similar interventions to enhance the quality of coaching.

Keywords: *Behavior, coaching, intervention, racket sport, technology.*

Resumen

Los entrenadores deportivos desempeñan un papel importante en el desarrollo de sus deportistas. Una forma en que los entrenadores pueden hacer esto de manera efectiva es asegurándose de que su comportamiento sea apropiado para las personas a las que entrenan. Investigaciones anteriores han encontrado que los entrenadores no son conscientes de su comportamiento y de cómo este afecta a sus deportistas. El objetivo de este estudio fue investigar la eficacia de la tecnología en la reflexión de los entrenadores deportivos y explorar la influencia de una mayor reflexión crítica en el comportamiento de los entrenadores. El estudio se basó en marcos teóricos sobre la reflexión. En este estudio se grabaron en video y audio tres veces durante nueve semanas a entrenadores de tenis experimentados y cualificados (n = 3) impartiendo sesiones a deportistas jóvenes (n = 7). Se codificó el comportamiento de los entrenadores utilizando el Instrumento de Observación de la Universidad Estatal de Arizona (ASUOI). Después de cada sesión, los entrenadores reflexionaron sobre las grabaciones y enviaron sus reflexiones a los investigadores. Se realizaron entrevistas de seguimiento con cada entrenador. Los resultados mostraron una mayor conciencia de la conducta, una mayor calidad de la reflexión y una mejora en la conducta de entrenamiento. Los resultados del estudio sugieren que la tecnología es eficaz para ayudar a la reflexión y a la conducta de entrenamiento en los entrenadores de tenis juvenil. A partir de esto, se recomienda que los órganos rectores nacionales, los clubes y los formadores de entrenadores utilicen intervenciones similares para mejorar la calidad del entrenamiento.

Palabras clave: *conducta, entrenamiento, intervención, deportes de raqueta, tecnología.*

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INTRODUCTION

Sports coaching has become increasingly professionalized in recent decades, reflected in the growing emphasis on learning and development (Cope et al., 2022). Common methods that have been employed to help coaches learn and develop have included reflection, mentorship, coach education qualifications, networking, and continuous professional development (CPD) (Stodter & Cushion, 2019). An additional method that has been used for decades with coaches is systematic observation, which is a process in which an observer codes behavior that a coach exhibits during their practice using an inventory of behaviors for reference (e.g., Lacy & Darst, 1984; Partington et al., 2015). Systematic observation comes with benefits for coaches, observers and researchers such as increased awareness of behavior and providing quantitative data for comparison between various contexts. However systematic observation also comes with a significant limitation – results provide little on the quality, or effectiveness, of the coaching behavior observed (Cushion et al., 2012). To address this issue, mixed methods approaches have been applied when studying coach behavior. Researchers employ quantitative methods (e.g., systematic observation using an observation schedule) (e.g., Cope et al., 2021) and follow-up with qualitative methods such as interviews and video and audio recordings of the coach during the session (e.g., Glen et al., 2020), which allows for behavior, and the underlying reasons for the behavior, to be studied and better understood.

One of the most influential factors in all levels of sport is coaching behavior. How a coach behaves with the athletes under their tuition can have a significant influence on the participation, retention, skill acquisition and, for many the pinnacle, the performance of their athletes (Berntsen & Kristiansen, 2019). The desired and required behavior of sports coaches varies and is affected by a range of factors and contexts. These factors include, but are not limited to, age, gender, ability level and cultural influences such as nationality (Henderson et al., 2022). A coach who can adapt their behavior to meet the athletes' needs and desires to maximize participation and performance benefits for their athletes. For a coach to align their behavior with the needs and desires of their athletes, they need to be aware of the factors discussed. Coaches can only align their behavior if they are aware of how they normally behave when interacting with their athletes. This may seem like a statement that lacks influence, but there is often misalignment between how a coach thinks they behave and how they actually behave, or, more importantly, how they are perceived by their athletes (Partington et al., 2015). Without an increase in coach self-awareness, some suggest that coach education can be effectively futile (Cope et al., 2022). One of the main implications of this misalignment is that increasing awareness of one's own behavior can be highly beneficial to improving coaching behavior in future sessions (Partington et al., 2015).

A growing body of literature has suggested ways to improve the awareness of coaching behavior and how to integrate it into coach education programs and NGB structures. One way to do this is through the incorporation of technology into coaching practice. When integrating technology into coaching behavior interventions, the apparatus and delivery method used must be up-to-date and fit-for-purpose as failure to do so may result in disengagement from coaches because of issues such as time and technical difficulties (Schenk & Miltenberger, 2019). This is becoming less of an issue, as technology within the context of sport and coaching is becoming ever more accessible (Lavallee et al., 2020). Technology to aid coaching awareness has been studied (e.g., Cope et al., 2021; Partington et al., 2015), but it is still used more for athletes than coaches. Further integration should enhance self-awareness and monitor changes over time. Systematic observation, alongside video technology, has been recommended to be integrated into coach education and practice (Cope et al., 2022), with researchers encouraged to use it as a tool to aid the learning and development of the coaching participants within studies.

Reflective practice is an area that has been investigated in numerous fields for various practitioners, including sports coaching, for decades. It is crucial for the development of expertise and improved practice of coaching (Silva et al., 2020). The work of Gilbert and Trudel (2001) within a sports coaching environment was informed by the reflective framework proposed by Schön (1983) that highlighted that professional development is accelerated by practitioners reflecting 'in practice' (during the event) and reflecting 'on practice' (after the event). Gilbert and Trudel (2001) developed this model further in their observational research with youth soccer and ice-hockey coaches to investigate how coaches reflect in their environment. They proposed in their adapted reflective framework that there are three distinct ways that accomplished coaches learn through reflection: reflection in-action (*during the action of coaching*); reflection on-action (*within the action, but not actively coaching it*); and retrospective reflection on-action (*away from the action of coaching)* (Gilbert & Trudel, 2001).

This work has informed several more recent studies into the area which have been systematically reviewed (Silva et al., 2020) and has also had a direct impact on the work of coaches and those associated with coaches and coaching (Cope et al., 2022). In the United Kingdom, NGBs have realized the importance of reflective practice and many embed this as a key component in their higher-level coaching badges. Initially this was conducted through real life 'scenario' type coaching sessions under assessment conditions (Nelson & Cushion, 2006); however, within more recent research there have been attempts made to incorporate modern technology, such as video, audio and online reflective journals, alongside this reflection to improve the validity and accessibility of these reflections (Silva et al., 2020). This work can have practical implications for the future of sports coaching and sports coaching education.

This study aimed to investigate the effectiveness of technology on reflection in sports coaches employing the framework proposed by Gilbert and Trudel (2001). We also aimed to explore the impact of enhanced critical reflection on coaching behavior. Our study focused on longitudinal behavior change in tennis integrating video and audio resources available to aid reflection, with a focus on retrospective reflection on-action (Gilbert and Trudel, 2001). The study used audio and video technology, alongside measures to code coaching behavior using the Arizona State University Observation Inventory (ASUOI) and qualitative measures (semi-structured interviews) post-observation to gain an understanding as to why, or why not, behaviors changed.

MATERIAL AND METHODS

Participants

Coaches. Three tennis coaches took part in this study. This is typical of observation-based research in the field of sports coaching (cf. Partington et al., 2015; Guzmán & Calpe-Gomez, 2012). The coaches recruited had a minimum of Lawn Tennis Association (LTA) Level 2 coaching qualification and one was working towards their LTA Level 3 during this study. The coaches each had a minimum of two years coaching experience at the time of recording and all continue to play competitively. Coaching participants received a participant information sheet and participation was entirely voluntary. The study received institutional ethical approval and informed consent was attained from coaches prior to any data collection. Two of the coaches participated in a previous study by the researchers (Glen et al., 2020). They were contacted by a research advertisement within the club sent via email. The other participant joined as a result of the research advertisement in the club. Each coach was at a different stage in their coaching pathway: Coach 1 (Female, LTA Level 5, 32 years of experience, national level coach); Coach 2 (Male, LTA Level 3, 4 years of experience, regional and club level coach); and Coach 3 (Female, LTA Level 2, 2 years of experience, regional and club level coach).

Players. Players (N=7) were between the ages of 7-12 years old and were a mixture of male (N=6) and female (N=1). Playing participants who took part in the study competed at a range of regional and national level and therefore had experience being coached and playing competitively. Each player had participated in coaching sessions delivered by the associated coach prior to the commencement of this study and therefore had a pre-existing relationship with the coach. Parental informed consent and player informed assent were attained before any data collection. These forms were emailed to parents by the coach before the sessions. They were then handed in to the researchers by both email and hard copies. These were stored under the ethics protocol and data management plan approved by the university.

Procedure

Quantitative. Sessions were all recorded at an outdoor artificial clay court at a tennis club in a major city in Scotland. No sessions were postponed because of the weather, but conditions were variable, with wind and rain affecting several sessions. The sessions took place between the months of May and July. This was in order to have the best possible chance of consistent weather in a climate that is very changeable (James et al., 2019). This also aligned with the sessions put on by the club and availability of court times. Each coach was recorded on three separate occasions similar to Cope et al. (2021) with a minimum of two weeks and a maximum of four weeks between each session per coach to allow for in-depth reflection between sessions. Two coaches (Coach 1 & 2) were filmed delivering individual sessions, while one coach (Coach 3) was filmed delivering group sessions. This was based on their timetable and availability and allowed consistency between sessions. The time gap between sessions also allowed the researchers time to upload, combine and share the relevant audio and video files. The average time per coaching session was 40 minutes and 24 seconds and sessions ranged between 31-48 minutes across all coaches.

Video Collection Procedure. A Panasonic Model SD90-04 was used to record each session and was mounted on a tripod and placed in an elevated position at the back of the court for each session. This allowed for the entire court to be observed throughout the session. The only movement of the camera was zooming in and out at appropriate times throughout the session. Upon completion of each session the files were saved into MP4 format for integration with audio files.

Audio Collection Procedure. A wireless microphone (Fifine Technology model K031) was used to collect audio recordings from the coach. The microphone was clipped onto to a t-shirt or tracksuit top between 10-20cm from the mouth of the coach. Audacity technology was used on the first author's laptop with the receiver USB drive attached. This allowed for the quality of sound and pitch of the recordings to be checked as they were taking place. The first author was also listening as recordings were taking place. Upon completion of each session the files were saved into MP3 format for integration with video files.

Procedure for Sharing Files. Video and audio files were combined to allow for ease of use for the coaching participants. This was achieved by using Adobe Acrobat Pro. The audio from the MP3 files was uploaded into the MP4 (video) files with the audio from the original MP4 (video) files being removed. This allowed the researchers to overlay the higher quality audio collected by the wireless microphone over the lesser quality audio collected by the camera. The integrated file was uploaded to a private YouTube channel and the link was shared with the relevant coach.

Coding of Behavior. The apparatus used for quantitative data collection was the ASUOI; Lacy & Darst, 1984). The ASUOI has 15 categories of behavior which are distinct and well defined (see Table 1). The ASUOI is among the most commonly used method of measuring and coding coaching behavior (Cope et al., 2017). Coaching behavior in tennis has been measured using the ASUOI in both face-to-face (e.g., Claxton, 1988) and online (e.g., Glen et al., 2020) environments, enhancing the rationale for the choice of this method. The first author observed the coaching sessions live and coded coaching behaviors via the ASUOI afterwards using the audio and video available to ensure accurate recording. The first author made field notes for each session to give context around factors, such as weather and incidents, that may have affected the session. After each session, the results of the ASUOI and the combined audio/video file were made available to the coach for reflection to take place. This was conducted in accordance with previous studies (e.g., Potrac et al., 2007; Glen et al., 2020).

Upon completion of all sessions, data from each coaching session was presented in a Figure (Figures 2, 3 and 4) where the data was presented in total number of behaviors, rates of behaviors exhibited per minute (RPM) and total percentage of behavior. The 'Use of first name' was treated as an independent category (cf., Lacy & Darst, 1984). This was presented for each coach individually. Overall results were also shared with the relevant coach prior to the interview at the end of the study. Because of the small sample size, no statistical tests were conducted to check for statistically significant differences and effect sizes.

Qualitative

Reflections on Sessions. Reflective practice, particularly when combined with video footage, has been instrumental to the behavior change of sports coaches (Partington et al., 2015). After reviewing their session back on the combined video and audio file shared with them, the coaching participant sent their reflections on their session to the researchers. The coaches were given the option of providing their reflections in either written format (Cronin & Armour, 2017) or audio recording (Stoszkowski & Collins, 2014). The purpose of this was for the researchers to evidence that the participants were reflecting upon their session in depth and thinking about the implications for future sessions. Nine detailed reflections were provided to the researchers and retained by each participant (three each). These reflections were recorded and transcribed (where audio was provided). This was conducted to allow more depth in their answers regarding specific instances and thoughts that were highlighted in the reflections provided. The researcher then used the reflections to inform the semi-structured interview for each participant.

Table 1
ASUOI Categories and Definitions

Category	Definition
Use of First name	Using first, or nickname when talking to a player
Pre-Instruction	Information given to players prior to desired action to be executed
Concurrent Instruction	Cues or reminders given during the skills or play
Post-Instruction	Correction, re-explanation or instrumental feedback given after drill/play
Questioning	Any question to platers concerning strategies or techniques
Physical Assistance	Physically moving the player's body to proper position or correction motion
Positive Modelling	A demonstration of correct performance/technique
Negative Modelling	A demonstration of incorrect performance/technique
Hustle	Verbal statements designed to intensify the efforts of the player(s)
Praise	Verbal or non-verbal compliments, statements or signs of approval
Scold	Verbal or non-verbal behaviours of displeasure
Management	Verbal statement related to organisational details of practice or games
Uncodable	Any behaviour that cannot be seen/hear or fits into the above categories.
Silence (On-task)	Coach isn't talking but is obviously involved in action of game.
Silence (Off-task)	Coach isn't talking and obviously involved in tasks unrelated to the game

Data Collection. A semi-structured interview was conducted with each coach (three total interviews). The areas for discussion and potential prompts were in accordance with the interview schedule. The mean length of the interview was 34 minutes 27 seconds, with interviews ranging in length between 24 minutes, 4 seconds and 39 minutes, 46 seconds. Each interview was conducted face-to-face in a quiet, private room at the tennis club where the coaches were based to ensure that a suitable location was used and there was less chance of interruption from external sources (Eppich et al., 2019). Each interview was recorded using a Zoom H1 dictaphone which has been used by the researchers in a prior study (Glen & Lavallee, 2019). Interviews were then transcribed verbatim for analysis.

Data Analysis. Upon transcription of the interviews, a thematic analysis was conducted to identify common themes (Braun & Clarke, 2022). The initial coding stages were conducted by the lead author. Following this, both authors collaborated on the remaining stages of the analysis. Consequently, the data from the initial codes was reviewed for potential themes by both authors; this allowed for the authors to recognize perceptions of the coaches involved and understand commonalities between their answers.

RESULTS AND DISCUSSION

The analysis process resulted in the development of seven subthemes and three main themes. The three main themes were termed: Technology Raises Awareness of Behavior; Increased Awareness of Behavior Leads to Enhanced Reflection; and Enhanced Reflection Can Lead to More Effective Coaching Behavior. Consistent with conceptualizing reflection as a process involving learning and adaptation through experience, the main themes are not discrete but overlap across three stages, with each stage building on the previous one (Figure 1). The results are presented below in order across this three-stage process, with quotes highlighting relevant subthemes.

Technology Raises Awareness of Behavior

All coaches noted that the video and audio technology was minimally intrusive and had little effect on their behaviors and interactions with their participants. One of the coaching participants (Coach 2) offered insight into this below:

> I think after the first like 15 minutes of the first lesson or something I've settled into doing it normally and I think it was good cause

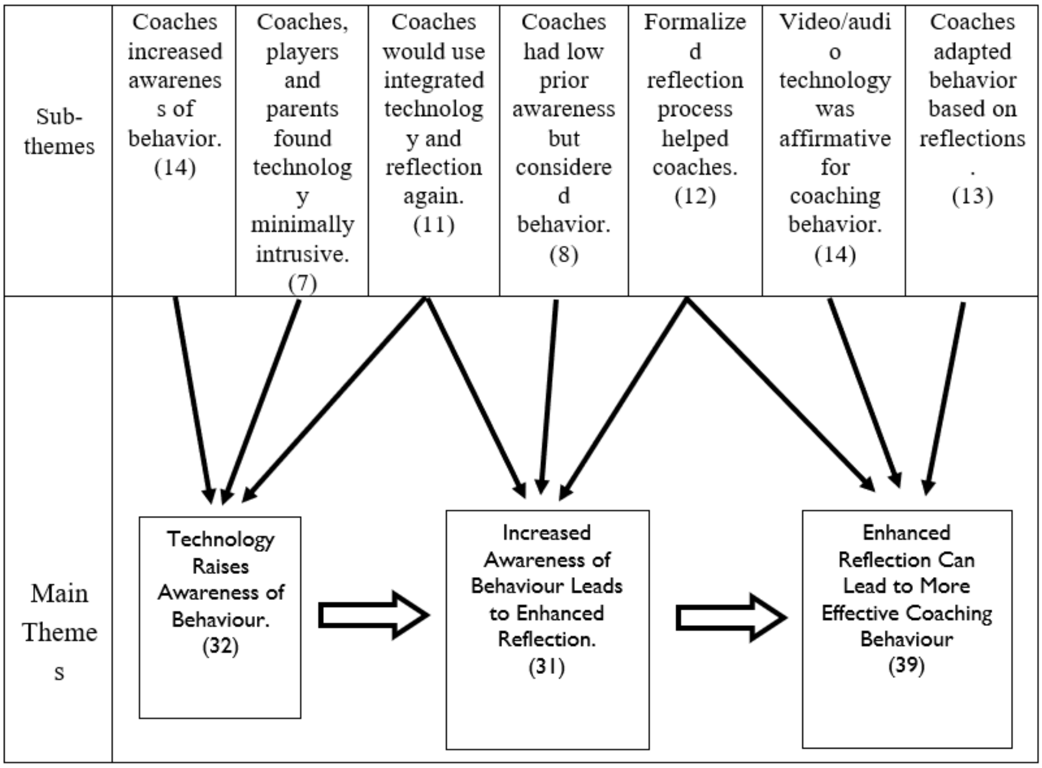

Figure 1.
Thematic Analysis: Sub-themes and Main Themes

Note: Brackets indicate the number of quotes.

> even towards the end of the first lesson I was just having normal conversations with the participant that weren't necessarily related to tennis.

The quote from the coach above highlights that the technology used was not obtrusive to their sessions. They did however acknowledge that there was an initial period where they were aware of being observed, this is not unusual and has been noted in other previous studies in the area (Stoszkowski & Collins, 2022). The coaches involved in the present study noted that they got used to the camera and wireless microphone quickly and this period of assimilation was quicker than in Stoszkowski and Collins (2022) where coaches took several sessions to become comfortable. This is perhaps because of the non-intrusive nature of the recording in the present study, sessions were filmed via a fixed camera elevated on a tripod above the level of the court. In a sport where the coach would cover a greater distance during delivery of a session (such as football) the researcher would be more likely to follow the coach with the camera increasing awareness of the presence of the camera and changes in behavior. In Stoszkowski and Collins (2022) the coaches filmed were across various sports, which may explain why the coaches in the present study were more comfortable. Additionally, one of the coaching participants in this study had previous experience being filmed for research (Glen et al., 2020) and the other two participants had previous experience being filmed for their LTA coaching qualifications. This would suggest that they are more comfortable being filmed than the 'average' coach. For this type of intervention to be applied elsewhere may require more time for participants to become comfortable being recorded.

Previous research has highlighted a lack of self-awareness regarding coaching behavior (Partington et al., 2014; Partington et al., 2015). An area of interest that emerged from the coaching participants in this study was that using the technology to view and hear the sessions back can help the coaches be aware of the things they are doing well:

> I felt it (lack of confidence) in the session, but when I watched it back, it wasn't as bad as I thought. Watching it back made me think 'that was better than you thought it was'. I was very critical of myself (initially)... watching myself back helped my confidence! (Coach 1)

This was expanded upon by two other coaches, the first of whom said that using the technology to watch and listen back to her session made her more aware of how she conducted herself during the sessions: I knew that I looked enthusiastic and positive, but I wasn't really aware of my presence on the court (Coach 3). The other coach (Coach 2) also expressed a similar view and highlighted the areas for development as well as areas he was pleased about with his coaching delivery:

> Being able to see yourself back and hear yourself back is a big thing because sometimes your memory serves a bit differently from how the lesson actually went... so it can be positive, it's not all gonna be unflattering.

Viewing and listening back to the sessions improved the confidence of coaches and increased awareness of their behavior; however, it was also beneficial for them to highlight areas of improvement. The quotes above highlight the importance of retrospective reflection on-action (Gilbert & Trudel, 2001) as this helped alleviate their concerns in their initial retrospective reflection in-action. This can be achieved without technology, however the presence of technology and a formal reflection process likely enhanced the likelihood and quality of reflection. Coaches can be unaware how they actually behave, and how they are perceived by others, in their daily lives. Prior research with experienced coaches has highlighted that having the respect of athletes is critical for a coach in maintaining an effective coach-athlete relationship (Potrac et al., 2002). The athletes must have respect for the coach in order for coaches to transfer knowledge effectively to the athletes and to retain their engagement (Potrac et al., 2002). The most experienced and qualified coach in the study (Coach 1) touched on this regarding working with female players:

> It made me more aware of gender differences in coaching... the second player was female, in general I have the same issues with girl players. I'm not sure if they're really with you? I just find it easier with boys. They seem more naturally competitive; it's kind of easy to feel they're all out there trying their hardest. I find that more difficult with girls. So, it was probably more an increased awareness of the gender differences.

Gender differences and preferences in coaching are areas that have been extensively researched but with no established conclusion that fits all contexts (Henderson et al., 2022; Partington et al., 2014). This is because how males or females are coached is a highly nuanced area that is affected by several factors (Cope et al., 2022). One positive point in the quote above outlined by the coach is that she became more aware of an area where she would like to improve her coaching practice. Indeed, all coaches interviewed in the study stated that the use of video and audio technology helped them become more aware of the impacts of their behavior and consider their behavior for future sessions:

> I think it definitely made me more aware of what I was doing, I think some of the stats like positive feedback because you don't really think about what you're doing. You're just like it's more of a throw away thing that I just do every now and again, the thing is you don't think how much of that is built into the lessons. (Coach 2)

Increasing coach self-awareness of behavior is critical for their development. The coach above never paid much attention to the positive feedback he was giving to his athletes, but by reflecting on the footage, he could see the value that this behavior was bringing to his sessions and to his participant. Another coach (Coach 3) spoke about the benefits of integrating technology into her sessions and highlighted the role of the wireless microphone in aiding awareness:

> It picked up my voice very clearly, when I was on the other side of the court, it still picked it up and it really helped to hear everything that I said, not just the encouragements and the shouting, really the conversations between the players, that really helped to hear them back.

The quote above highlights the benefits of adding wireless microphone and audio recording technology to the study. Previous research (Cope et al., 2022; Partington et al., 2015) has highlighted the benefits of video technology in aiding awareness in sports coaches, however in these studies there is little detail in how the audio recordings were obtained. It is possible to pick up audio through the camera, however in-built microphones in cameras are not effective in picking up volume in larger spaces and as a result external microphones can be required (Zoder-Martell et al., 2020). This would likely be made worse when coaches are on the move, meaning that many of the interactions could be missed if the audio from the camera was used. A previous study conducted by Guzmán & Calpe-Gomez (2012) integrated a handheld tape recorder in a pouch wrapped around the waist of their participant in their observation of a coach. This allowed for better quality audio to be obtained than that from a camera as may have been the case in other observational studies in the area. Although this was an improvement, the microphone used in the present study was designed in such a way that it clipped in with minimal intrusion and saved to MP3 format for simple merging with video. This allowed coaches to view video and audio together in one merged file after each session. This is not a criticism of the previous research. This is merely because of advances in wireless audio recording technology over the last decade.

Increased Awareness of Behavior Leads to Enhanced Reflection

From analyzing the interviews with each coaching participant, it became clear that the increased awareness of their behavior, caused by watching and listening back to their sessions, helped them reflect in a more meaningful way. Similar results for this were found by Partington et al. (2015) who found that by sharing the videos with coaches to review in their own time gave them ownership of the process and enhanced their motivation to improve behavior. Despite our coaching participants reflecting on coaching practice before this study, these reflections were relatively informal. Their only experience of formalized reflection had been during studying for coaching qualifications. None had ever reflected with technology regarding their coaching practice, however all coaches interviewed stated that they would use integrated technology and reflection again within their coaching practice. The most experienced coach (Coach 1) highlighted the benefits of the formalized reflection and added insight about when it should be carried out:

> You do it and it's done. The first one, I went away and did it straight away that night... it's better doing it at the time, you watch it and remember it more as opposed to doing it later.

Another example is below where Coach 2 outlines the benefits of doing reflection as soon as possible after watching the videos back as well as touching upon perceived mistakes:

> It's obviously good to see the mistakes you're making during the lesson cause you don't always realize until you see them, so I think the footage and audio, seeing and hearing it back is better than even if you just walk straight after lesson then write down points on a sheet of paper. Things have already been shaped quite a lot by how you've remembered them in your mind, or how much you've dwelled on them during the lesson.

The coaches above make an important point about the reflection being carried out as soon as possible after viewing and listening to the session. Studies have previously used video clips in their 'stimulated recall' interviews with participants to help them recall behavior. (e.g., Stodter & Cushion, 2019). In the present study, coaches viewed the clips back before reflecting and in advance of being interviewed. This should reduce the chances of key incidents being forgotten prior to reflecting. This is a significant point raised by Coach 1, as the recall of key events is relatively poor for sports coaches and this is particularly evident in lesser experienced coaches (Coaches 2 and 3), who can recall significantly fewer events than more experienced coaches (Laird & Waters, 2008). The least experienced coach in the study (Coach 3) highlighted some of the benefits that the formalized reflection process provided. Previously she had been less inclined to think about the positive aspects of her coaching sessions, but the formal reflection integrated with the technology helped affirm desirable coaching behavior and helped make her aware of what she was doing well:

> It was good. A lot of the time I've got a feeling of how the session went, but putting it into words is sometimes quite hard, and I had to think of stuff that I thought I did well and stuff that I could have done better. And because I'm so hard on myself, the stuff that I did well, it's harder to find! But doing that (reflecting on recordings) really made me notice it.

These sentiments were echoed by Coach 2, who became more aware of the importance of the quality of feedback he was giving his participant during the sessions:

> I'm guilty of giving poor quality positive feedback like 'good shot'. That's terrible feedback. You're not getting the feedback on the teaching point. Not like, 'good follow through in that shot' it just you know all that 'good one' is about trying to cut that out.

Coach 2 did also raise the issue of contextual factors, notably the changeable Scottish weather, and how this affected his coaching behavior, specifically for his second session conducted:

> We were having to battle against the weather. We couldn't keep, you know, trying to shout over them just to keep like, trying to be heard alone, knowing that you're not being heard so well. I mean, you can't give as good feedback during the lesson.

The quotes above highlight that weather conditions for coaching should be considered when discussing coach behavior. Author 1 is a practicing coach in a very similar climate (James et al., 2019) and would echo that the weather does indeed affect the type of coaching behavior one exhibits. This is also supported in other studies, including Partington et al. (2014) when youth football coaches in their interviews stated that they consider contextual factors including cold conditions when deciding how long to speak to athletes and what type of question to ask them. This study was conducted in a similar climate (England) to the present study (Scotland) and is a very interesting insight from Coach 2. Additionally, other contextual factors such as age of athlete and ability level can affect coaching behavior and should be taken into consideration (Cope et al., 2022; Partington et al., 2015).

It is common for coaches to view reflection as a negative experience and to prioritize aspects that did not go well in their practice (Knowles et al., 2006). Although it is acknowledged that in-depth critical reflection is essential for raising awareness and promoting changes in behavior (Partington et al., 2015), this should not mean that coaches only view the negative aspects of their practice. In this study, as part of their critical reflection the coaches were asked to think about what they did well besides what could be improved in future sessions. One coach (Coach 3) in the study was happy to look back on her previous reflections and video clips to aid future development:

> I've obviously saved those videos, so I'll just look back on the videos and again reflect on if I do lose my sight of what I'm doing, go back and see what I've done well.

This is another perceived benefit of using technology to aid reflection. The formal reflections have been stored, and the merged file can be reflected on at any time to remind them of the positive aspects of their coaching in addition to the areas for further development. Coaches are open to different methods of learning to develop (Christensen, 2013), so they could be keen to try out interventions and support similarly to this study or the work of Partington et al. (2015). As well as the benefits of formalized reflection with the technology discussed, the depth of reflection that coaches went through was very thorough. Below, Coach 1 explains the detail that went into this:

> I've got to have confidence in what I'm doing, but also, I have to have confidence in that relationship (with the player). I think part of the goal for him just now is to let him have these behaviors in that session, so that we can then work on it in session, or out of session to try and help him when he is competing. Sometimes it's hard to get kids into a stage where they behave like that (frustrated) and if you're only seeing it in matches, it's tricky.... I wouldn't have put up with that in the past. But he keeps trying, if he stopped trying then I wouldn't be able to (put up with that). You can be like that if you want but, if you're able to be in a point 1 minute later, then at least that person is trying.

The quote above from the most experienced coach highlights the development that she has gone through in her 32 years of coaching. In the session she is reflecting on, the player being coached was exhibiting levels of frustration and the coach dealt with it by letting the player release this on the court. A coach with less experience, or who did not have the same relationship with the player, may have reacted in a different way to the player's actions. By reflecting on the session and watching it back, the coach affirmed she made the right choice in her behavior and acknowledged that this would have been something she would have been less likely to tolerate in the past. This shows a high level of self-awareness which is possibly because of her experience of coach education and higher educational background in sport and psychology compared to other coaches in this study. Previous research has shown that coaches who have had similar educational experiences are more likely to carefully consider their behavior and show higher levels of self-awareness (Stodter & Cushion, 2019). Additionally, it is worth considering the motivation of a coach to reflect. Coach 3 was very positive about using the technology enhanced reflection for her own future practice, but did state that this may not be applicable to all coaches:

> If the coach wants to improve, they'll do it. If they don't care or they don't want the truth, I guess they're not gonna do it. So it's really up to the coach I think. The coach will find a way, because it's different for people, different people reflect differently, and you have to find your own way to reflect.

The quote above gives an interesting insight. It should be noted that all coaches in the present study were likely highly motivated as they participated voluntarily. It is likely that there are many coaches working in sport who are less motivated to take part in technology enhanced reflection as it may be seen as additional work as suggested by Coach 3 above.

Each coach reflected on each individual session and provided evidence within one week of the session concluding. As the coaches were asked to reflect after each session, this type of reflection would be classed as retrospective reflection on-action (Gilbert and Trudel, 2001), which is one of the most common types of reflection used by sports coaches. All coaches showed that they could highlight key details in their sessions that they would not have had the awareness of without the technology to aid this. Coach 2 discusses the nuance in his questioning with his player:

> It was like I think I said at the end 'is everything clear there?' and it's like obviously, they're gonna say 'yes', just out of social awkwardness, but I think the trick's probably to ask a question that they can't dodge. You can even just ask them to teach on it or something then. That way you're actually checking for understanding, not just like ticking a box.

The quote above shows that the coach is trying to use questioning behavior more effectively. Rather than asking closed questions that are simple for athletes to evade, they are trying to ask more open questions to allow the athlete to show greater understanding. This type of questioning has been used by more experienced coaches (Partington et al., 2014) and the fact that the coach in this study is now aware of their previous limitations regarding questioning is positive. It highlights an understandable desire on their part to learn and develop.

Enhanced Reflection Can Lead to More Effective Coaching Behavior

It cannot be overstated how important the behavior of the coach is when dealing with athletes, as it has a significant influence in various contexts and can affect the participation, performance and development of the athletes coached (Partington et al., 2015; Schenk & Miltenberger, 2019). The importance of coach behavior is well known; what is less well known is that for coaches to deliberately behave a certain way requires both self-awareness and motivation to change (Glen & Lavallee, 2019; Partington et al., 2015). Coaches in the current study could articulate the underlying reasons why they changed their behavior when coaching, or why they kept some behaviors consistent. Below is a summary of how each coach behaved throughout the duration of the study and areas where they adapted behavior based on their reflections are discussed. Potential underlying reasons for any changes are given and quantitative ASUOI results are referred to.

Coach 1. Coach 1 was in individual sessions on all three occasions. However, because of circumstances outside the control of the coach, playing participants or the researchers, she was never observed coaching the same player more than once. Despite this being a limitation of the intervention for her, Coach 1 offered insights into the underlying reasons behind her behavior:

> With participant 3 (male), I feel a lot more confident. Therefor I don't feel I have to do as much. I feel like I am confident enough to let things go, even if they walk away from this lesson not liking me because maybe they haven't won the point at the end. With participant 2 (female), I feel like if she felt a bit flat at the end then she might not book a lesson again…. I maybe don't feel like I have the skillset for the girls, but I do for the boys. I feel like lots of praise and hustle is a reflection of my own anxieties. I reflect on this whole process and think I just need to be a bit calmer. You know, it's not up to me, I am not going to make you a better player, my job is to help you help yourself to be a better player. I would like that to be my philosophy. That is most reflected in the session and results with participant 3.

As previously discussed in relation to the first main theme, earlier on in the interview Coach 1 stated that she felt better, and more confident, about the session with the female athlete (participant 2) when watching the footage of and reflecting on the session. This is further reflected in this quote above as she stated she would like to be more relaxed in future deliveries with this participant and other female participants. From analyzing the ASUOI across all three sessions (Figure 2) all participants received a similar amount of instruction, however Participant 2 (female, referred to in the quote above) received very different frequencies of behavior compared to male participants. The female participant received more hustle (4.35% of total behavior) and more praise (21.96% of total behavior) than the male players. Interestingly the female participant also received far less questioning (13.26% of total behavior) compared to the male participants 1 and 3 (22.83% and 20.55% of total behavior respectively) which ties into the quote above. One change that happened with Coach 1 across all sessions was that she exhibited higher levels of silence on-task and gave less concurrent instruction as the sessions progressed. Levels of silence on-task increased: session 1 (3.18%), session 2 (5.65%) and session 3 (17.56% of total behavior respectively). The coach hinted at a possible underlying reason for this:

> The highness or frequency (of initial concurrent instruction) kind of highlights a lack of confidence in myself that I'm not sure if they're responding to me. That's how I felt in the session.

Coach 1 earlier stated that watching the sessions back helped her confidence, and this also partially explains the lower levels of silence in the initial session. Contextual factors surrounding a session or athlete can also impact on the behaviors of a coach (Cope et al., 2022; Partington et al., 2015). When discussing the reduced levels of concurrent instruction and increased levels of silence on-task for their third session specifically, the coach offered a further insight:

> I think it's about the context of that lesson. It was a pre-tournament session, so we were playing points and things like that.... I think for me reflecting on that kind of session, I felt I had a really good session with him, because we did a task, and he stayed on it for ages. I set up the right task. I think it's a great thing if a child can focus and do something for 20 minutes.

Silence has been a deliberate action taken by coaches (Partington et al., 2014). Changes in silence on-task have been seen before (Partington et al., 2015) when coaches deliberately increase the use of this as they became more aware of their behavior to allow for more observation and increased decision making for players. In order for more silence on-task to occur, other behaviors often reduce in rate, in the case of coach 1, this was concurrent instruction. A similar pattern for Coach 3 emerged in this present study in relation to both silence and levels of instruction.

Coach 2. Coach 2 was observed in individual sessions on all three occasions and coached the same player each time. This allowed for a better understanding of how behavior developed over time than in the sessions conducted by Coach 1. Below Coach 2 explains how he changed the way he played points in-game against the player as sessions progressed:

> I was trying to ensure that when we did play the open points, I gave him the ball so that he could then do what we were working on, so if we were just trying to get lots of volleys, I would force him to come into the net... I think what I was trying to avoid doing was working on something all lesson and getting to the point, and then not having him get a chance to work on it. I felt like that would have been a bit silly. I enjoyed watching that lesson.

The quote above shows a high level of insight and reflection from the coach. In earlier sessions that he reflected on, he showed annoyance at himself for going overly hard on the player during points and not giving them a chance to work on skills the lesson had been designed to work on in-game. Above he highlights that this improved across all three sessions with the same player and he also highlighted his own satisfaction in seeing this. Whilst this is very difficult to quantify on the ASUOI as there are no categories that can adequately quantify such behavior, the first author who observed all sessions would be inclined to agree with this comment. In previous sessions the coach would be more likely to hit winners against a player at a lower skill level than himself and this limited the opportunities in the game for the player to develop the skills worked on prior in drill like scenarios. It again shows critical reflection being acted upon positively.

Aside from in-game tactics, Coach 2 expanded how he developed the use questioning over the duration of the sessions and how he tried to improve his relationship with the player:

> I think you heard me say a couple things to the player like 'so tell me, give me a tip on how to hit a backhand' then he can begin to understand that he has to actually volunteer the information. There was one point where he came back with a very confused answer. I was like, 'Oh, I've not made that clear enough'. So that made me realize, I need to go back and clarify that. So, I found that useful, but I also

Behaviour	*Freq*	*% of Total*	*RPM*	*Freq*	*% of Total*	*RPM*	*Freq*	*% of Total*	*RPM*	*%Total (1-2)*	*%Total (2-3)*	*%Total 1-3)*	*RPM (1-2)*	*RPM (2-3)*	*RPM (1-3)*
Use of First Name	8	2.26	0.26	16	3.36	0.36	3	1.35	0.07	1.10	-2.01	-0.91	0.09	-0.28	-0.19
Pre-Instruction	70	20.23	2.28	81	17.61	1.80	36	16.44	0.89	-2.62	-1.17	-3.79	-0.48	-0.91	-1.40
Concurrent Instruction	28	8.09	0.91	25	5.43	0.56	3	1.37	0.07	-2.66	-4.06	-6.72	-0.36	-0.48	-0.84
Post Instruction	21	6.07	0.68	35	7.61	0.78	15	6.85	0.37	1.54	-0.76	0.78	0.09	-0.41	-0.32
Questioning	79	22.83	2.58	61	13.26	1.36	45	20.55	1.11	-9.57	7.29	-2.28	-1.22	-0.25	-1.47
Physical Assistance	0	0.00	0.00	5	1.09	0.11	0	0.00	0.00	1.09	-1.09	0.00	0.11	-0.11	0.00
Positive Modelling	28	8.09	0.91	42	9.13	0.93	3	1.37	0.07	1.04	-7.76	-6.72	0.02	-0.86	-0.84
Negative Modelling	1	0.29	0.03	12	2.61	0.27	0	0.00	0.00	2.32	-2.61	-0.29	0.23	-0.27	-0.03
Hustle	9	2.60	0.29	20	4.35	0.44	6	2.74	0.15	1.75	-1.61	0.14	0.15	-0.30	-0.15
Praise	68	19.65	2.22	101	21.96	2.25	37	16.89	0.91	2.30	-5.06	-2.76	0.03	-1.33	-1.31
Scold	2	0.58	0.07	1	0.22	0.02	2	0.91	0.05	-0.36	0.70	0.34	-0.04	0.03	-0.02
Management	13	3.76	0.42	25	5.43	0.56	18	8.22	0.44	1.68	2.78	4.46	0.13	-0.11	0.02
Uncodable	16	4.62	0.52	26	5.65	0.58	15	6.85	0.37	1.03	1.20	2.23	0.06	-0.21	-0.15
Silence (On-task)	11	3.18	0.36	26	5.65	0.58	38	17.35	0.94	2.47	11.70	14.17	0.22	0.36	0.58
Silence (Off-task)	0	0.00	0.00	0	0.00	0.00	1	0.46	0.02	0.00	0.46	0.46	0.00	0.02	0.02
	354	*100% (102.26%)**	*Time 30m 39s*	476	*100% (103.36%)**	*Time 44m 57s*	222	*100% (101.35%)**	*Time 40m 38s*						

Key: Freq = Frequency , % of Total = % of Total Behaviours Coded, RPM = Rate Per Minute, Green = Increase, Red = Decrease (Dark indicates greater change)

Figure 2
Coach 1 ASUOI Results and Changes in Behavior Between Sessions

found it's really good to be able to just have a chat with the player. I don't want them to feel awkward speaking to me, you want them to go to 'how you doing? How's your day? How's your week?. Before we could only talk about tennis... This has been a positive change from seeing that footage.

The quote above highlights that the coach reflected upon his prior sessions and noticed that he put poor quality questions to the player. Coach 2 also reflected that he asked many 'closed questions' in session 1. This frequency of questioning actually reduced throughout his sessions (14% of total behavior in session 1 to 11.16% in session 3), but what was perhaps more important was that the quality and types of question asked to the player became more open and allowed the player to demonstrate a higher level of understanding. This is a behavior associated with higher level coaches (Partington et al., 2014). This was particularly the case with technical points and tactical decisions such as shot selection. Another point of interest here was that Coach 2 used questioning to further enhance his existing relationship with the player. Coach 2 had worked with the player for several sessions prior to the start of the study, however expressed a desire to improve this relationship. The changes in questioning style were not performance related and could not therefore be coded under the definitions of the ASUOI. It is clear from the explanation above, and from observing the sessions, that this was a deliberate change from the coach. This use of questioning has been a method used by coaches to develop trust and enhance relationships with athletes (Lavallee et al., 2020). The coach also used the first name of the athlete more frequently as sessions progressed (7.61% of total behavior in session 1 to 10.20% in session 3) which has also been shown as an effective way of developing rapport with an athlete (Vinson et al., 2016) and may have been a deliberate strategy from Coach 2 (Figure 3). The quotes above suggest Coach 2 engaged with the process of reflection throughout the duration of the study and tried to change behavior to improve his interpersonal coaching behavior when working for an extended period with the same athlete. This shows a high level of motivation and self-awareness which are essential to changing behavior in sports coaches (Partington et al., 2015). Coach 2 also expressed a desire to continue technology-enhanced reflection post-study.

Coach 3. Coach 3 was observed in small group sessions on all three occasions and each player in the group was coached on more than one occasion. When questioned about which behaviors she was happy with and tried to keep constant Coach 3 offered this insight:

I was honestly quite happy with my explanations. I was quite self-conscious of them before, but when I watched them back, I was quite happy with the way I sounded and the way I explained things. I was clearer than I thought I was.

The above quote from the least experienced coach highlights that she was satisfied with her quality of explanation to her athletes. This ties into the study by Henderson et al. (2022) who found that athletes prefer instruction that is varied and reduces the chance of over-coaching. Whilst she was happy with her explanations and instruction, she found she gave too much feedback during the sessions and talked too much:

I obviously didn't realize that in the first session I talked so much, when I watched it, I obviously toned it down every time. It highlighted points with my session that I never really thought about. Like my, not hustle, but management, or how much I'm talking.

Behaviour	*Freq*	*% of Total*	*RPM*	*Freq*	*% of Total*	*RPM*	*Freq*	*% of Total*	*RPM*	*%Total (1-2)*	*%Total (2-3)*	*%Total 1-3)*	*RPM (1-2)*	*RPM (2-3)*	*RPM (1-3)*
Use of First Name	29	7.61	0.66	35	11.40	0.74	40	10.20	0.85	3.79	-1.20	2.59	0.09	0.10	0.19
Pre-Instruction	35	9.94	0.80	38	13.97	0.81	42	11.93	0.89	4.03	-2.04	1.99	0.01	0.08	0.10
Concurrent Instruction	9	2.56	0.20	4	1.47	0.09	3	0.85	0.06	-1.09	-0.62	-1.70	-0.12	-0.02	-0.14
Post Instruction	34	9.66	0.77	39	14.34	0.83	32	9.09	0.68	4.68	-5.25	-0.57	0.06	-0.15	-0.09
Questioning	52	14.77	1.18	31	11.40	0.66	40	11.36	0.85	-3.38	-0.03	-3.41	-0.52	0.19	-0.33
Physical Assistance	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Positive Modelling	38	10.80	0.86	27	9.93	0.57	36	10.23	0.76	-0.87	0.30	-0.57	-0.29	0.19	-0.10
Negative Modelling	14	3.98	0.32	13	4.78	0.28	25	7.10	0.53	0.80	2.32	3.13	-0.04	0.25	0.21
Hustle	14	3.98	0.32	4	1.47	0.09	12	3.41	0.25	-2.51	1.94	-0.57	-0.23	0.17	-0.06
Praise	64	18.18	1.45	51	18.75	1.09	67	19.03	1.42	0.57	0.28	0.85	-0.37	0.34	-0.03
Scold	4	1.14	0.09	1	0.37	0.02	4	1.14	0.08	-0.77	0.77	0.00	-0.07	0.06	-0.01
Management	38	10.80	0.86	24	8.82	0.51	42	11.93	0.89	-1.97	3.11	1.14	-0.35	0.38	0.03
Uncodable	26	7.39	0.59	20	7.35	0.43	25	7.10	0.53	-0.03	-0.25	-0.28	-0.17	0.11	-0.06
Silence (On-task)	24	6.82	0.55	19	6.99	0.40	22	6.25	0.47	0.17	-0.74	-0.57	-0.14	0.06	-0.08
Silence (Off-task)	0	0.00	0.00	1	0.37	0.02	2	0.57	0.04	0.37	0.20	0.57	0.02	0.02	0.04
	381	*100% (107.61%)**	*Time 44m 0s*	307	*100% (111.40%)**	*Time 47m 1s*	392	*100% (110.20%)**	*Time 47m 7s*						

Key: Freq = Frequency , % of Total = % of Total Behaviours Coded, RPM = Rate Per Minute, Green = Increase, Red = Decrease (Dark indicates greater change)

Figure 3
Coach 2 ASUOI Results and Changes in Behavior Between Sessions

This is something the coach above was very keen to avoid. This was influenced by her experience of being coached as she alluded to below:

> When I'm being coached, I don't really like that much talking. I want to get on with it and figure it out on my own.

Furthermore, Coach 3 highlights how she could adapt her behavior based upon the reflections, her beliefs and by considering the session from a player's perspective:

> I talked less as the sessions went on, I let the play, the game flow more. On the courses you're told to talk more, at least I was told to talk, talk, talk and give lots of feedback. But after I saw the first session, I thought I actually don't need to give as much feedback. I don't like if the coaches give me too much feedback, so I shouldn't do that to my players. So, I just started talking less and letting them figure it out on their own.

The above quotes are backed up from the ASUOI data for this coach (Figure 4), in session 1 instructional behavior (pre, concurrent and post instruction combined) accounted for 38% of total behavior. This decreased session by session and in the final session only 24.79% could be attributed to instructional behavior. This aligns with previous research that suggests that once coaches become aware of overly high levels of instruction, they try to reduce it (Partington et al., 2015). The coach above also increased her 'silence on task' across all sessions from 5% to 13.41% of total behavior across sessions 1-3. Prior research shows that silence on-task is the most common in-game behavior of elite youth coaches, and this is a deliberate strategy to be more observant and allow players to make decisions (Partington et al., 2014). It is clear then that the coach above has attempted to be quieter, more observant and give less instruction to help the players find solutions themselves. These changes suggest the coach is motivated to change their behavior and is seeking to develop.

Study Limitations and Future Research

It is important to acknowledge the limitations of the current study. It is clear that the study had a small sample size of both participants and coaches. This means that we cannot be certain that all findings will be able to be universally applied to all coaching contexts. However, when discussing longitudinal research around coaching behaviors, sample sizes are often small due to the amount of data required to be collected and analyzed for each coach (cf. Partington et al., 2015; Guzmán & Calpe-Gomez, 2012). Future research may wish to consider a larger sample size of coaches and participants.

The variance in participants for Coach 1 could also be regarded as a limitation. Coach 2 and 3 both coached the same players in all sessions, however Coach 1 did not. This was the case because the researchers in this study had to work around the availability of the coaches and the participants. For future research it may be recommended that there is consistency amongst both coaches and participants.

Another limitation is that the present study did not consider player perceptions of the session. If further studies are to be conducted in this area, it may be worth considering taking player perspectives into account. The authors acknowledge that player perspectives may differ from that of the coaches.

Finally, it should be noted that the sessions were filmed outdoors, and weather is a factor that can impact coach behavior (Partington et al., 2015; Cope et al., 2022). Whilst efforts were made to make the climate as stable as possible (it was conducted in

Figure 4
Coach 3 ASUOI Results and Changes in Behavior Between Sessions

Behaviour	*Freq*	*% of Total*	*RPM*	*Freq*	*% of Total*	*RPM*	*Freq*	*% of Total*	*RPM*	*%Total (1-2)*	*%Total (2-3)*	*%Total 1-3)*	*RPM (1-2)*	*RPM (2-3)*	*RPM (1-3)*
Use of First Name	56	15.73	1.84	40	10.13	0.81	31	11.19	1.00	-5.60	1.06	-4.54	-1.03	0.19	-0.84
Pre-Instruction	49	16.33	1.61	48	13.52	0.97	11	4.47	0.35	-2.81	-9.05	-11.86	-0.64	-0.61	-1.25
Concurrent Instruction	32	10.67	1.05	37	10.42	0.75	25	10.16	0.81	-0.24	-0.26	-0.50	-0.30	0.06	-0.24
Post Instruction	33	11.00	1.08	30	8.45	0.60	25	10.16	0.81	-2.55	1.71	-0.84	-0.48	0.20	-0.28
Questioning	34	11.33	1.11	23	6.48	0.46	27	10.98	0.87	-4.85	4.50	-0.36	-0.65	0.41	-0.24
Physical Assistance	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Positive Modelling	17	5.67	0.56	16	4.51	0.32	11	4.47	0.35	-1.16	-0.04	-1.20	-0.24	0.03	-0.20
Negative Modelling	0	0.00	0.00	3	0.85	0.06	2	0.81	0.06	0.85	-0.03	0.81	0.06	0.00	0.06
Hustle	10	3.33	0.33	25	7.04	0.50	20	8.13	0.65	3.71	1.09	4.80	0.18	0.14	0.32
Praise	67	22.33	2.20	75	21.13	1.51	53	21.54	1.71	-1.21	0.42	-0.79	-0.69	0.20	-0.49
Scold	0	0.00	0.00	3	0.85	0.06	1	0.41	0.03	0.85	-0.44	0.41	0.06	-0.03	0.03
Management	25	8.33	0.82	42	11.83	0.85	24	9.76	0.77	3.50	-2.07	1.42	0.03	-0.07	-0.05
Uncodable	17	5.67	0.56	14	3.94	0.28	12	4.88	0.39	-1.72	0.93	-0.79	-0.28	0.11	-0.17
Silence (On-task)	15	5.00	0.49	38	10.70	0.77	33	13.41	1.06	5.70	2.71	8.41	0.27	0.30	0.57
Silence (Off-task)	1	0.33	0.03	1	0.28	0.02	2	0.81	0.06	-0.05	0.53	0.48	-0.01	0.04	0.03
	356	*100% (115.73)**	*Time 30m 32s*	395	*100% (110.13%)**	*Time 49m 40s*	277	*100% (111.19%)**	*Time 31m 0s*						

Key: Freq = Frequency , % of Total = % of Total Behaviours Coded, RPM = Rate Per Minute, Green = Increase, Red = Decrease (Dark indicates greater change) summer months), future research may wish to consider conducting the study in an indoor environment. Whilst this is a limitation of the present study, it did yield an interesting insight from one coach in particular (Coach 2) into how his behavior adapted to the conditions and context of the session.

Overall, all the tennis coaches engaged well with the technology and were supportive of its use in future sessions for themselves and others. Subsequently this led to in-depth critical reflection across all coaches. This showed that they were all very keen to engage with technology and apply their reflections to their tennis coaching and interactions with participants. It remains to be seen if these adaptations will become permanent, and a follow-up study could explore this research question. There were no instances of coaches believing that they didn't have to change any aspects of their behavior. This suggests that coaches engaged well with the technology to enhance their reflections and think about the implications of their behavior on their participants. Finally, Coaches 2 and 3 did deliberately begin to change aspects of their behavior because of this reflection process. This was not quantifiable for all aspects of change, due in-part to limitations of the ASUOI, but there were some changes in the results that were very apparent. The increased use of silence on-task for Coaches 1 and 3 was noted and was very apparent from observation of sessions. Whilst there are other methods of systematically observing coaching behavior that are arguably more complex and contain more sub-sections of certain behaviors, there is no distinguished method that is all encompassing and meets the context of all sports and criteria associated (Cope et al., 2017). The rationale for using the ASUOI was clear, it is among the most used systematic observation method in coaching behavior research and has been used in the specific tennis coaching context in prior published studies (Claxton, 1988; Glen et al., 2020).

CONCLUSIONS

The results suggest that technology is effective in aiding reflection and coaching behaviour in youth tennis coaches. Based upon the study findings we recommend the integration of audio and video technology into tennis coach education programmes to help improve coach self-awareness of behaviour. By integrating this technology effectively, it will give coaches a chance to reflect on their behaviour and interactions with athletes. Without this, coaches are more likely to be relatively unaware of their behaviors (both desirable and undesirable) and as a result will have less motivation, or reason, to adapt their behavior accordingly. Additionally, we recommend that tennis clubs should look at using similar types of intervention to work with their coaches in a less formal setting away from national governing body coach education. Doing so would put the responsibility on clubs to make this standard practice for coaches and allow them to become more familiar with technology and ongoing deliberate reflective practice. This could be further enhanced by using more experienced tennis coaches as mentors to help the younger coaches with the reflection process. Young tennis coaches often find it hard to improve their coaching practice and behavior and many do not know exactly how to, or are not aware of the need to enhance their behavior. By harnessing the technology available and working in conjunction with mentors this could help them improve their tennis coaching and have positive impacts on the overall development of their participants.

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REFERENCES

Berntsen, H., & Kristiansen, E. (2019). Guidelines for need-supportive coach development: The Motivation Activation Program in Sports. *International Sport Coaching Journal, 6*(1), 88-97. https://doi.org/10.1123/iscj.2018-0066

Braun, V., & Clarke, V. (2022). *Thematic analysis: A practical guide.* Sage.

Christensen, M. K. (2013). Outlining a typology of sports coaching careers: Paradigmatic trajectories and ideal career types among high-performance sports coaches. *Sports Coaching Review, 2*(2), 98-113. https://doi.org/10.1080/21640629.2013.775102

Claxton, D. B. (1988). A systematic observation of more and less successful high school tennis coaches. *Journal of Teaching in Physical Education, 7*(4), 302-310. https://doi.org/10.1123/jtpe.7.4.302

Cope, E., Cushion, C. J., Harvey, S., & Partington, M. (2021). Investigating the impact of a Freirean informed coach education programme. *Physical Education and Sport Pedagogy, 26*(1), 65-78. https://doi.org/10.1080/17408989.2020.1800619

Cope, E., Cushion, C. J., Harvey, S., & Partington, M. (2022). *Re-visiting systematic observation. Frontiers in Sports and Active Living, 310.* https://doi.org/10.3389/fspor.2021.656771

Cope, E., Partington, M., & Harvey, S. (2017). A review of the use of a systematic observation method in coaching research between 1997 and 2016. *Journal of Sports Sciences, 35*(20), 2042-2050. https://doi.org/10.1080/02640414.2016.1241138

Cronin, C., & Armour, K. M. (2017). 'Being' in the coaching world: New insights on youth performance coaching from an interpretative phenomenological approach. *Sport, Education and Society, 22*(8), 919-931. https://doi.org/10.1080/13573322.2016.1276626

Cushion, C., Harvey, S., Muir, B., & Nelson, L. (2012). Developing the Coach Analysis and Intervention System (CAIS): Establishing validity and reliability of a computerized systematic observation instrument. *Journal of Sports Sciences, 30*(2), 201-216. https://doi.org/10.1080/02640414.2011.635310

Eppich, W. J., Gormley, G. J., & Teunissen, P. W. (2019). In-depth interviews. In *Healthcare Simulation Research: A Practical Guide* (pp. 85-91). Spring International Publishing.

Gilbert, W., & Trudel, P. (2001). Learning to coach through experience: Reflection in model youth sport coaches. *Journal of Teaching in Physical Education, 21*(1), 16-34. https://doi.org/10.1123/jtpe.21.1.16

Glen, J., Gordon, J., & Lavallee, D. (2020). Investigating coaching behaviors during the COVID-19 pandemic: A case study within a case study. *Case Studies in Sport and Exercise Psychology, 4*(1), 125-133. https://doi.org/10.1123/cssep.2020-0014

Glen, J., & Lavallee, D. (2019). How do coach educators influence meaningful behavior change in sports coaches? *Kinesiologia Slovenica, 25*(3), 16-30. DOI: https://doi.org/10.15292/kin.2019.03.16-30

Guzmán, J. F., & Calpe-Gómez, V. (2012). Preliminary study of coach verbal behavior according to game actions. *Journal of Human Sport and Exercise, 7*(2), 376-382. https://www.redalyc.org/pdf/3010/301023544004.pdf

Henderson, S., Bloom, G. A., & Alexander, D. (2022). Desired coaching behaviors of elite divers during competition. *International Journal of Sport and Exercise Psychology, 20*, 1777-1794. https://doi.org/10.1080/1612197X.2021.2003417

James, K., Craig, T., Hassan, A., & Guo, X. (2019). Exploring Issues Faced by the Scottish Snowsports Industry. *Journal of Physical Fitness, Medicine & Treatment in Sports, 6*(1). https://ssrn.com/abstract=3322066

Knowles, Z., Tyler, G., Gilbourne, D., & Eubank, M. (2006). Reflecting on reflection: Exploring the practice of sports coaching graduates. *Reflective Practice, 7*(2), 163-179. https://doi.org/10.1080/14623940600688423

Lacy, A. C., & Darst, P. W. (1984). Evolution of a systematic observation system: The ASU coaching observation instrument. *Journal of Teaching in Physical Education, 3*(3), 59-66. https://doi.org/10.1123/jtpe.3.3.59

Laird, P., & Waters, L. (2008). Eyewitness recollection of sport coaches. *International Journal of Performance Analysis in Sport, 8*(1), 76-84. https://doi.org/10.1080/24748668.2008.11868460

Lavallee, D., Lowder, J., & Lowder, J. (2020). Clear data as a new data typology to enhance sustainability in sport. *Sustainability, 12*(11), 4527. https://doi.org/10.3390/su12114527

Nelson, L. J., & Cushion, C. J. (2006). Reflection in coach education: The case of the national governing body coaching certificate. *The Sport Psychologist, 20*(2), 174-183. https://doi.org/10.1123/tsp.20.2.174

Partington, M., Cushion, C. J., Cope, E., & Harvey, S. (2015). The impact of video feedback on professional youth football coaches' reflection and practice behavior: A longitudinal investigation of behavior change. *Reflective Practice, 16*(5), 700-716. https://doi.org/10.1080/14623943.2015.1071707

Partington, M., Cushion, C., & Harvey, S. (2014). An investigation of the effect of athletes' age on the coaching behaviors of professional top-level youth soccer coaches. *Journal of Sports Sciences, 32*(5), 403-414. https://doi.org/10.1080/02640414.2013.821309

Potrac, P., Jones, R., & Armour, K. (2002). 'It's All About Getting Respect': The coaching behaviors of an expert English soccer coach. *Sport, Education and Society, 7*(2), 183-202. https://doi.org/10.1080/1357332022000018869

Potrac, P., Jones, R., & Cushion, C. (2007). Understanding power and the coach's role in professional English soccer: Anh investigation of coach behavior. *Soccer & Society, 8*(1), 33-49. https://doi.org/10.1080/14660970600989509

Schenk, M., & Miltenberger, R. (2019). A review of behavioral interventions to enhance sports performance. *Behavioral Interventions, 34*(2), 248-279. https://doi.org/10.1002/bin.1675

Schön, D. (1983). *The reflective practitioner.* Temple Smith.

Silva, E. J. D., Evans, M. B., Lefebvre, J. S., Allan, V., Côté, J., & Palmeira, A. (2020). A systematic review of intrapersonal coach development programs: Examining the development and evaluation of programs to elicit coach reflection.*International Journal of Sports Science & Coaching, 15*, 818-837. https://doi.org/10.1177/1747954120946101

Stodter, A., & Cushion, C. J. (2019). Evidencing the impact of coaches' learning: Changes in coaching knowledge and practice over time. *Journal of Sports Sciences, 37*(18), 2086-2093. https://doi.org/10.1080/02640414.2019.1621

Stoszkowski, J., & Collins, D. (2014). Blogs: A tool to facilitate reflection and community of practice in sports coaching?. *International Sport Coaching Journal, 1*(3), 139-151. https://doi.org/10.1123/iscj.2013-0030

Stoszkowski, J., & Collins, D. (2022). A realist evaluation of the use of Flipgrid to facilitate collaborative online learning and reflection in sport coaching. *Sport, Education and Society, 27*(8), 906-921. https://doi.org/10.1080/13573322.2020.1867124

Vinson, D., Brady, A., Moreland, B., & Judge, N. (2016). Exploring coach behaviors, session contexts, and key stakeholder perceptions of non-linear coaching approaches in youth sport. *International Journal of Sports Science & Coaching, 11*(1), 54-68. https://doi.org/10.1177/1747954115624824

Zoder-Martell, K. A., Markelz, A. M., Floress, M. T., & Sayyah, L. E. (2020). Technology to facilitate telehealth in applied behavior analysis. *Behavior Analysis in Practice, 13*, 596-603. https://doi.org/10.1007/s40617-020-00449-4

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Physical Growth and Biological Maturity Status of Young Table Tennis Players

Crecimiento físico y madurez biológica de jugadores jóvenes de tenis de mesa

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Abstract

Although table tennis is a popular sport played by millions of people regularly and competitively, and the studies devoted to table tennis are increasing, the extent of literature on the growth and maturity status of young table tennis players is not extensive. The present study aimed to assess the growth and maturity status of young medal-winning table tennis players and compare them with non-medal-winning players. A group of 117 competitive players, consisting of 57 males (12.87±1.35 years) and 60 females (12.99±1.24 years), underwent measurements of standing height, sitting height, and body mass. Body mass index (BMI) was calculated by dividing weight (in kilograms) by the square of height (in meters), and growth status was determined using a reference database. Somatic maturity status was estimated using age at peak height velocity (APHV) and maturity offset, calculated by the difference between APHV and chronological age. The results indicated that the mean height, body mass, and BMI percentiles of both genders were higher than the 37th percentile when compared to normative references. There were no significant differences in terms of growth and maturity status between medal-winning and non-medal-winning players in both genders. The study suggests that coaches might consider closely monitoring the growth and maturity levels of their players and potentially consider adjusting training strategies based on the players' physical characteristics. These findings could contribute valuable insights into talent identification, physical development, and their potential influence on performance in youth table tennis.

Keywords: *Racket sports, talent identification, youth athletes, biological maturation, physical growth.*

Resumen

Aunque el tenis de mesa es un deporte popular practicado por millones de personas de forma regular y competitiva, y los estudios dedicados al tenis de mesa van en aumento, la literatura sobre el crecimiento y la madurez de los jugadores jóvenes de tenis de mesa no es extensa. El objetivo de este estudio fue evaluar el crecimiento y la madurez de jugadores jóvenes de tenis de mesa que han ganado medallas y compararlos con jugadores que no han ganado medallas. Se midió la altura de pie, la altura sentados y la masa corporal de un grupo de 117 jugadores de competición compuesto por 57 hombres (12,87 ± 1,35 años) y 60 mujeres (12,99 ± 1,24 años). El índice de masa corporal (IMC) se calculó dividiendo el peso (en kilogramos) por el cuadrado de la altura (en metros) y el estado de crecimiento se determinó utilizando una base de datos de referencia. El estado de madurez somática se estimó utilizando la edad al pico de la velocidad de crecimiento (PVC) y el desfase madurativo fue calculado por la diferencia entre la edad al PVC y la edad cronológica. Los resultados indicaron que la estatura media, la masa corporal y los percentiles de IMC de ambos sexos eran superiores al percentil 37º en comparación con las referencias normativas. No hubo diferencias significativas en términos de crecimiento y estado de madurez entre los jugadores ganadores y no ganadores de medallas en ambos sexos. El estudio sugiere que los entrenadores podrían considerar la posibilidad de vigilar de cerca los niveles de crecimiento y madurez de sus jugadores y, potencialmente, considerar ajustar las estrategias de entrenamiento en función de las características físicas de los jugadores. Estos hallazgos podrían aportar valiosos conocimientos sobre la identificación de talentos, el desarrollo físico y su posible influencia en el rendimiento en el tenis de mesa juvenil.

Palabras clave: *deportes de raqueta, identificación de talentos, atletas jóvenes, maduración biológica, crecimiento físico*

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INTRODUCTION

Racket sports have been popular worldwide for over a century (Lees, 2003; Robertson et al., 2018) and studies have shown that practicing racket sports such as tennis, table tennis, badminton, and squash can improve the brain's ability to coordinate movements of the body, which can lead to better hand-eye coordination, reflexes, speed, endurance, flexibility, agility, and overall physical fitness (Jaworski et al., 2020; Schaefer & Scornaienchi, 2019). Racket sports are similar in that they all require players to use a racket to hit a ball or shuttlecock over a net and involve bursts of high-intensity exercise (Faber er al., 2016; Pluim, 2004). However, there are some key differences between racket sports, such as the swinging patterns used, the size of the court, and the speed of the ball (Ak & Koçak, 2010; Akpınar et al., 2012). For instance, tennis players have more time to anticipate the placement of the ball and react accordingly to the speed and spin of the shots, as the ball travels slower and has a larger trajectory than in other racket sports, whereas table tennis players have less time to react to the speed and spin of the shots, as the ball travels much faster and has a much shorter trajectory (Ak & Koçak, 2010).

Developing effective training programs for young athletes relies on a profound understanding of how growth and maturation impact a child's development (Balyi & Hamilton, 2004; Balyi et al., 2013; Ford et al., 2011). To ensure that young athletes receive training that fosters their overall growth, it is imperative to fully grasp these two biological processes since they play pivotal roles in a child's development and significantly influence their physical, mental, and emotional well-being (Beunen & Malina, 2007). Despite often being used interchangeably and mistakenly perceived as referring to the same concepts, it is crucial to recognize that growth and maturation are separate biological processes (Cameron, 2022a; Malina et al., 2004). Maturation pertains to the progression of the body's skeletal, sexual, and somatic systems towards adulthood, while growth involves alterations in size and body composition that occur as individuals age (Baxter-Jones et al., 1995; Baxter-Jones et al., 2005; Cameron, 2022b; Malina et al., 2004).

In the context of youth sports, research on the relationship between growth, maturation, and sports performance is important for talent identification and development (Malina et al., 2004). During the last decades, there has been a lot of research on this topic, especially in team sports like soccer and basketball. However, there is a gap in knowledge about this relationship in racket sports, particularly table tennis, badminton, and squash (Coelho-e-Silva et al., 2021). A recent study by Coelho-E-Silva et al. (2021) found that most young male table tennis players were early maturing based on skeletal age and average maturing based on somatic indicators. Their heights and body masses were above the reference medians from 10 to 13 years, and their skeletal ages were generally advanced relative to chronological age. Another study by Doherty et al. (2018) showed that there were significant correlations between actual performance rating and age at peak height velocity (APHV), sprint test, years of practice, positive refocusing, self-regulation in learning, and evaluation in elite youth male table tennis players. The study also found that APHV, sprint test, years of practice, self-monitoring, and evaluation were significantly correlated with progression scores.

The research on growth and maturation in racket sports has mostly focused on tennis, with only two studies on table tennis (Coelho-E-Silva et al., 2021; Doherty et al., 2018). Both table tennis studies were conducted with male players, and they did not report any information about medal-winning or ranking status. This study is original in the sense that it investigates the relationship between growth and maturity status and the medal-winning status of young competitive table tennis players at consecutive ages. Therefore, the purposes of this study are: (1) to determine the growth and maturity status of young medal-winning table tennis players, and (2) to compare these players with their non-medal-winning counterparts. The study hypothesized that medal-winning players were expected to have a more advanced growth and maturity status compared to non-medal-winning players.

METHODS

Participants

In this cross-sectional study, convenience sampling method was utilized. A total of 117 table tennis players (57 males aged 12.87 ± 1.35 years, and 60 females aged 12.99 ± 1.24 years) were measured for their standing height, sitting height, and body mass. To be included in the study, the players had to meet the following criteria: (i) they had to be registered with the Turkish Table Tennis Federation, and (ii) they had to have at least two years of training experience in organized and competitive table tennis. The study was approved by the Human Subjects Ethics Committee of Middle East Technical University, and written informed consent was obtained from the children and their parents or legal guardians after the measurements and purpose of the study were explained. Means and standard deviations for chronological age, training age, weekly training, height, sitting height, body mass, body mass index (BMI), APHV, and maturity offset of female and male table tennis players are summarized in Table 1.

Table 1
Descriptive statistics

Variables	Girls (n = 60)	Boys (n =57)
Chronological age (years)	12.9 ± 1.2	12.9 ± 1.4
Training age (years)	5.2 ± 1.3	4.9 ± 1.7
Weekly training (hours/week)	15.3 ± 5.5	14.6 ± 6.8
Height (cm)	155.9 ± 7.01	159.3 ± 9.4
Sitting height (cm)	81.5 ± 4.3	82.1 ± 45
Body mass (kg)	47.2 ± 9.6	50.9 ± 11.6
Body Mass Index (kg/m^2)	19.4 ± 3.3	19.9 ± 3.4
Height (z-scores)	0.1 ± 0.8	0.4 ± 0.8
Height (percentiles)	51.7 ± 24.9	62.9 ± 23.3
Body mass (z-scores)	0.1 ± 0.7	0.3 ± 0.7
Body mass (percentiles)	53.1 ± 23.7	58.6 ± 21.7
Body Mass Index (z-scores)	-0.03 ± 0.8	0.3 ± 0.9
Body Mass Index (percentiles)	49.4 ± 26.6	57.4 ± 26.2
APHV (years)	12.2 ± 0.5	13.7 ± 0.6
Maturity offset (years)	0.8 ± 1.04	-0.8 ± 1.2

Z-scores represent how many standard deviations a value deviates from the mean of a reference population, allowing for standardized comparisons across different age groups. Percentiles, on the other hand, indicate the relative ranking of a player's measurement within a reference data set, showing the percentage of individuals with lower values. In this context, the percentile of height indicates the relative ranking of a player's height compared to a reference population of the same age and gender, with a higher percentile suggesting that the player is taller than most of their peers and a lower percentile indicating they are shorter. Similarly, the percentiles of body mass and BMI reflect how a player's weight and BMI compare to normative values. These measures are crucial for contextualizing the physical development of young table tennis players within a broader population and for identifying potential advantages or limitations in their growth trajectories.

Procedures

Birth dates, training age, and weekly training information were collected from the players, coaches, and parents. In addition to general information about the players, anthropometric measurements, including body mass, stature, and sitting height, were taken. Height measurements were taken using a portable stadiometer (Seca 213, Hamburg, Germany) for both standing and sitting heights, and body weight was assessed using a digital weighing scale. To be used in calculation of APHV, leg length was computed by finding the difference between standing and sitting heights. BMI was calculated by dividing body mass (kg) by the squared height (m). Height-for-age, weight-for-age, and BMI-for-age were compared to reference data (Frisancho, 2008). Percentile and z-score values were calculated for height, body weight, and BMI. The APHV was estimated using the predictive equation developed by Mirwald et al. (2002). The maturity offset was calculated by subtracting the chronological age from the APHV. The chronological ages of the players were determined by subtracting their birthdate from the date of measurement.

Statistical analysis

A gender-based descriptive analysis of the data was conducted, with all values presented as means and standard deviations. The normality of the data was assessed using the Kolmogorov-Smirnov test. The results indicated no significant deviations from normality, suggesting that the data were normally distributed. Independent samples t-tests were conducted to examine differences between medal-winning and non-medal-winning players, separately for boys and girls. The effect size was quantified using Cohen's d, with the following interpretation: <0.20 (trivial), 0.20–0.59 (small), 0.60–1.19 (moderate), 1.20–1.99 (large), 2.0–3.9 (very large), and >4.0 (extremely large) (Hopkins et al., 2009). The significance threshold was set at $p < 0.05$. IBM SPSS Statistics for Windows, Version 26.0 (SPSS Inc., Chicago IL), was used for all statistical analyses in this study.

RESULTS

Means and standard deviations for chronological ages, height, sitting height, body mass, BMI, height z-score, height percentile, body mass z-score, body mass percentile, BMI z-score, BMI percentile, APHV, and maturity offset are presented by five age groups (U11, U12, U13, U14, and U15) in Table 2.

Figures 1, 2 and 3 show the mean values of height, body mass, and BMI for each age group, along with the corresponding percentiles within a reference population.

The mean height percentiles of players are shown in Figure 1. Female players had heights between the 45th and 57th percentiles, with the lowest mean values in U15 girls and the highest mean values in U12 girls. Male players had heights between the 54th and 69th percentiles, with the lowest mean values in U14 boys and the highest in U11 boys. The percentiles of other age groups for female players were mostly around the 50th percentile mark, while the percentiles of other age groups for male players were between the 60th and 65th percentiles.

Table 2.
Descriptive statistics by age groups

Ages	11		12		13		14		15	
Gender	**Boys (M ± SD)**	**Girls (M ± SD)**	**Boys (M ± SD)**	**Girls (M ± SD)**	**Boys (M ± SD)**	**Girls (M ± SD)**	**Boys (M ± SD)**	**Girls (M ± SD)**	**Boys (M ± SD)**	**Girls (M ± SD)**
Chronological age (years)	10.8 ± 0.3	10.9 ± 0.2	12.1 ± 0.3	11.9 ± 0.4	12.9 ± 0.3	12.8 ± 0.4	13.8 ± 0.4	13.7 ± 0.4	14.6 ± 0.3	14.8 ± 0.3
Height (cm)	149.4 ± 8.1	146.6 ± 2.8	155.8 ± 5.5	152.8 ± 6.3	159.6 ± 6.6	155.9 ± 5.6	162.2 ± 6.1	158.9 ± 5.2	169.2 ± 7.1	160.3 ± 7.7
Sitting height (cm)	77.5 ± 3.8	77.1 ± 1.6	80.5 ± 3.1	78.7 ± 4.2	81.7 ± 4.1	81.4 ± 3.3	84.2 ± 2.6	83.4 ± 2.8	87.3 ± 4.1	84.9 ± 3.9
Body mass (kg)	43.5 ± 13.9	36.3 ± 3.7	44.3 ± 4.8	40.6 ± 7.4	49.2 ± 8.4	46.9 ± 9.2	61.8 ± 12.4	53.7 ± 8.4	58.5 ± 7.3	52.9 ± 5.1
Body Mass Index (kg/m²)	19.3 ± 4.6	16.9 ± 1.9	18.3 ± 1.8	17.4 ± 2.9	19.4 ± 3.1	19.3 ± 3.3	23.4 ± 3.3	21.3 ± 3.3	20.6 ± 2.1	20.8 ± 2.1
Stature (z-scores)	0.8 ± 1.1	0.1 ± 0.4	0.5 ± 0.6	0.3 ± 0.8	0.4 ± 0.7	0.1 ± 0.8	0.1 ± 0.7	0.1 ± 0.7	0.4 ± 0.8	-0.1 ± 1.1
Stature (percentiles)	68.7 ± 29.4	52.2 ± 14.2	65.6 ± 17.7	57.2 ± 21.1	63.0 ± 22.3	50.2 ± 24.9	53.8 ± 24.7	51.7 ± 23.9	60.7 ± 22.1	45.0 ± 35.9
Body mass (z-scores)	0.2 ± 1.1	-0.3 ± 0.4	-0.1 ± 0.4	-0.2 ± 0.7	0.1 ± 0.6	0.1 ± 0.9	0.8 ± 0.7	0.4 ± 0.7	0.4 ± 0.5	0.2 ± 0.4
Body mass (percentiles)	55.2 ± 28.1	40.5 ± 15.2	49.2 ± 15.3	44.4 ± 23.9	55.1 ± 21.8	53.3 ± 27.9	74.2 ± 18.9	64.6 ± 23.5	63.9 ± 14.9	55.7 ± 15.5
Body Mass Index (z-scores)	0.4 ± 1.3	-0.3 ± 0.7	-0.1 ± 0.6	-0.4 ± 0.9	0.1 ± 0.9	-0.1 ± 0.9	1.1 ± 0.7	0.4 ± 0.8	0.2 ± 0.6	0.1 ± 0.5
Body Mass Index (percentiles)	58.1 ± 32.9	39.0 ± 23.7	47.6 ± 21.3	37.1 ± 26.7	53.4 ± 27.1	49.4 ± 30.5	80.1 ± 15.1	61.8 ± 24.7	55.6 ± 20.7	55.1 ± 18.3
APHV (years)	13.1 ± 0.5	11.9 ± 0.1	13.5 ± 0.3	11.9 ± 0.4	13.8 ± 0.5	12.1 ± 0.5	13.8 ± 0.4	12.3 ± 0.3	13.9 ± 0.5	12.7 ± 0.5
Maturity offset (years)	-2.3 ± 0.5	-0.9 ± 0.2	-1.4 ± 0.4	-0.1 ± 0.5	-0.9 ± 0.6	0.7 ± 0.5	0.1 ± 0.5	1.4 ± 0.4	0.7 ± 0.6	2.1 ± 0.4

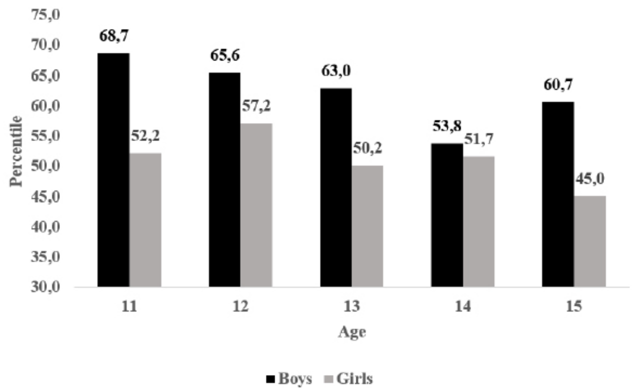

Figure 1. Mean height and corresponding percentiles by age group [1]

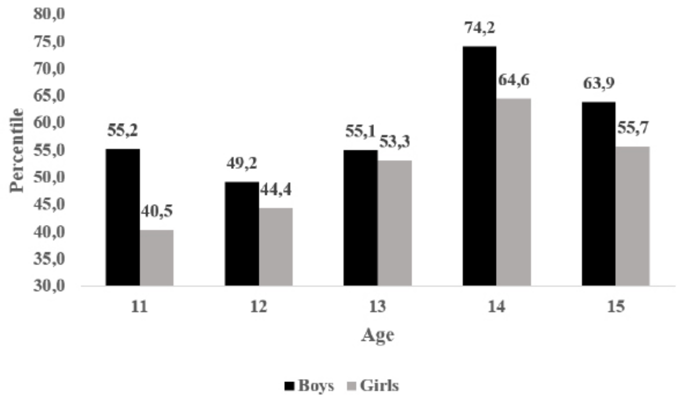

Figure 2. Mean body mass and corresponding percentiles by age group [2]

[1] Each column in the figure represents the mean value of height for a given age group, along with its corresponding percentile within the reference dataset.
[2] Each column in the figure represents the mean value of body mass for a given age group, along with its corresponding percentile within the reference dataset.

The mean body mass percentiles of players are given in Figure 2. The body masses of the female players were between the 40th and 65th percentiles, with the U11 girls having the lowest mean values and the U14 girls having the highest. The other age groups had percentiles between the 44th and 56th. The body masses of the male players were between the 49th and 74th percentiles, with the U12 boys having the lowest mean values and the U14 boys having the highest. The other age groups had percentiles between the 55th and 64th.

The mean BMI percentiles of players are given in Figure 3. The BMI values of the female players were between the 37th and 62nd percentiles, with the U12 girls having the lowest mean values and the U14 girls having the highest. The other age groups had percentiles between the 39th and 55th. The BMI values of the male players were between the 48th and 80th percentiles, with the U12 boys having the lowest mean values and the U14 boys having the highest. The other age groups had percentiles around the 55th.

Table 3 shows a comparison of medal-winning and non-medal-winning players. There were no significant differences between the two groups of girls in any of the variables measured. Among boys, there were no significant differences between the two groups in any of the variables measured except for training age. Medal-winning boys had significantly more experience in regular table tennis training than non-medal-winning boys ($p < 0.05$).

DISCUSSION

This study aimed to determine the growth and maturity status of young medal-winning table tennis players and compare them with their non-medal-winning counterparts. The study hypothesized that medal-winning players were expected to have a more advanced growth and maturity status compared to non-medal-winning players; however, the findings of the study failed to support this hypothesis. The main findings of the study highlight that, compared to normative references for the same age and gender, both boys and girls exhibited mean height, body mass, and BMI percentiles above the 37th percentile. Notably, there were no significant differences in any variable between medal-winning and non-medal-winning girls, whereas the only significant difference observed among boys was in training age.

The research revealed that female table tennis players had heights that fell between the 45th and 57th percentiles, while male players had heights ranging from the 54th to the 69th percentiles. Additionally, the study noted that female table tennis players had body masses spanning from the 40th to the 65th percentiles, whereas male players had body masses ranging from the 49th to the 74th percentiles. In terms of BMI percentiles, the study indicated that female table tennis players had BMI values ranging from the 37th to the 62nd percentiles, while male players had BMI values ranging from the 48th to the 80th percentiles. These findings are consistent with previous research conducted in racket sports (Baxter-Jones et al., 1995; Coelho-E-Silva et al., 2021; Erlandson et al., 2008; Myburgh et al., 2016; Söğüt et al., 2019; Söğüt et al., 2023).

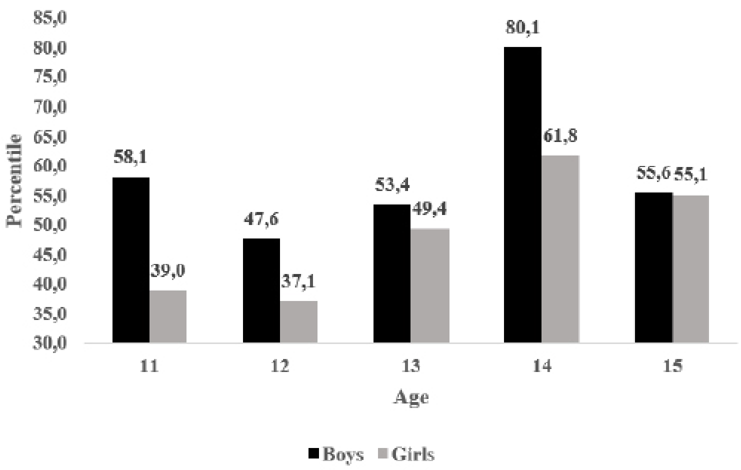

Figure 3. Mean BMI and corresponding percentiles by age group [3]

[3] Each column in the figure represents the mean value of BMI for a given age group, along with its corresponding percentile within the reference dataset

Table 3
Comparison between Medal-Winning and Non-Medal-Winning players

	Gender	Medal-winning	Non-medal-winning	t	p	d	Qualitative
Chronological age (years)	Girls	13.1 ± 1.2	12.9 ± 1.3	-0.282	0.779	0.001	Trivial
	Boys	12.5 ± 1.3	12.9 ± 1.4	1.039	0.303	0.019	Trivial
Training age (years)	Girls	5.7 ± 1.2	5.1 ± 1.3	-1.672	0.100	0.046	Trivial
	Boys	5.9 ± 1.3	4.7 ± 1.7	-2.230	0.030*	0.083	Trivial
Weekly training (hours/ week)	Girls	15.9 ± 6.7	15.1 ± 5.04	-0.512	0.610	0.004	Trivial
	Boys	17.9 ± 6.2	13.9 ± 6.8	-1.833	0.072	0.058	Trivial
Height (cm)	Girls	157.9 ± 6.6	155.1 ± 7.1	-1.373	0.175	0.031	Trivial
	Boys	157.6 ± 11.9	159.7 ± 8.8	0.664	0.509	0.008	Trivial
Sitting height (cm)	Girls	82.8 ± 4.8	81.0 ± 4.1	-1.414	0.163	0.033	Trivial
	Boys	80.9 ± 5.9	82.4 ± 4.7	0.917	0.363	0.015	Trivial
Body mass (kg)	Girls	46.6 ± 9.7	47.4 ± 9.7	0.274	0.785	0.001	Trivial
	Boys	47.9 ± 12.8	51.7 ± 11.2	0.972	0.335	0.017	Trivial
Body Mass Index (kg/m^2)	Girls	18.6 ± 2.9	19.7 ± 3.4	1.130	0.263	0.022	Trivial
	Boys	18.9 ± 2.8	20.2 ± 3.5	1.047	0.300	0.020	Trivial
Height (z-scores)	Girls	0.3 ± 0.9	-0.02 ± 0.7	-1.333	0.188	0.030	Trivial
	Boys	0.5 ± 0.9	0.4 ± 0.8	-0.290	0.773	0.002	Trivial
Height (percentiles)	Girls	58.2 ± 27.7	49.3 ± 23.8	-1.224	0.226	0.025	Trivial
	Boys	63.9 ± 26.5	62.7 ± 22.8	-0.149	0.882	0.000	Trivial
Body mass (z-scores)	Girls	0.01 ± 0.7	0.1 ± 0.7	0.489	0.626	0.004	Trivial
	Boys	0.1 ± 0.8	0.3 ± 0.7	0.760	0.450	0.010	Trivial
Body mass (percentiles)	Girls	51.5 ± 24	53.7 ± 23.8	0.325	0.746	0.002	Trivial
	Boys	55.2 ± 22.5	59.4 ± 21.6	0.568	0.572	0.006	Trivial
Body Mass Index (z-scores)	Girls	-0.3 ± 0.7	0.1 ± 0.9	1.289	0.203	0.028	Trivial
	Boys	0.1 ± 0.8	0.3 ± 0.9	0.714	0.478	0.009	Trivial
Body Mass Index (percentiles)	Girls	42.7 ± 24.1	51.8 ± 27.2	1.181	0.242	0.023	Trivial
	Boys	54.8 ± 24.9	58.1 ± 26.8	0.371	0.712	0.002	Trivial
APHV (years)	Girls	12.2 ± 0.6	12.2 ± 0.4	0.564	0.575	0.005	Trivial
	Boys	13.6 ± 0.6	13.7 ± 0.6	0.311	0.757	0.002	Trivial
Maturity offset (years)	Girls	0.9 ± 0.9	0.7 ± 1.1	-0.646	0.521	0.007	Trivial
	Boys	-1.1 ± 1.3	-0.7 ± 1.1	1.102	0.275	0.022	Trivial

* $p < .05$

Parallel with the findings of the present study, in their study conducted on male table tennis players aged between 10 and 14, Coelho-E-Silva et al. (2021) displayed that the mean heights exhibited a range between the 75th and 90th percentiles for players aged 10 to 13, while U14 players had mean heights approximately at the 50th percentile. As for body masses, the mean values were around the median for both U10s and U14s, whereas for U11, U12, and U13, the average body masses were around the 75th percentile. Similar to table tennis, the study by Söğüt et al. (2019) on competitive U12 tennis players showed that both male and female players were taller than average children of the same age and gender. Additionally, the body masses of both boys and girls were above the 45th percentile, and the BMI percentiles of male and female players were higher than the average. In another study conducted on U14 competitive tennis players, Söğüt et al. (2023) found that the mean heights and body masses of both male and female players were above the 60th percentile. Moreover, the BMI percentiles of male tennis players were slightly below the median, whereas the BMI percentiles of female tennis players were above the median.

In terms of performance, there were no significant differences observed between girls across any of the variables. However, among boys, no significant differences were identified except for the training age. It was found that boys who won medals had significantly more experience in regular table tennis training compared to those who were not able to win medals. Consistent with the findings of the present study, a prior study by Söğüt et al. (2019) revealed no association between maturity status and rankings, whereas significant associations were found between factors like experience, training volume, and motor performance with rankings in both boys and girls. Conversely, another study by Söğüt et al. (2023) presented different findings. Their research found no notable disparities in all parameters among the three groups (national team, main draw, and qualifying) for boys. In contrast, among girls, both national and main draw players were observed to be significantly more advanced in terms of maturation and exhibited higher BMI values in comparison to qualifying players.

This study has several limitations that should be acknowledged. Firstly, the exclusion of tactical, technical, and psychological performance indicators limits the ability to gain a comprehensive understanding of the overall performance of the players. These factors are known to play a significant role in table tennis performance and should be included in future studies to provide a more well-rounded assessment. Secondly, it is important to note that the sample in this study is confined to young Turkish table tennis players aged between 10 and 15 years. This limited sample size and geographical focus may restrict the generalizability of the findings to a broader population of table tennis players from various regions and age groups. Including participants from diverse backgrounds would enhance the representativeness and inclusivity of analyzing physical growth and maturity in table tennis. Furthermore, the study primarily employs a cross-sectional design, offering a snapshot of the characteristics of the participants at a specific moment in time. Longitudinal studies are crucial for gaining a comprehensive understanding of the development and long-term implications of physical growth and maturity in table tennis. Long-term follow-up studies that track participants into young adulthood would provide valuable insights into the trajectory of physical growth and maturity and their influence on performance. Given these limitations, future research should encompass a broader array of performance indicators, diversify the participant pool, and utilize longitudinal designs with extended follow-up periods. Such efforts would contribute significantly to a more comprehensive understanding of the multifaceted nature of table tennis performance and the enduring effects of physical growth and maturity.

CONCLUSIONS

This study highlights the variability in growth and maturity status among young table tennis players, emphasizing that physical characteristics alone may not determine competitive success. While growth and maturity monitoring remains relevant for understanding long-term athlete development, its direct impact on medal-winning ability appears limited based on these findings. The role of growth and maturation in talent selection should be viewed in the broader context of competitiveness. Research in racket sports (e.g., table tennis, tennis, badminton) suggests that while top athletes tend to exhibit advanced growth and maturation patterns, these factors alone do not guarantee success, as technical proficiency, tactical awareness, and psychological resilience play equally crucial roles (Coelho-E-Silva et al., 2021; Söğüt et al., 2019; 2023). Similarly, studies in team sports (e.g., soccer, basketball) emphasize that although biological maturity can provide temporary advantages, long-term performance is shaped by multidimensional factors, including training experience and skill acquisition (Malina et al., 2004; Baxter-Jones et al., 2005). Therefore, a more comprehensive approach to athlete development should be adopted, integrating physical, technical, and cognitive assessments. Future studies should explore longitudinal data to determine whether growth and maturation influence performance outcomes in the long run, particularly as players transition from youth to elite levels. Incorporating these factors may provide valuable insights into best practices for talent identification and athlete development.

PRACTICAL IMPLICATIONS

The study findings hold several practical implications for coaches, trainers, and policymakers. Firstly, while physical characteristics such as height, body mass, and BMI play an important role in athlete development, they should not be used as the sole criteria for talent identification.A more holistic approach is needed, incorporating technical proficiency, tactical awareness, and psychological resilience alongside physical attributes. Secondly, given the connection between training age and winning medals, policymakers should prioritize providing ample training opportunities and structured programs to support long-term athlete development. Ensuring that young athletes receive high-quality coaching and consistent training experiences is crucial for their progression. Thirdly, although no significant differences in growth and maturity status were found between medal-winning and non-medal-winning players, monitoring these factors is still valuable. Understanding physical development trends can assist coaches in identifying long-term potential and ensuring that training programs align with individual needs. Lastly, considering these factors may yield important insights into best practices for talent identification and athlete development. A multidisciplinary approach that includes physical, technical, cognitive, and psychological factors will help create more effective athlete development pathways.

CONTRIBUTIONS

Both authors contributed to data collection, data analysis, bibliographic review, manuscript writing, revision and correction.

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REFERENCES

Ak, E., & Koçak, S. (2010). Coincidence-Anticipation Timing and Reaction Time in Youth Tennis and Table Tennis Players. *Perceptual and Motor Skills*, *110*(3), 879-887. https://doi.org/10.2466/pms.110.3.879-887

Akpinar, S., Devrilmez, E., & Kirazci, S. (2012). Coincidence-Anticipation Timing Requirements are Different in Racket Sports. *Perceptual and Motor Skills*, *115*(2), 581-593. https://doi.org/10.2466/30.25.27.pms.115.5.581-593

Balyi, I., & Hamilton, A. (2004). *Long-Term Athlete Development: Trainability in Childhood and Adolescence—Windows of Opportunity—Optimal Trainability*. National Coaching Institute British Columbia and Advanced Training and Performance Ltd.

Balyi, I., Way, R., & Higgs, C. (2013). *Long-Term Athlete Development*. Human Kinetics eBooks. https://doi.org/10.5040/9781492596318

Baxter-Jones, A. D. (2012). Growth and Development of Young Athletes. *Sports Medicine*, *20*(2), 59-64. https://doi.org/10.2165/00007256-199520020-00001

Baxter-Jones, A. D., Eisenmann, J. C., & Sherar, L. B. (2005). Controlling for Maturation in Pediatric Exercise Science. *Pediatric Exercise Science*, *17*(1), 18-30. https://doi.org/10.1123/pes.17.1.18

Baxter-Jones, A. D., Helms, P. J. B., Maffulli, N., Baines-Preece, J., & Preece, M. A. (1995). Growth and development of male gymnasts, swimmers, soccer and tennis players: A longitudinal study. *Annals of Human Biology*, *22*(5), 381-394. https://doi.org/10.1080/03014469500004072

Beunen, G., & Malina, R. M. (2007). Growth and Biologic Maturation: Relevance to Athletic Performance. In H. Hebestreit & O. Bar-Or (eds.), *The Young Athlete* (pp. 3-17). Blackwell Publishing Ltd eBooks. https://doi.org/10.1002/9780470696255.ch1

Cameron, N. (2022a). Assessment of maturation. In N. Cameron & L. M. Schell (eds.), *Human Growth and Development* (pp. 347-369). Elsevier eBooks. https://doi.org/10.1016/b978-0-12-822652-0.00003-1

Cameron, N. (2022b). The pattern of human growth. In N. Cameron & L. M. Schell (eds.), *Human Growth and Development* (pp. 1-22). Elsevier eBooks. https://doi.org/10.1016/b978-0-12-822652-0.00004-3

Coelho-E-Silva, M. J., Konarski, J. M., Krzykała, M., Galas, S., Pluta, B., Żurek, P., Faria, J. M. S., Tavares, Ó. M., Oliveira, T. G., Rodrigues, I., Martinho, D., Valente-Dos-Santos, J., & Malina, R. M. (2021). Growth and maturity status of young male table tennis players. *Research in Sports Medicine*, *30*(1), 61-79. https://doi.org/10.1080/15438627.2021.1888099

Doherty, S. A., Martinent, G., Martindale, A., & Faber, I. R. (2018). Determinants for table tennis performance in elite Scottish youth players using a multidimensional approach: A pilot study. *High Ability Studies*, *29*(2), 241-254. https://doi.org/10.1080/13598139.2018.1496069

Erlandson, M. C., Sherar, L. B., Mirwald, R. L., Maffulli, N., & Baxter-Jones, A. D. (2008). Growth and Maturation of Adolescent Female Gymnasts, Swimmers, and Tennis Players. *Medicine and Science in Sports and Exercise*, *40*(1), 34-42. https://doi.org/10.1249/mss.0b013e3181596678

Faber, I. R., Bustin, P. M. J., Oosterveld, F. G. J., Elferink-Gemser, M. T., & Sanden, M. W. N. D. (2016). Assessing personal talent determinants in young racquet sport players: a systematic review. *Journal of Sports Sciences*, *34*(5), 395-410. https://doi.org/10.1080/02640414.2015.1061201

Ford, P. J., De Ste Croix, M., Lloyd, R. S., Meyers, R. K., Moosavi, M., Oliver, J. L., Till, K., & Williams, C. M. (2011). The Long-Term Athlete Development model: Physiological evidence and application. *Journal of Sports Sciences*, *29*(4), 389-402. https://doi.org/10.1080/02640414.2010.536849

Frisancho, A. R. (2008). *Anthropometric standards: an interactive nutritional reference of body size and body composition for children and adults*. University of Michigan Press.

Hopkins, W. D., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive Statistics for Studies in Sports Medicine and Exercise Science. *Medicine and Science in Sports and Exercise*, *41*(1), 3-12. https://doi.org/10.1249/mss.0b013e31818cb278

Jaworski, J., Lech, G., Ambroży, T., & Żak, M. (2020). Profile of coordination motor abilities in elite judokas and badminton players compared to non-athletes. *Biomedical Human Kinetics*, *12*(1), 17-24. https://doi.org/10.2478/bhk-2020-0003

Lees, A. (2003). Science and the major racket sports: a review. *Journal of Sports Sciences*, *21*(9), 707-732. https://doi.org/10.1080/0264041031000140275

Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). *Growth, Maturation, and Physical Activity*. Human Kinetics eBooks. https://doi.org/10.5040/9781492596837

Mirwald, R. L., Baxter-Jones, A. D., Bailey, D. B., & Beunen, G. (2002). An assessment of maturity from anthropometric measurements. *Medicine and Science in Sports and Exercise*, *34*(4), 689-694. https://doi.org/10.1097/00005768-200204000-00020

Myburgh, G. K., Cumming, S. P., Silva, M., Cooke, K., & Malina, R. M. (2016). Growth and maturity status of elite British junior tennis players. *Journal of Sports Sciences*, *34*(20), 1957-1964. https://doi.org/10.1080/02640414.2016.1149213

Pluim, B. (2004). Physiological demands and injury in racket sports: Differences and similarities. In A. Lees, J.-F. Kahn, & I. Maynard (Eds.), *Science and Racket Sports III* (1st ed., pp. 69-78). Taylor & Francis.

Robertson, K., Pion, J., Mostaert, M., Wazir, M. R. W. N., Kramer, T., Faber, I. R., Vansteenkiste, P., & Lenoir, M. (2018). A coaches' perspective on the contribution of anthropometry, physical performance, and motor coordination in racquet sports. *Journal of Sports Sciences*, *36*(23), 2706-2715. https://doi.org/10.1080/02640414.2018.1441941

Schaefer, S., & Scornaienchi, D. (2019). Table Tennis Experts Outperform Novices in a Demanding Cognitive-Motor Dual-Task Situation. *Journal of Motor Behavior*, *52*(2), 204-213. https://doi.org/10.1080/00222895.2019.1602506

Söğüt, M., De Oliveira Luz, L. G., Kaya, Ö. B., & Altunsoy, K. (2019). Ranking in young tennis players—a study to determine possible correlates. *German Journal of Exercise and Sport Research, 49,* 325-331. https://doi.org/10.1007/s12662-019-00580-7

Söğüt, M., Ödemiş, H., & Durmuş, D. (2023). Growth and maturity status of young elite and sub-elite tennis players. *ITF Coaching* & *Sport Science Review*, *31*(89), 21-26. https://doi.org/10.52383/itfcoaching.v31i89.373

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Analysis of successive badminton matches accumulation on neuromuscular fatigue and perceived effort in a national badminton competition

Análisis de la acumulación sucesiva de partidos de bádminton en la fatiga neuromuscular y el esfuerzo percibido en una competición nacional de bádminton

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Abstract

The present study explores how fatigue evolves throughout a single-day national badminton tournament involving five consecutive matches, by examining practical and low-cost fatigue metrics. Eleven U-17 athletes (14-16 years old; 45% women) were evaluated in a real competition using subjective assessments, including the rate of perceived exertion (RPE), session RPE (sRPE), the muscular fatigue visual analog scale (MFVAS), and the total quality recovery test (TQR), as well as objective measures like countermovement jump peak height (CMJh), drop jump peak height (DJh), and drop jump reactive strength index (RSI) before and after each match. Results showed significantly higher RPE, sRPE, and MFVAS scores and significantly lower CMJh and DJh values in the last matches compared to the first (p<0.05; large effect). sRPE showed a positive moderate-strong relationship with match characteristics, including the number of points (p<0.01), sets played (p<0.05), and match duration (p<0.01). The findings indicate that RPE, sRPE, and MFVAS are the most sensitive metrics for assessing fatigue, with DJh being more effective than CMJh among objective measures, while RSI and TQR showed limited sensitivity. These results offer coaches practical tools for monitoring athlete fatigue during competitions.

Keywords: *competition, fatigue, performance, badminton, youth.*

Resumen

El presente estudio explora cómo evoluciona la fatiga a lo largo de un torneo nacional de bádminton de un solo día que incluyó cinco partidos consecutivos, examinando métricas subjetivas y objetivas. Once atletas sub-17 (14-16 años; 45% mujeres) fueron evaluados en una competición real utilizando evaluaciones subjetivas, incluyendo la tasa de esfuerzo percibido (RPE), la RPE de la sesión (sRPE), la escala visual analógica de fatiga muscular (MFVAS) y la prueba de recuperación de calidad total (TQR), así como medidas objetivas como la altura máxima del salto con contramovimiento (CMJh), la altura máxima del salto con caída (DJh) y el índice de fuerza reactiva del salto con caída (RSI) antes y después de cada partido. Los resultados mostraron puntuaciones significativamente más altas de RPE, sRPE y MFVAS y valores significativamente más bajos de CMJh y DJh en los últimos partidos en comparación con el primero (p<0,05; gran efecto). El sRPE mostró una relación positiva, moderada-fuerte, con las características del partido, incluyendo el número de puntos (p<0,01), los sets jugados (p<0,05) y la duración del partido (p<0,01). Los hallazgos indican que el RPE, el sRPE y la MFVAS son las métricas más sensibles para evaluar la fatiga, siendo el DJh más eficaz que el CMJh entre las medidas objetivas, mientras que el RSI y el TQR mostraron una sensibilidad limitada. Estos resultados ofrecen a los entrenadores herramientas prácticas para monitorizar la fatiga de los atletas durante las competiciones.

Palabras clave: *competición, fatiga, rendimiento, bádminton, joven.*

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INTRODUCTION

Badminton is a racket sport characterized by intermittent actions, jumping, changes of direction and rapid arm movements with a high demand on aerobic power, alactic anaerobic and to a lesser extent lactic anaerobic metabolic systems (Cabello Manrique & González-Badillo, 2003). Achieving high levels of physical performance is essential for success, given the sport's intense physiological requirements (Phomsoupha & Laffaye, 2015). Torres-Luque et al. (2019) investigating both male and female high-level adult badminton players across group and elimination phases of international competitions, recorded notable differences in match characteristics as championships progressed. Similarly, in a study focusing on Olympic-level male singles (Chiminazzo et al., 2018), observed that point duration and strokes per point increased from the group phase to the elimination phase, particularly in the third set. In competitive badminton, athletes often face multiple matches in a single day, especially during tournaments. While the physical toll of such match schedules has been acknowledged, there is limited research addressing how the cumulative demands of several matches affect young athletes' performance during real competitions. Existing studies have primarily focused on isolated matches or simulated conditions, in many cases with adult athletes (Birdsey et al., 2019; Ojala & Häkkinen, 2013), whereas Moreno-Perez et al. (2020) did examine junior players, underscoring the need for research on how multiple matches within a single day affect fatigue and recovery in developmental-aged badminton athletes under real competitive conditions.

Monitoring athlete response to fatigue or physical performance during competition is a common approach that reveals the competition requirements, facilitating preparation and guiding athletes and coaches towards practices that can lead to increased athletic performance (Abián-Vicén et al., 2014; Faude et al., 2007; Gomes et al., 2014; Maraga et al., 2018; Ojala & Häkkinen, 2013). Understanding the progression of fatigue during competition is essential for coaches and athletes to optimize performance and recovery strategies. Monitoring tools like the rate of perceived exertion (RPE), session RPE (sRPE), and the Muscle Fatigue Visual Analog Scale (MFVAS) offer practical, subjective methods to assess internal load (Foster et al., 2001; Kenttä & Hassmén, 1998). Meanwhile, objective measures such as countermovement jump peak height (CMJh) provide insights into neuromuscular fatigue, although their sensitivity in racket sports remains debated (Heishman et al., 2020; Abián-Vicén et al., 2012).

In relation to the perceived load and the characteristics of the matches, it has been reported that after two accumulated matches in a real competition, no significant differences are seen in perceived exertion in the match during the session sRPE, muscle pain or lower limb strength determined by CMJh - suggesting that the muscular performance of the lower limbs is not negatively affected by the accumulation of matches. Moreno-Perez et al. (2020) and Abián-Vicén et al. (2014) found that although a single match did not lead to a reduction in CMJh in a real competition, the accumulation of competitive rounds during competition did lead to a reduction in relation to the post-match vertical jump of previous rounds. Moreover, CMJh was not only not negatively affected after a singles badminton match, but the peak jump height was greater post-match versus pre-match, suggesting a lack of muscle fatigue caused by the match (Abián-Vicén et al., 2012). The absence of negative effects on CMJh would agree with the results obtained in tennis (López-Samanes et al., 2018; Maraga et al., 2018; Ojala & Häkkinen, 2013) and in accordance with other authors (Bishop et al., 2023) indicating the lack of sensitivity of CMJh as a neuromuscular fatigue monitoring metric. Thus, to date, the data found in the scientific literature are controversial and inconsistent.

Many studies have examined a simulated competitive situation or analyzed the effect of one or two badminton matches on jumping ability, vertical strength or RPE of elite senior athletes (Abián-Vicén et al., 2012, 2014; Lin et al., 2023), though no studies to date have analyzed the cumulative effect of more than two matches during a real competition on the same day in young athletes.

To address this gap, the present study aimed to investigate the evolution of fatigue across five consecutive matches during a single-day U17 national badminton tournament. A combination of subjective —RPE, sRPE, MFVAS, total quality recovery test (TQR)— and objective —CMJh, drop jump peak height (DJh), reactive strength index (RSI)— measures was employed to examine changes in internal and neuromuscular load. These tools were selected based on their frequent use in monitoring fatigue and recovery in athletic populations, although their sensitivity in youth badminton contexts remains unclear. Rather than offering generalizable claims, this study seeks to provide context-specific insights that may assist coaches and practitioners in understanding the fatigue profiles of youth athletes and selecting practical monitoring tools in real-world competition.

MATERIALS AND METHODS

Participants

A total of 11 badminton players with a mean age, height and weight of 15±0.7 years, 172.2±7.81 cm and 63.3±9.77 kg were voluntarily recruited from two Specialized Centers for Sports Technification (CETD). All the athletes were U17 Spanish players. Among the athletes, four had been selected at least once as members of the National Team to participate in International Competitions, including one of the athletes participating in the U15 European Championship the previous year, and another of them ranked third in the U17 European Badminton Circuit Rankings in Singles (Table 1). As inclusion criteria for participation in the study, all the athletes had to train regularly at least 5 days a week (12-15h per week); were required to have a minimum of two years of experience in strength training; were required to have been competing at a national level for at least 5 years; had to participate annually in National and International Competitions; and had to be free of current injury or injury in the three months prior to the competition.

Design & procedures

A quasi-experimental repeated measures study was designed to determine the evolution of neuromuscular fatigue before and after each match, as well as its evolution throughout 5 matches in a one-day national competition, and its influence on sports performance. The measurements were performed during a badminton competition scoring for the National Ranking (8/10*) at the beginning of the competitive season in Huelva (Spain), in October 2020. The present study was conducted according to the principles of the Declaration of Helsinki. Written informed consent was obtained from all participants, and the study was approved by the local Research Ethics Committee.

Two weeks before the competition, the organizational staff were informed, and the study protocol was approved. The week prior to the competition, the athletes were informed of the objectives of the study and were specifically familiarized with the protocol and the tests to be performed. On the day of the competition itself, and before it began, the club managers and referees were informed of the pre-match and post-match measurement procedures for data collection.

The competition was indoors and at a room temperature of 21ºC. The matches were played on painted courts on the floor of the facility (floating platform) or on a two-piece badminton court, and the shuttlecocks used were "Yonex Aerosensa 30" speed 3 - both approved by the Badminton World Federation (BWF). No nutritional, recovery or warm-up recommendations were given before or during the competition, so as not to influence the individual competitive routine of each athlete. The athletes played a total of 5 matches throughout the same day (9:00 am to 9:00 pm) during a real competition and scoring for the National Ranking (8 stars complying with the requirements imposed by the Spanish Badminton Federation) (Federación Española de Bádminton [FESBA], n.d.). The measurements were taken both before (pre-match) and after (post-match) each match played. The pre-match measurement was performed just after the warm-up and approximately 5 minutes before the match started (MFVAS, TQR, CMJh and DJh). Post-match measurements in turn were taken within 5 minutes after the end of the match (MFVAS, RPE, sRPE, CMJh and DJh). Both the pre- and the post-match measurements were performed in the same order.

Session Rating of Perceived Session Effort Ratio (sRPE)

The internal load imposed on the athletes by each match was monitored through the rate of perceived exertion RPE in the 5 minutes following the end of each match. The measurement was made based on a scale from 0 to 10, where the athletes were informed that 0 meant "not being fatigued at all" and 10 meant "the most extreme physical fatigue they could imagine". This value was then multiplied by the corresponding match time in minutes, indicating the total match load (sRPE) in Arbitrary Units (AU) (Foster et al., 2001). Athletes were encouraged to give the most representative value of the real situation.

Muscle Fatigue Visual Analog Scale (MFVAS)

To determine the level of muscle fatigue in the lower body, the Muscle Fatigue Visual Analog Scale MFVAS was used both pre- and post-match (Leung et al., 2004). This scale consisted of a 100 mm line on which the athletes were instructed to mark a transversal line with a ballpoint pen. Bearing in mind

Table 1
Sample characteristics

Characteristics	Age (years)	Height (cm)	Body mass (Kg)	Category	National Team	Training frequency (days/week)	Training volume (hours/week)	National experience (years)	International experience (years)	Singles ranking (position)	Doubles ranking (position)
Athlete 1	15	185	71	17	Si	5	12	5	1	9	-
Athlete 2	15	167	58	17	No	5	12	5	1	22	2
Athlete 3	15	164	51	17	No	5	12	5	1	16	2
Athlete 4	15	168	62	17	Si	5	14	5	5	43	-
Athlete 5	15	160	62	17	Si	5	14	6	6	6	71
Athlete 6	16	173	63	17	No	5	10	5	1	15	1
Athlete 7	16	178	62	17	No	5	14	5	2	37	5
Athlete 8	14	168	59	17	Si	5	14	5	5	-	-
Athlete 9	16	183	79	17	No	5	12	5	1	116	-
Athlete 10	14	176	79.7	17	No	5	14	5	3	114	-
Athlete 11	15	172	50	17	No	5	14	5	5	108	-

that the beginning of the line meant "very muscularly rested" and the end "very muscularly fatigued", the athlete had to mark the point within the range with which he/she best identified muscle fatigue in his/her legs at that moment. The final value was the distance in millimeters from the beginning of the line to the mark made by the athlete.

Total Quality Recovery (TQR) scale

As a method of monitoring the psycho-physiological recovery of the athletes between matches, use was made of the Total Quality Recovery TQR scale, a numerical score from 6 to 20, where the athlete was required to report the subjective value within the scale that best represented his/her current recovery status (Kenttä & Hassmén, 1998). Before the start of each match, the athletes were asked about their state of recovery using this scale. On the latter, the athletes were instructed to indicate a value between 6 ("totally rested") and 20 ("not rested at all"), encouraging them to give the value most representative of reality.

Lower Extremity Muscle Strength

The countermovement jump CMJ and drop jump DJ tests were performed (Chronojump BoscoSystem®, Barcelona, Spain) with the objective of measuring the application of force in lower limb plyometric actions of long (CMJ) and short (DJ) stretch shortening cycles (SSC) (Young et al., 1995). Both jumps were performed bilaterally, and the athletes were instructed to jump with their hands on their waists to limit contribution of the upper limbs to jump height. The landing contact position had to be identical to the take-off position. In this way, if at the first landing contact the ankle, knee and hip were not fully extended, the jump was not considered valid and had to be repeated after a brief rest. The CMJ and DJ by peak height and minimum contact time were performed according to the described literature (Young et al., 1995). The reactive strength index RSI was calculated using the time of flight to contact time ratio - both times drawn to the DJ test. For both jumps, a total of two attempts were performed, with a resting time of 90 seconds between jumps. Then, the mean of the peak height achieved in both attempts was used for further analysis. The reliability of CMJh, DJh and RSI was established, yielding a coefficient of variation (CV) of 8.7%, 9.3% and 14.8%, with an inter-class correlation coefficient (ICC) of 0.94, 0.87 and 0.82, respectively.

Analysis

Data analyses were performed using the SPSS version 25 statistical package for MS Windows (SPSS, Inc., Chicago, IL, USA). Data were expressed as means and standard deviations (SD). The normality of the data was tested using the Shapiro-Wilks test. The student t-test for paired samples was used to determine the mean differences between paired observations. Statistical differences were calculated, and the precision of the estimates was indicated with 95% confidence. Cohen's d coefficient determined the magnitude of the differences: trivial (0-0.2); small (0.2-0.6); moderate (0.6-1.2); large (1.2-2); or very large (>2) (Batterham & Hopkins, 2006). Pearson's correlation coefficients (r) were calculated to examine the relationship between the match characteristics and the athlete performance variables of interest: trivial (0.0-0.1); small (0.1-0.3); moderate (0.3-0.5); high (0.5-0.7); or very high (> 0.7) (Hopkins et al., 2009).

RESULTS

Match characteristics

Table 2 shows the match characteristics during the one-day competition. The match duration was 27.9±9.29 minutes, with an average rest time of 51.7±45.0 minutes between matches. Games were decided into 2.27±0.46 sets and 80.6±19.8 points per match.

Pre-post-match effect on physical performance

Table 3 shows the physical performance outcomes before and after the matches. Regarding CMJh, DJh and RSI, no significant changes were observed for any of

Table 2
Match characteristics

Variable	Match 1	Match 2	Match 3	Match 4	Match 5	Total
Rest time (min)	-	54.4 (48.3)	66.8 (60.0)	46.6 (33.7)^{d3}	75.6 (32.9)^{d3}	51.7 (45.0)
Points (nº)	85.4 (17.1)^{a3}	72.1 (17.8)^{a3}	80.5 (21.9)	81.54 (24.0)	83.36 (18.45)	80.6 (19.8)
Sets (nº)	2.36 (0.5)	2.18 (0.40)	2.27 (0.5)	2.27 (0.5)	2.27 (0.47)	2.27 (0.5)
Match duration (min)	29.0 (6.6)^{a3}	22.6 (10.14) a^{3,b3}	28.2 (8.9)	28.4 (11.9)	31.2 (8.9)^{b3}	27.9 (9.3)

*Statistically significant differences (p<0.05): a = Match 1 vs rest of matches; b = Match 2 vs rest of matches; c = Match 3 vs rest of matches; d = Match 4 vs rest of matches; e = Match 5 vs rest of matches. Cohen's d effect size: trivial (0 to 0.2); small (0.2 to 0.6); moderate (0.6 to 1.2); large (1.2 to 2) and very large (> 2).

the analyzed study outcomes. In relation to MFVAS, a significant increase was observed as the competition evolved in both the pre-match and the post-match values, with a statistically significant increase between the average of all the pre-match and post-match values (p <0.05). Specifically, moderate to large effects were observed between the pre-match and post-match values in matches 1, 4 and 5 (all, p <0.05; ES = 1.17 to 1.81).

Effect of match accumulation on physical performance

Badminton players progressively increased RPE from the second match, with an increase between the post-match values of matches 2 and 4 (p<0.05; ES = 0.99), as well as between the post-match values of matches 2 and 5 (all p<0.05; ES = 0.83 to 0.99). In relation to sRPE, were significantly higher in the first match, match 4, and match 5 (all p < 0.05; ES = 1.18 to1.41) compared with the second match, with the last showing the highest values

Regarding lower limb strength, a moderate to large increase in CMJh was observed from post-matches 1 and 2 with match 5 (all p <0.05; ES = 1.17 to 1.38). For DJh, moderate reductions were recorded between post-matches 2 and 4, as well as a large reduction between post-matches 2 and 5 (all p <0.05; ES = 0.94 and 1.63, respectively) - evidencing a downward trend in post-match values as the competition progressed. Likewise, for the pre-match DJh values, moderate reductions were found between pre-matches 2 and 5, pre-matches 3 and 4 and pre-matches 3 and 5 (all p <0.05; ES = 0.93 to 1.17), again with a clear reduction as the competition progressed, and all with a moderate effect. Finally, for MFVAS, a moderate increase were observed between post-matches 2 and 4 (p <0.05; ES = 1.11), with an upward post-match trend from match 2, and a notable increase in match 4.

Relationship between match characteristics and physical performance

Table 4 reports the relationship between the match characteristics and physical performance. Regarding the subjective load variables, a moderate-strong association was observed between sRPE and match duration in match 2 (r=0.782; p<0.05), match 4 and match 5 (r=0.964 and r=0.966 respectively; both p<0.01); the number of sets played in match 2, match 3, match 5 (r=0.782, r=0.789 and r=0.688 respectively; all p<0.05) and match 4 (r=0.941; p <0.01); and the points played in match 4 and match 5 (r=0.902 and r=0.920; both p<0.01). In turn, TQR was associated with the points played in match 3 (r=-0.058; p=0.001). Finally, post MFVAS was moderately related to the number of sets played in match 5 (r=0.703; p = 0.035). With respect to objective load, in the case of CMJh an indirect association was observed to the number of sets played in match 5 (r=-0.767; p = 0.044), the rest time in match 4 (r=-0.785; p = 0.036), the points played in match 5 (r=-0.711; p = 0.032), and the match duration in match 5 (r=0.757; p = 0.018).

DISCUSSION

This study explores how fatigue evolves throughout a single-day national badminton tournament involving five consecutive matches, by examining subjective and objective metrics. We also aim to identify practical, cost-effective monitoring strategies that coaches and organizations with limited resources can implement. Our main findings indicate that match time,: (i) match time, RPE, sRPE and MFVAS (pre- and post-match) increased as the competition evolved, while DJh (pre- and post-match) decreased; (ii) the first match of the day was physically more demanding than the second

Table 3

Comparative analysis of the physical performance outcomes before and after match throughout one-day competition

Variable	Match 1	Match 2	Match 3	Match 4	Match 5	Mean
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
RPE (AU)	7.33 (1.59)	5.21 (2.16)^{b34}	6.26 (2.41)	7.29 (1.64)^{b3}	7.12 (1.76)^{b4}	6.64 (1.91)
sRPE (AU)	195.0 (96.1)^{a4}	94.4 (95.0)^{a4,b34}	187.7(100.5)	254.9 (130.8)^{b3}	240.5 (117.5)^{b4}	194.5 (108.0)
TQR (AU)	16.1 (3.06)	15.3 (3.95)	16.1 (2.52)	14.2 (2.86)	16.0 (2.45)	15.4 (2.86)
CMJh (cm)						
Pre-match	29.6 (7.03)	29.31 (6.71)	29.2 (7.12)	28.7 (6.75)	29.2 (6.27)	29.2 (6.78)
Post-match	30.1 (5.27)	28.3 (7.38)^{b3}	28.7 (5.83)	28.6 (4.87)	29.4 (6.70)^{b3}	29.0 (6.01)
DJh (cm)						
Pre-match	24.8 (3.92)	25.8 (5.50)^{b3}	25.1 (3.80)^{c3}	22.4 (2.74)^{c3}	22.9 (3.12)^{b3,c3}	24.2 (3.82)
Post-match	25.7 (4.08)	25.7 (4.57)^{b344}	24.2 (4.32)^{c5}	24.5 (5.00)^{b3}	23.7 (4.07)^{b4}	24.7 (4.41)
RSI						
Pre-match	1.77 (0.48)	2.08 (0.42)	1.97 (0.47)	1.85 (0.39)	1.84 (0.25)	1.90 (0.49)
Post-match	1.81 (0.39)	1.95 (0.53)	1.96 (0.34)	2.00 (0.68)	1.80 (0.51)	1.90 (0.40)
MFVAS (mm)						
Pre-match	25.9 (19.8)	36.9 (29.0)	34.1 (29.1)	37.6 (23.5)	41.5 (23.1)	35.2 (24.9)
Post-match	54.0 (23.4)^{*4}	42.0 (23.9)^{b3}	53.1 (26.3)	60.7 (13.9)^{*4,b3}	54.7 (20.8)^{*3}	52.9 (21.7)^{*5}

RPE, Rate of perceived exertion; sRPE, session RPE; TQR, total quality recovery test; CMJh, countermovement jump peak height; DJh, drop jump peak height; RSI, drop jump reactive strength index; MFVAS, muscular fatigue visual analog scale. *Statistically significant pre-post differences (p<0.05): a = Match 1 vs rest of matches; b = Match 2 vs rest of matches; c = Match 3 vs rest of matches; d = Match 4 vs rest of matches; e = Match 5 vs rest of matches; f = Mean pre vs Mean post. Cohen's d effect size: 1 = trivial (0 to 0.2); 2 = small (0.2 to 0.6); 3 = moderate (0.6 to 1.2); 4 = large (1.2 to 2); 5 = very large (> 2).

and even the third in terms of match time, points played, RPE, sRPE and post-match MFVAS and; (iii) a positive stable relationship was present between sRPE and the number of points and sets played in a match, as well as its duration. This would suggest that the accumulation of 5 matches in the same day in a national U-17 8* badminton competition would lead to an increase in physical demands as the competition progresses, with RPE, sRPE, MFVAS and DJh being metrics more sensitive to such fatigue than CMJh, RSI and TQR.

Our results evidenced a clear increase in the demands imposed by the matches as the competition progressed, with an increase in match time and a slight increase in the number of sets played. The mean match duration of 27.9±9.3 minutes was shorter than that recorded in other studies analyzing Spanish badminton championships, with a mean duration of 34.6±8.4 and 41.3±15.9 minutes in the second round and quarterfinals, respectively (Abián-Vicén et al., 2014). These differences in terms of match duration with respect to the data provided by the study of Abián-Vicén et al. (2014) may be due to the fact that the competitive level of the athletes was higher in their study (an absolute category tournament versus U17 in our work). Despite this, our results are in agreement with the findings of other authors in which a mean match duration of 27.1±5.6 was reported in the "XI Spanish Junior International" (Moreno-Perez et al., 2020).

To gain a more insightful overview of match demands as the competitive round progresses, we observed changes in match duration, rest time and in the RPE, sRPE, DJh and MFVAS scores. Authors such as Moreno-Pérez et al. (2020) did not find significant differences between daytime sRPE values (148.6±66.0 versus 156.6±74.8 AU) or in post-match MFVAS scores (28±24 versus 32±21 mm) between two matches performed on the same day in 21 badminton players in an international junior competition. This suggests that two matches may not induce sufficient cumulative fatigue, whereas five matches provide a clearer picture of accumulated physical demands. In our study, the increased demands were accompanied by an increase in RPE and a reduction in DJh as the competition progressed. This would make sense given the structure and organization of the competition, where those athletes with the highest-level move from round to round so that in each round the confrontation proves more demanding than the previous one, resulting in an increase in points played per match, match time and rest time within the match due to the high

Table 4

Relationship between match characteristics and both pre-match and post-match performance variables

	RPE (AU)	sRPE (AU)	TQR (AU)	CMJh (cm)		DJh (cm)		RSI		MFVAS (mm)	
				Pre	Post	Pre	Post	Pre	Post	Pre	Post
Match 1											
Rest time (min)	.104	.404	.354	-.115	-.245	.033	-.108	-.237	-.256	-.434	-.150
Played points	.462	.132	-.500	-.163	.481	-.058	.590	-.383	-.083	-.195	.346
Played sets (nº)	.334	.093	.054	-.411	.234	-.127	.552	-.200	.109	-.363	.275
Match duration (min)	.669*	.441	-.122	-.210	.060	-.424	-.054	-.703*	-.641*	.086	.421
Match 2											
Rest time (min)	.457	.197	-.504	.285	-.050	-.509	-.512	-.320	-.323	-.086	.029
Played points	.252	.583	.343	-.134	-.193	-.215	-.323	-.336	-.324	-.409	-.390
Played sets (nº)	.256	.782*	.415	-.201	-.213	-.103	-.258	-.199	-.188	-.469	-.386
Match duration (min)	.434	.668*	.546	-.437	-.411	-.281	-.348	-.178	-.165	-.299	-.139
Match 3											
Rest time (min)	-.674	-.423	.307	-.175	-.011	.225	.042	.089	.082	.212	.148
Played points	-.008	.603	-.058**	-.348	-.036	-.435	.126	.815*	.830*	-.137	-.137
Played sets (nº)	.140	.789*	-.358	-.462	-.205	-.595	-.203	.669	.693	.219	.022
Match duration (min)	.001	.716	-.357	-.506	-.169	-.633	-.252	.644	.668	.299	-.012
Match 4											
Rest time (min)	.445	.699	.029	-.401	-.785*	-.618	-.683	-.083	-.092	.360	.264
Played points	.552	.902**	.357	-.225	-.484	-.067	-.528	-.311	-.342	.124	.438
Played sets (nº)	.596	.941**	.380	-.357	-.581	-.117	-.585	-.288	-.317	.171	.46
Match duration (min)	.657	.964**	.309	-.350	-.571	-.208	-.554	-.243	-.269	.139	.453
Match 5											
Rest time (min)	.324	.578	.133	-.219	-.631	.040	-.860**	-.266	-.303	.431	.309
Played points	.601	.920**	.071	-.538	-.711*	-.537	-.594	-.182	-.197	.632	.530
Played sets (nº)	.603	.688*	.148	-.767*	-.627	-.492	-.574	-.364	-.388	.664	.703*
Match duration (min)	.702*	.966**	.094	-.648	.757*	-.574	-.598	-.243	-.256	.715	.649

RPE, Rate of perceived exertion; sRPE, session RPE; TQR, total quality recovery test; CMJh, countermovement jump peak height; DJh, drop jump peak height; RSI, drop jump reactive strength index; MFVAS, muscular fatigue visual analog scale. Data are presented as Pearson correlations (r), being trivial (0.0 - 0.1); small (0.1 - 0.3), moderate (0.3 - 0.5), high (0.5 - 0.7) and very high (> 0.7). *Significant correlation (p<0.05). **Significant correlation (p<0.01).

demands and more similar levels between players. Our data are consistent with those reported by Torres-Luque et al. (2019) and Abián-Vicén et al. (2014), who found an increase in the demands of each match as the competition progressed. When comparing the demands and characteristics between the matches analyzed in this study and those found in other high-level competitions, it becomes evident that our athletes are in a process of development as badminton players.

Our findings regarding MFVAS are in accordance with those of Lin et al., (2023), who also found a significant increase between pre- and post- singles simulated 1-h matches, supporting the observation of the neuromuscular fatigue caused by a single match. Although MFVAS reflects accumulated fatigue in the lower body, this fatigue affected performance in DJh, but not CMJh or RSI. The absence of CMJh jump reduction would coincide with the observations of Moreno-Pérez et al. (2020) and Abián-Vicén et al. (2012) in several badminton matches on the same day, while differing with those of Abián-Vicén et al. (2014). In our study, the lack of CMJh sensitivity as a metric of lower limb neuromuscular fatigue, likewise reported by RPE, sRPE, MFVAS and DJh after several matches is in accordance with Bishop et al. (2023), which supports the theory that CMJ neuromuscular fatigue sensitive metrics are time-based and not output based. To our knowledge, no studies have evaluated RSI or DJh as a reliable metric of lower body neuromuscular fatigue in an official racquet sports competition involving 5 matches on the same day.

In our study, we also observed that the requirements of the first match were greater than in the second match for RPE, sRPE, points played and game duration, and even greater than in match 3 for RPE, sRPE, post-match MFVAS and game duration. Such findings are consistent with those of Maraga et al. (2018), who found the first match to be more demanding than the second match, and with the second match in turn being less demanding than the third match in junior athletes during a simulated tennis competition with three singles matches on the same day. This could be due to the psychological difficulty for athletes to solve the first match of the day and thus start the tournament, though the difference in the level of the players is even greater than in the later matches. In contrast, Gallo-Salazar et al. (2019) documented an increase in total match duration, point duration, rest duration and RPE in the second match with respect to the first match during a simulated competition with two tennis matches on the same day (one in the morning and the other in the afternoon). The comparison of our results with those of other studies is difficult, to the best of our knowledge, no other studies have analyzed 5 or more matches on the same day in a real badminton competition in this age group, and the evidence is still inconsistent.

Regarding the relationships between the match characteristics and physical performance, we found a clear correlation between the number of sets, the number of points, match time and sRPE. As match duration and points played increase, so does effort, which directly influences sRPE calculations (Foster et al., 2001), These associations align with expectations for cumulative fatigue markers. Likewise, RPE was also positively related to match time, indicating that the longer the match time, the greater the athlete perception of effort. Moreover, our match characteristics were also associated - albeit punctually - to the physical performance variables, which would indicate the lack of a stable association between the two. These findings may be indicative of the complex nature of a badminton match and competition where several factors, in addition to those contemplated in our study, may influence cumulative fatigue - thus making it difficult to identify a more stable association between match-specific demands and the physiological response of the badminton player.

This study has some limitations that should be addressed. On one hand, the public health situation caused by Covid-19 forced paralyzing training of the athletes while they advanced in category during that time. This produced a mismatch in the national ranking, due to which the level of the athletes in the category was not faithfully represented by their position in the ranking and therefore the seeded athletes in the competition. On the other hand, the organizational health and safety procedures that had to be adopted, added to the natural rhythm of the competition, did not allow the participation of a greater volume of athletes. Thus, future research should focus on clarifying the relationship between objective and subjective variables with respect to their sensitivity to fatigue, as well as the SSC mechanisms most affected by fatigue in a badminton competition with several matches on the same day in a more stable national ranking situation and with a larger volume of subjects.

CONCLUSIONS

Our results evidenced a clear increase in the demands imposed by the matches as the competition progressed, with an increase in match time and a slight increase in the number of sets played. Interestingly, the first match of the competition, contrary to expectations, was observed to be more physically demanding than the second or third matches. This seems to indicate that even the highest-level athletes within a competition find it difficult to debut and deal with the first match and start the competition. In the context of this specific U17 national badminton competition, RPE, sRPE, DJh, and MFVAS appeared to be the most sensitive parameters for monitoring fatigue across multiple matches in a single day. These findings should be interpreted as exploratory and context-specific, as further research is needed to confirm their sensitivity and generalizability to other age groups or competitive settings. Conversely, TQR, CMJh, and RSI demonstrated more limited sensitivity in this context. Lastly, preliminary relationships were observed between match characteristics (e.g., duration) and sRPE, RPE, and other fatigue indicators. These results contribute to the scientific understanding of fatigue dynamics during youth competitions and may offer practical guidance for coaches seeking cost-effective, portable tools to assess fatigue. However, caution is warranted in generalizing these results beyond this specific competition setting.

CONTRIBUTIONS

All the authors contributed to data collection, data analysis, bibliographic review, manuscript writing, revision and correction.

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REFERENCES

Abián-Vicén, J., Castanedo, A., Abián, P., Gonzalez-Millan, C., Salinero, J. J., & Del Coso, J. (2014). Influence of successive badminton matches on muscle strength, power, and body-fluid balance in elite players. *International Journal of Sports Physiology and Performance*, *9*(4), 689-694. https://doi.org/10.1123/ijspp.2013-0269

Abián-Vicén, J., Del Coso, J., González-Millán, C., Salinero, J. J., & Abián, P. (2012). Analysis of dehydration and strength in elite badminton players. *PloS One*, *7*(5), e37821. https://doi.org/10.1371/journal.pone.0037821

Batterham, A. M., & Hopkins, W. G. (2006). Making Meaningful Inferences About Magnitudes. *International Journal of Sports Physiology and Performance*, *1*(1), 50-57. https://doi.org/10.1123/ijspp.1.1.50

Birdsey, L. P., Weston, M., Russell, M., Johnston, M., Cook, C. J., & Kilduff, L. P. (2019). Neuromuscular, physiological and perceptual responses to an elite netball tournament. *Journal of Sports Sciences*, *37*(19), 2169-2174. https://doi.org/10.1080/02640414.2019.1625613

Bishop, C., Jordan, M., Torres-Ronda, L., Loturco, I., Harry, J., Virgile, A., Mundy, P., Turner, A., & Comfort, P. (2023). Selecting Metrics that Matter: Comparing the use of the Countermovement Jump for Performance Profiling, Neuromuscular Fatigue Monitoring and Injury Rehabilitation Testing. Strength and Conditioning Journal, 45(5), 545-553. https://doi.org/10.1519/SSC.0000000000000772

Cabello Manrique, D., & González-Badillo, J. J. (2003). Analysis of the characteristics of competitive badminton. *British Journal of Sports Medicine*, *37*(1), 62-66. https://doi.org/10.1136/bjsm.37.1.62

Chiminazzo, J., Barreira, J., Luz, L., Saraiva, W., & Cayres, J. (2018). Technical and timing characteristics of badminton men's single: Comparison between groups and play-offs stages in 2016 Rio Olympic Games. *International Journal of Performance Analysis in Sport*, *18*, 1-10. https://doi.org/10.1080/24748668.2018.1463785

Faude, O., Meyer, T., Rosenberger, F., Fries, M., Huber, G., & Kindermann, W. (2007). Physiological characteristics of badminton match play. *European Journal of Applied Physiology*, *100*(4), 479-485. https://doi.org/10.1007/s00421-007-0441-8

Federación Española de Bádminton [FESBA] [Spanish Badminton Federation]. (n.d.). *EVENTOS | Normativa*. Federación Española de Bádminton. https://www.badminton.es/page/30983/EVENTOS-Normativa

Foster, C., Florhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., Doleshal, P., & Dodge, C. (2001). A new approach to monitoring exercise training. *Journal of Strength and Conditioning Research*, *15*(1), 109-115. https://pubmed.ncbi.nlm.nih.gov/11708692/

Gallo-Salazar, C., Del Coso, J., Sanz-Rivas, D., & Fernandez-Fernandez, J. (2019). Game Activity and Physiological Responses of Young Tennis Players in a Competition With Two Consecutive Matches in a Day. *International Journal of Sports Physiology and Performance*, *14*(7), 887-893. https://doi.org/10.1123/ijspp.2018-0234

Gomes, R. V., Santos, R. C. O., Nosaka, K., Moreira, A., Miyabara, E. H., & Aoki, M. S. (2014). Muscle damage after a tennis match in young players. *Biology of Sport*, *31*(1), 27-32. https://doi.org/10.5604/20831862.1083276

Heishman, A. D., Daub, B. D., Miller, R. M., Freitas, E. D. S., Frantz, B. A., & Bemben, M. G. (2020). Countermovement Jump Reliability Performed

With and Without an Arm Swing in NCAA Division 1 Intercollegiate Basketball Players. *Journal of Strength and Conditioning Research*, *34*(2), 546-558. https://doi.org/10.1519/JSC.0000000000002812

Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine and Science in Sports and Exercise*, *41*(1), 3-13. https://doi.org/10.1249/MSS.0b013e31818cb278

Kenttä, G., & Hassmén, P. (1998). Overtraining and recovery. A conceptual model. *Sports Medicine (Auckland, N.Z.)*, *26*(1), 1-16. https://doi.org/10.2165/00007256-199826010-00001

Leung, A. W. S., Chan, C. C. H., Lee, A. H. S., & Lam, K. W. H. (2004). Visual analogue scale correlates of musculoskeletal fatigue. *Perceptual and Motor Skills*, *99*(1), 235-246. https://doi.org/10.2466/pms.99.1.235-246

Lin, Z., Blazevich, A. J., Abbiss, C. R., Wilkie, J. C., & Nosaka, K. (2023). Neuromuscular fatigue and muscle damage following a simulated singles badminton match. *European Journal of Applied Physiology*, *123(6)*, 1229-1240. https://doi.org/10.1007/s00421-023-05148-w

López-Samanes, Á., G Pallarés, J., Pérez-López, A., Mora-Rodríguez, R., & Ortega, J. F. (2018). Hormonal and neuromuscular responses during a singles match in male professional tennis players. *PloS One*, *13*(4), e0195242. https://doi.org/10.1371/journal.pone.0195242

Maraga, N., Duffield, R., Gescheit, D., Perri, T., & Reid, M. (2018). Playing not once, not twice but three times in a day: The effect of fatigue on performance in junior tennis players. *International Journal of Performance Analysis in Sport*, *18*(1), 104-114. https://doi.org/10.1080/24748668.2018.1452110

Moreno-Perez, V., Gallo-Salazar, C., Coso, J. D., Ruiz-Pérez, I., Lopez-Valenciano, A., Barbado, D., Cabello-Manrique, D., & Fernandez-Fernandez, J. (2020). The influence of a badminton competition with two matches in a day on muscle damage and physical performance in elite junior badminton players. *Biology of Sport*, *37*(2), 195-201. https://doi.org/10.5114/biolsport.2020.94243

Ojala, T., & Häkkinen, K. (2013). Effects of the tennis tournament on players' physical performance, hormonal responses, muscle damage and recovery. *Journal of Sports Science & Medicine*, *12*(2), 240-248. https://pmc.ncbi.nlm.nih.gov/articles/PMC3761840/

Phomsoupha, M., & Laffaye, G. (2015). The Science of Badminton: Game Characteristics, Anthropometry, Physiology, Visual Fitness and Biomechanics. *Sports Medicine*, *45*(4), 473-495. https://doi.org/10.1007/s40279-014-0287-2

Torres-Luque, G., Fernández-García, Á. I., Blanca-Torres, J. C., Kondric, M., & Cabello-Manrique, D. (2019). Statistical Differences in Set Analysis in Badminton at the RIO 2016 Olympic Games. *Frontiers in Psychology*, *10*, 731. https://doi.org/10.3389/fpsyg.2019.00731

Young, W. B., Pryor, J. F., & Wilson, G. J. (1995). Effect of Instructions on characteristics of Countermovement and Drop Jump Performance. *The Journal of Strength & Conditioning Research*, *9*(4), 232-236. https://journals.lww.com/nsca-jscr/abstract/1995/11000/effect_of_instructions_on_characteristics_of.5.aspx

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International Sports Federations Voting System: A Case Study of the Badminton World Federation

Sistema de votación en federaciones deportivas internacionales: estudio de caso de la Federación Mundial de Bádminton

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Abstract

This study examines the governance and voting power structures of International Sports Federations (IFs), with a specific focus on the Badminton World Federation (BWF) as a case study. For National Sports Associations (Members), democratic representation within IFs is fundamental to good governance, with voting systems serving as a key mechanism for equitable participation. This research critically evaluates the strengths and weaknesses of IF voting systems, proposing actionable reforms to enhance fairness and transparency. Benchmarking against governance models used by FIFA and the International Olympic Committee (IOC), the study explores the broader applicability of differential voting structures. Additionally, the Sport Governance Observer (SGO) Index is employed as an analytical framework to assess governance quality, including transparency, decision-making, financial management, representation, inclusivity, and accountability mechanisms. The BWF employs a differential voting system for both governance decisions and elections at its Annual General Meeting (AGM), where Members are allocated between one and five votes based on their active participation in badminton. This study examines the historical evolution, operational framework, and implications of this system. Findings confirm that differential voting remains a viable governance model for IFs but underscore the need for well-defined, transparent, and verifiable criteria. Specifically, the study recommends that voting rights be allocated based on measurable engagement in the sport, such as development initiatives and competitive participation, ensuring a governance system that is both equitable and resistant to manipulation.

Keywords: *Sports Governance, Voting System Model, Differential Voting System, International Sports Federation.*

Resumen

Este estudio examina las estructuras de gobernanza y de poder de voto en federaciones deportivas internacionales (FI) con un enfoque específico en la Federación Mundial de Bádminton (BWF) como estudio de caso. Para las asociaciones deportivas nacionales (miembros), la representación democrática dentro de las FI es fundamental para una buena gobernanza, siendo los sistemas de votación un mecanismo clave para la participación equitativa. Esta investigación evalúa críticamente las fortalezas y debilidades de los sistemas de votación en las FI y propone reformas prácticas para mejorar la equidad y la transparencia. A través de la comparación con modelos de gobernanza utilizados por la FIFA y el Comité Olímpico Internacional (COI), el estudio explora la aplicabilidad más amplia de los sistemas de votación diferenciada. Además, se emplea el índice de Observación de Gobernanza Deportiva (SGO) como marco analítico para evaluar la calidad de la gobernanza, incluyendo la transparencia, la toma de decisiones, la gestión financiera, la representación, la inclusión y los mecanismos de rendición de cuentas. La BWF utiliza un sistema de votación diferenciada tanto para decisiones de gobernanza como para elecciones durante su Asamblea General Anual, en la que a los miembros se les asigna entre uno y cinco votos según su participación activa en el bádminton. Este estudio examina la evolución histórica, el marco operativo y las implicaciones de este sistema. Los hallazgos confirman que la votación diferenciada sigue siendo un modelo de gobernanza viable para las FI, pero resaltan la necesidad de contar con criterios bien definidos, transparentes y verificables. En concreto, se recomienda que los derechos de voto se asignen con base en una participación medible

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en el deporte, como iniciativas de desarrollo y participación competitiva, asegurando así un sistema de gobernanza equitativo y resistente a la manipulación.tenis está asociado con un mayor bienestar. Es necesario realizar estudios prospectivos a mayor escala para entender la direccionalidad de estos hallazgos.

Palabras clave: *gobernanza deportiva, modelo de sistema de votación, sistema de votación diferenciada, federación deportiva internacional.*

Introduction

The governance structures of International Sports Federations (IFs) play a critical role in shaping the trajectory of global sports. Among these structures, voting models hold particular significance, influencing decision-making processes that affect athletes, events, and the integrity of sports worldwide. These models not only determine the allocation of resources and the establishment of policies but also reflect the values of fairness, inclusivity, and efficiency that underpin the global sports community (Mills et al., 2024).

In recent years, the diversity of voting mechanisms employed by IFs has sparked increasing debate, particularly regarding their effectiveness in achieving equitable representation (Henry, 2013). Voting structures in IFs range from one-Member-one-vote systems, which promote absolute equality, to weighted voting models, where voting power is distributed based on factors such as population size, economic contribution, or sporting success (Forster, 2016). While one-Member-one-vote systems emphasise democratic equality, they can lead to disproportionate influence from smaller nations, which may not contribute equally to the sport's development (Schubert & Könecke, 2015). Conversely, weighted systems ensure that influential stakeholders have greater input, but they risk marginalising smaller National Sports Federations (Member) and creating governance imbalances (Geeraert, 2018).

Beyond these traditional models, recent governance reforms have sought to balance representational fairness with operational efficiency. The International Olympic Committee (IOC), for example, employs a mixed governance structure that incorporates both equal representation and strategic weighting based on sporting performance and financial contributions (Chappelet, 2021). Similarly, FIFA's council voting system grants different levels of representation to Continental Confederations (CC), ensuring that larger footballing Members have a proportionate voice while maintaining global inclusivity (Hassan & McCarthy, 2014). These examples highlight the ongoing evolution of IF governance structures in response to growing demands for transparency, inclusivity, and accountability (Geeraert, 2018; Henry, 2013).

This article critically examines the voting models adopted by IFs, focusing on their ability to balance the competing priorities of equity, representation, and efficiency. Specifically, it analyses the Badminton World Federation [BWF] as a case study, evaluating the impact of differential voting, a model where voting power is assigned based on a Member's active participation in the sport. By applying theoretical governance frameworks, this study aims to provide insights into the strengths, weaknesses, and future evolution of IF governance models.

The experience of voters in elections is pivotal in shaping the democratic integrity of governance structures (James & Garnett, 2023). While extensive literature exists on governance principles, studies indicate that governance can be assessed through three primary lenses: organisational, systemic, and political (Dowling et al., 2018). The Sports Governance Observer (SGO) Index, developed as a benchmarking tool, offers measurable indicators for evaluating governance quality, including decision-making transparency, accountability mechanisms, and representational inclusivity (Geeraert, 2018). However, despite the emphasis on governance in IFs, voting systems and their direct impact on representational fairness remain underexplored in academic literature (Thompson et al., 2023; Parent et al., 2021). Addressing this gap, this study explores the implications of differential voting for decision-making and governance legitimacy in international sports.

Many IFs apply a one-Member-one-vote system for major decisions in their Annual General Meetings (AGMs) or equivalent governance forums. This model ensures formal equality among all Member nations, irrespective of population size or sporting success (Hoye & Cuskelly, 2007). However, the effectiveness of this approach is debated, particularly in Members where there are significant disparities in financial contributions, player participation, and competitive achievements (Forster, 2016).

At the BWF, however, a differential voting system is applied for decisions related to sporting matters and elections. Under this system, Members are allocated between one and five votes based on their level of active engagement in the sport. This model seeks to incentivise participation and recognise national contributions, while maintaining a governance structure that ensures inclusivity and fairness (Badminton World Federation [BWF], 2024).

This paper examines the historical evolution, strengths, and potential areas for reform in the BWF's differential voting system. By comparing this model to the one-Member-one-vote system and other IF governance structures, the study evaluates the impact of different voting frameworks on governance effectiveness and decision-making legitimacy.

Previous Differential Voting Systems in BWF

BWF was founded in 1934 as the IBF, by nine Members. Until 1958, the Founder Members held two votes while other Members had one vote each. From 1959 a system of five votes was based on (1) membership, (2) 10 years of membership of the Federation, (3) 20 years of membership of the Federation, (4) participation in the most recent Men's World Team Championship, the Thomas Cup, (5) participation in the most recent Women's World Team Championship, the Uber Cup. From 1981 a system of four votes was based on (1) membership, (2) 10.000 registered players. (3) 50.000 registered players, (4) participation in the most recent Thomas and Uber Cup. From 1990 a system of five votes based on size only was adopted; (1) membership, (2) more than 5.000 registered players. (3) more than 10.000 registered players, (4) more than 25.000 registered players, (5) more than 50.000 registered players. This system was applied until the current, activity-based system replaced it in 2012. In all these years, voting by proxy was allowed and commonly used.

The BWF Voting System Since 2012

The BWF differential voting system is defined in the BWF Constitution (2024), Clause 15.20 as follows:

15. 20. A Member in Good Standing shall be entitled to a minimum of one (1) vote and a maximum of five (5) votes as confirmed by Council in accordance with the following criteria applied over the Assessment Period.

- 1 vote - Membership to the Federation (membership in good standing).
- 1 additional vote - More than 10,000 registered players in each of the four years of the Assessment Period.
- 1 additional vote - Participation in 6 out of these 10 events during the Assessment Period: Individual Continental Championships (a maximum of 2 events), World Championships (3 events), Olympic Games (1 event), World Junior Team Championships (4 events)
- 1 additional vote - Having one player or more in the top 40 world ranking in any of the five (5) disciplines as per the world ranking list for the qualification for the most recent Olympic Games held.
- 1 additional vote - Hosting at least one (1) of these events in three (3) out of the four (4) years of the Assessment Period: Super Series, Grand Prix, International Challenge or the equivalent World Tour events.

The number of votes a Member is entitled to is fixed for a four (4) year period starting after the end of the Assessment Period. The Assessment period is defined in the Constitution, Clause 7.3, as follows:

> 7.3. Assessment Period – means a four (4) year period over which the criteria in Clause 15.20 are applied to determine voting strength and extends from 1 October in the year of the Summer Olympic Games to 30 September of the year of the subsequent Summer Olympic Games (BWF, 2024).

This voting system applies to all decisions of the AGM with a few exceptions as described in the Constitution, Clause 15.21, where a one Member - one vote system is used:

> 15.21 The voting strength of a Member in Good Standing as described in Clause 15.20 shall apply to any proposal to the AGM under the Constitution of the Federation except for Clauses 12 (Admission to Membership), Clause 13.11 (Expulsion), and Clause 36 (Dissolution). For a proposal under Clauses 12, 13.11 or 36, each Member in Good Standing shall be entitled to one vote only (BWF, 2024).

A further clause of relevance covers proxy voting, which is not allowed under Clause 15.22:

> 15.22. No delegate shall be permitted to cast a vote on behalf of more than one Member (BWF, 2024).

The annual subscription fee is linked to the number of votes. The subscriptions are now a marginal source of income for BWF, but for many years they were the major and originally the only income of the federation.

Unlike earlier models, the 2012 system prioritises measurable contributions, reducing reliance on self-reported data and promoting fairness and competitive engagement (BWF, 2024). This paper examines the effectiveness, transparency, and sustainability of this model in comparison to alternative IF governance structures.

Methodology

This study employs a qualitative research approach, utilising document analysis as the primary method to evaluate the historical and operational aspects of the BWF differential voting system. Document analysis is a widely accepted qualitative research method for examining institutional governance structures, policy evolution, and organisational decision-making processes (Bowen, 2009; Yin, 2018). The research focuses on systematically reviewing primary documents, such as constitutions, AGM minutes, and voting records, to trace the evolution of the BWF voting system and assess its impact on governance outcomes.

Document analysis is particularly suited for examining the legislative and procedural evolution of governance systems in IFs, as it allows for a structured assessment of key documents to identify patterns, consistencies, and areas for reform (Corbetta, 2003). Given that sports governance research often relies on archival data due to the structured nature of IF constitutions and policies, this method provides a reliable framework for evaluating BWF's governance model (Geeraert, 2018; Chappelet, 2021).

Data Collection

This study relies on archival document analysis, which is a method frequently employed in sports governance research to track policy changes, structural adjustments, and voting mechanisms (Hoye & Cuskelly, 2007). The primary sources for this study include:

- BWF Constitutions (1934–2024) to analyse historical changes in the voting system.
- Annual General Meeting (AGM) minutes from pivotal years (1959, 1981, 1990, 2008, and 2009), detailing voting system changes and their contexts.
- Governance reports and benchmark studies, such as those outlined in the Sports Governance Observer Index (Geeraert, 2018), which assess governance structures across IFs.
- Development, operational mechanisms, and regulatory frameworks of the BWF voting systems.

The selection criteria were based on the availability, completeness, and importance of the documents in reflecting governance shifts (Bryman, 2012) (see Table 1).

Table 1
Analysed sources that provide information for this research.

Entity	Source Name	Year(s)
IBF	Inaugural General Meeting minutes	(5 July) 1934
IBF	Rules (*i.e. Constitution*) of 1934	(Amended)1959, 1981, and 1990
IBF	Annual General Meeting minutes	1959, 1981 and 1990
BWF	Constitution	2006
BWF	Annual General Meeting minutes	2008, and 2009
BWF	zConstitution	2012
BWF	Constitution, Annex 1, Council Geographical and Gender Rep.	(Added) 2020
BWF	Annual General Meeting minutes	2012, and 2020

This dataset enables a comprehensive historical analysis of BWF's voting system and governance reforms, ensuring that the findings are grounded in empirical evidence and historical context (Bowen, 2009).

Analytical Framework

The study adopts an institutional governance analysis framework, focusing on key governance dimensions, including democracy, transparency, and accountability (Dowling et al., 2018). Sports governance research suggests that IFs should be evaluated using structured indices such as the SGO Index, which assesses decision-making efficiency, inclusivity, and regulatory compliance (Geeraert, 2018).

The analytical approach includes evaluating the clarity and verifiability of voting criteria, ensuring that the differential voting system meets governance standards of transparency and fairness (Cabello-Manrique & Puga-González, 2023). Assessing the alignment of BWF's voting system with established principles of good governance, as identified in sports governance literature (Chappelet, 2021). Identifying the practical challenges and benefits associated with differential voting models in IFs (Parent et al., 2021).

A thematic coding approach was employed to identify recurring patterns, governance trends, and policy inconsistencies within BWF's constitutional documents and AGM minutes. Thematic analysis is widely used in sports management research to evaluate decision-making structures and power dynamics (Hassan & McCarthy, 2014).

Comparative Analysis

To enhance the robustness of the study, a comparative analysis was conducted by benchmarking BWF's differential voting system against governance models in other IFs such as FIFA, Federation Equestre International (FEI), and the IOC. Comparative governance research in IFs emphasises the need for contextual benchmarking to identify best practices and governance inefficiencies (Forster, 2016; Geeraert, 2018).

This comparative approach assesses voting power allocation in BWF vs. other IFs to determine whether differential voting enhances democratic legitimacy. Governance transparency in weighted vs. equal representation systems, and decision-making efficiency under different voting models, considering the need for equitable vs. merit-based representation in IF governance (Chappelet, 2021).

By analysing these aspects, the study provides a broader perspective on the implications of differential voting systems, ensuring that the findings contribute to ongoing debates in global sports governance (Henry, 2013).

Limitations

While document analysis provides a rich source of qualitative data, this study acknowledges certain limitations inherent in archival research potential gaps in historical records: Some AGM minutes and governance documents may not have been publicly accessible, limiting the completeness of the dataset (Bryman, 2012). The subjectivity of interpretation: Although document analysis allows for a structured review, researcher bias in interpreting governance changes remains a concern (Yin, 2018). Absence of direct stakeholder perspectives: While constitutional analysis provides insights into governance rules, qualitative interviews with stakeholders (e.g., BWF Council Members) could enhance understanding of governance dynamics (Hoye & Cuskelly, 2007).

To mitigate these limitations, findings are cross-referenced with secondary literature on sports governance reforms, ensuring that the conclusions are substantiated by multiple sources (Chappelet, 2021; Geeraert, 2018).

Results

The governance structure of IFs has evolved significantly over the past decades, influenced by the increasing commercialisation and global expansion of sports. The inclusion of badminton as an Olympic sport by the IOC on June 5, 1985, with its official debut in the 1992 Barcelona Olympic Games, marked a pivotal shift for the BWF (Chappelet, 2021). This transition coincided with the introduction of Open Badminton, which allowed professional players to compete internationally, leading to a surge in membership from approximately 60 Members in 1980 to 110 by 1992 (Forster, 2016).

As financial inflows increased from broadcasting rights, sponsorships, and Olympic funding, governance mechanisms required restructuring to accommodate new power dynamics within the federation (Geeraert, 2018). Traditionally, IFs have relied on membership subscriptions as a primary revenue source, but with increased financial stability, membership fees became a marginal contributor. Consequently, questions arose regarding equitable representation and voting rights, necessitating governance reforms (Cabello-Manrique & Puga-González, 2023).

The 1990 BWF voting system was primarily based on registered player numbers within a Member. However, a lack of verifiable data led to governance concerns. Many Members inflated registration figures to obtain additional votes, a governance loophole that compromised fairness and transparency (Schubert & Könecke, 2015).

Additionally, proxy voting, which had been permitted since BWF's inception, further exacerbated governance vulnerabilities. Members unable to attend Annual General Meetings (AGMs) often delegated their votes through proxy arrangements, leading the possible manipulation of elections (Hassan & McCarthy, 2014). This became particularly contentious around, and after BWF headquarters moved from Cheltenham, England, to Kuala Lumpur, Malaysia in 2005, leading to a period of internal instability and power struggles among leadership factions.

A critical turning point occurred in the 2008 AGM, where a vote of no confidence was passed against the Deputy President, exposing deep governance fractures (Kang, 2011). This prompted a complete overhaul of BWF's governance framework, culminating in the 2012 adoption of a new voting system, which introduced differential voting based on measurable participation in BWF-sanctioned events. This reform sought to reduce manipulation, enhance fairness, and ensure a more meritocratic allocation of voting power (Chappelet, 2021).

As part of its governance modernisation, BWF also eliminated proxy voting, replacing it with travel grants to ensure broader participation in AGMs. Additionally, real-time translation services in multiple languages (French, Spanish, Mandarin, Arabic, and Russian) were introduced to reduce linguistic barriers and foster inclusivity (BWF, 2024).

These reforms preserved the balance of power between Continental Confederations (CCs), ensuring that most Members either retained their existing votes or gained additional representation under the new framework.

The Current Voting System

The 2012 BWF voting system is designed to allocate votes based on objective and verifiable participation metrics, in alignment with principles of good governance, accountability, and inclusivity (Cabello-Manrique & Puga-González, 2023). Unlike the previous system, where voting rights were determined solely by self-reported membership figures, the current differential voting system assigns one to five votes per Member based on their active participation in badminton.

The criteria for additional votes include:

1. Participation in major international team events, such as the World Championships and Olympic Games.

2. Elite player development, assessed through the presence of top-ranked athletes in global competitions.

3. Hosting major BWF-sanctioned tournaments, which contribute to the international competitive calendar.

4. A minimum of 10,000 registered players, a criterion that remains contentious due to verification challenges.

While this system promotes merit-based voting power, it has not been without criticism. Researchers argue that alternative differential voting systems could further enhance governance integrity by integrating additional developmental, financial, and grassroots participation metrics (PlayTheGame, 2022).

Alternate Voting Systems in International Sports Federations

To contextualise BWF's differential voting system, it is useful to compare it to alternative voting models employed by other IFs.

(i) One Member, One Vote System

This model, used by the IOC and many IFs, grants each Member equal voting rights, regardless of size, population, or sporting contributions (Chappelet, 2021).

Advantages:

- Ensures absolute equality in governance representation.
- Simplifies decision-making processes.
- Prevents dominance by wealthier Members

Disadvantages:

- Susceptible to lobbying influence, and manipulation.
- Does not account for sporting development or contribution.
- Can lead to resource misallocation, as voting power does not reflect active engagement in the sport (Geeraert, 2018).

(ii) Weighted Voting Systems

FIFA and some other IFs employ weighted voting, where representation is based on factors such as financial contributions, competitive success, or membership size (Schubert & Könecke, 2015).

Advantages:

- Recognises Members contributing significantly to the sport's development.
- Enhances financial sustainability by rewarding Members that generate revenue.

Disadvantages:

- Risks entrenching power imbalances, favouring wealthier Members.
- Administratively complex to verify and adjust voting weights.

(iii) Activity-Based Differential Voting Systems

The BWF model aligns closely with this approach, wherein voting rights are allocated based on measurable participation metrics (Cabello-Manrique & Puga-González, 2023).

Advantages:

- Incentivises active engagement in the sport.
- Provides verifiable data to determine voting power, enhancing transparency.

Disadvantages:

- Some metrics, such as player registrations, remain difficult to verify.
- Smaller Members may struggle to meet participation thresholds, perpetuating disparities.

Each model presents unique advantages and governance trade-offs, underscoring the complexity of achieving fair and transparent representation in IF governance.

Strengths and Weaknesses of the BWF Voting System

Strengths:

- Fairness and transparency: Voting rights are linked to measurable contributions.
- Meritocratic structure: Encourages Members to actively engage in the sport.
- Reduced opportunities for manipulation: Unlike earlier models, votes are not allocated based on unverifiable membership figures.

Weaknesses:

- Equity concerns: Smaller Members may find it harder to meet certain participation criteria.
- Adaptability challenges: The model must remain flexible to accommodate emerging governance challenges, such as disruptions from global crises (e.g., COVID-19).

The BWF tournament programme was disrupted by the COVID 19 pandemic causing cancellations of several major events that were included in the calculation of criterion based on participation in the major world championship events. This was however easily managed by changing the number of tournaments required by an *ad hoc decision in the AGM.*

Further Development of the Voting and Election Systems since 2012

Governance reforms remain an ongoing process. Since 2020, BWF has introduced:

- Continental Confederation quotas, ensuring geographic balance.
- Gender representation quotas, mandating 30% minimum representation of each gender.

As governance trends evolve, BWF must continue adapting its voting system to maintain democratic legitimacy, fairness, and efficiency in international badminton governance.

Discussion

A well-structured differential voting system must be based on objective, measurable, and transparent criteria to ensure equitable representation and avoid governance manipulation (Geeraert, 2018). IFs can apply differential voting as an incentive for MAs to actively engage in the sport by participating in various programmes or emphasise performance-based rewards to encourage Members to foster the growth of their sport (Forster, 2016; Chappelet, 2021).

The following factors are critical in designing a differential voting system that enhances both representation and governance integrity.

Verifiability

Governance literature emphasises that transparency and standardised metrics are fundamental to decision-making in IFs (Dowling et al., 2018). Therefore, a criterion must be objectively verifiable, allowing stakeholders to audit and validate membership data, tournament participation, and player rankings. The use of centralised registration portals, external third-party data verification, and digital record-keeping (e.g., blockchain-based voting systems) can enhance data integrity and reduce subjectivity in voting power allocation (Geeraert, 2018).

For example, FIFA's player registration system requires Members to report verified club memberships through FIFA's Transfer Matching System (TMS), ensuring accountability in player data management (Schubert & Könecke, 2015).

Potential for Manipulation

One of the primary risks associated with metrics-based voting systems is the potential for data manipulation. Previous studies highlight that self-reported statistics from Members can be exaggerated or falsified to gain additional influence (Cabello-Manrique & Puga-González, 2023). This has been a recurring issue in IFs where voting power is tied to registered membership numbers.

To mitigate this risk, IFs should:

- Require independent audits of player registration figures.
- Establish penalties for false reporting to deter manipulation.
- Cross-reference tournament participation data with publicly available competition records.

The International Tennis Federation (ITF), for example, relies on tournament entry lists and world rankings rather than self-reported data to determine voting power, ensuring greater transparency and fairness (Chappelet, 2021).

Avoiding Disproportionate Advantage to Larger Nations

A well-designed voting system must prevent overrepresentation of larger Members while ensuring that smaller Members are not marginalised. Some IFs, such as World Athletics, employ geographically balanced voting systems to ensure that less populous regions maintain fair representation (Henry, 2013).

Potential solutions to mitigate imbalance include:

- Implementing a weighted tier system, where smaller Members receive a minimum guaranteed baseline of votes to ensure they retain influence.
- Assigning votes based on competition participation, and interaction with the sport, rather than sheer population size.

Active Participation Considerations

Governance frameworks must distinguish between active competitive participation and social/recreational engagement (Geeraert, 2018). Many IFs struggle to categorise player engagement levels, which impacts how votes are allocated.

For example, FIFA differentiates between elite players, semi-professional players, and grassroots development when structuring development funding allocation (Schubert & Könecke, 2015).

Equity Concerns

Equity is a core principle of good sports governance (Chappelet, 2021). If voting power is solely linked to financial or competitive success, developing Members may be disadvantaged. This issue is particularly prevalent in African and Caribbean Members, where resource limitations prevent consistent tournament participation (Henry, 2013).

An IF voting system could enhance equity by allocating development-focused votes for Members that invest in youth programmes or gender equity initiatives and ensuring that developing Members have a clear pathway to increase their influence over time.

Similar models have been proposed in Olympic governance, where smaller National Olympic Committees (NOCs) receive guaranteed baseline representation to prevent geopolitical marginalisation (Chappelet, 2021).

Impact on Democratic Decision-Making

The structure of a voting system directly affects democratic legitimacy within an international federation (Geeraert, 2018). If a small group of large Members dominates decision-making, governance risks becoming elitist and unrepresentative. Research highlights that decision-making diversity improves the long-term stability of IFs, as it ensures broad stakeholder representation (Hassan & McCarthy, 2014).

To ensure that differential voting does not undermine democratic principles, IFs must periodically review voting structures and adjust criteria to reflect evolving governance needs (Forster, 2016).

Adaptation to Global Trends

The nature of sports participation is changing, with shifts towards social, recreational, and digital engagement (Dowling et al., 2018). Many Members are moving away from traditional club-based models and adopting flexible engagement structures.

For example, Esports federations now include digital participation metrics, measuring online gaming and streaming engagement alongside in-person tournament participation (Geeraert, 2018).

For IFs to remain adaptable, its voting system must recognise non-traditional forms of sport participation (e.g., social), evaluate how technology is influencing sport development (e.g., virtual coaching platforms, esports), and ensure that governance structures accommodate emerging participation models while maintaining integrity and transparency.

By integrating governance flexibility, IFs can future proof its voting system, ensuring that it remains equitable, transparent, and aligned with global sports trends (Chappelet, 2021).

For a differential voting system to be effective, it must balance transparency, equity, and representational fairness. Governance research suggests that verifiable metrics, safeguards against manipulation, and provisions for equitable participation are essential in maintaining democratic legitimacy in IFs (Geeraert, 2018; Forster, 2016).

Recommendations for Criterion

To enhance the integrity, transparency, and fairness of the BWF differential voting system, it is essential to establish robust and verifiable criteria that align with best practices in sports governance (Chappelet, 2021; Geeraert, 2018). The following recommendations are aimed at improving data accuracy, inclusivity, and accountability while ensuring that voting allocations reflect genuine contributions to the sport.

Implement a Robust Verification Mechanism

One of the most significant governance challenges in differential voting systems is ensuring that self-reported data from Members is accurate and verifiable (Cabello-Manrique & Puga-González, 2023). To address this, independent auditing procedures should be introduced to validate the data used in voting criteria allocation.

Many IFs have already adopted technology-driven verification solutions. For example, the International Squash Federation (ISF) implemented ClubLocker in 2019, a Member registration system that integrates player data, event participation records, and membership tracking at the national and international levels (InsideTheGames, 2018). By leveraging centralised data management platforms, IFs can ensure that voting power is assigned based on verifiable contributions rather than self-reported statistics.

Additionally, data protection laws and Member consent must be considered. IFs must develop clear data policies, ensuring that:

- Data is stored securely in compliance with General Data Protection Regulation (GDPR) standards.
- Retention policies limit long-term storage of Member records to avoid privacy concerns.
- Independent audits are conducted regularly to ensure compliance and data integrity (Schubert & Könecke, 2015).

Proposed Best Practice:

- Mandate annual verification reports for Members claiming multiple votes.
- Establish a third-party compliance team to oversee data audits.
- Encourage MAs to adopt standardised digital reporting systems, reducing the risk of manipulation (Geeraert, 2018).

Develop Measurable and Transparent Metrics

The criteria for additional voting rights should be based on activity-based and performance-driven benchmarks that are recorded by third-party entities and publicly verifiable (Chappelet, 2021). This will enhance transparency and reduce opportunities for manipulation.

Examples of robust and measurable criteria include:

- International Tournament Participation: Members should earn additional voting rights based on the number of athletes competing in sanctioned events, ensuring that active engagement in the sport is rewarded (Hassan & McCarthy, 2014).
- Tournament Hosting Contributions: Members that organise major international events should receive recognition for their infrastructural and logistical investments.
- World Ranking Achievements: The presence of national players in the top 50 rankings across singles and doubles disciplines should contribute to voting weight (Geeraert, 2018).

By ensuring that all voting criteria are recorded, or verified by independent organisations, IFs can eliminate disputes over data accuracy and establish trust in the voting system (Forster, 2016).

Promote Inclusivity in Voting Power Allocation

To prevent dominance by wealthier IFs and ensure balanced global representation, voting systems should consider both size and contribution levels in its voting allocations (Henry, 2013). One method to balance voting power is through minimum representation thresholds for smaller Members.

An inclusivity model includes:

- Establishing baseline votes for all Members to prevent underrepresentation of smaller Members
- Implementing gender equity thresholds, requiring Members to achieve minimum female athlete participation in international competitions to qualify for additional votes (Chappelet, 2021).

The IOC's gender representation quotas have been instrumental in increasing female participation in sports governance, with IFs encouraged to meet a minimum 30% female representation at the executive level (Forster, 2016).

While gender quotas are a valuable step toward improving representation in sport governance, they are not sufficient on their own. Quotas are an outcome of poor governance, and address numerical imbalance, they do not improve the underlying poor governance culture which created the imbalance. Without broader governance reforms, such as term limits, inclusive leadership practices, and cultural change, quotas risk being symbolic (Claringboul & Knoppers, 2012, Geeraert, 2016).

Incorporate Developmental Goals in Voting Criteria

Voting rights should not be allocated solely based on elite-level performance but should also reward Members investing in long-term grassroots development (Schubert & Könecke, 2015).

IFs can enhance strategic alignment by incorporating:

- Youth Engagement Metrics: Members with structured national junior programmes should receive additional voting weight, reflecting their investment in badminton's long-term sustainability (Hassan & McCarthy, 2014).
- Para-Badminton Integration: Members that actively develop para-badminton programmes should receive greater governance influence, ensuring inclusivity in adaptive sports.
- Infrastructure and Capacity-Building Initiatives: Members investing in coach education, regional tournaments, and club development should be recognised as contributors to the sport's global growth (Geeraert, 2018).

However, any voting system inevitably privileges certain stakeholder groups over others, as no model can fully balance the competing interests of all members (Geeraert, 2016).

Proposed Best Practice:

- Implement a tiered points system, awarding Members with a vote for more holistic achievements, for example in junior development, para-sports, and grassroots engagement.
- Establish strategic funding rewards tied to governance participation, ensuring that Members investing in non-elite sport receive representation.

By adopting these recommended reforms, the IF voting system can:

- Enhance fairness, transparency, and credibility through data verification.
- Ensure equitable governance representation, balancing large and small Members.
- Align voting allocations with long-term strategic development, ensuring that grassroots, youth, and para-sport engagement are incentivised.

As IFs evolve, adapting governance models to align with modern sports participation trends is essential. By adopting technology-driven verification, promoting gender equity, and incorporating strategic development criteria (Chappelet, 2021).

Conclusion

A well-structured voting system is fundamental to the governance of IFs ensuring fairness, transparency, and equity in decision-making processes (Geeraert, 2018). The criteria used in voting allocation significantly impact the legitimacy, inclusivity, and democratic integrity of an IF. When designed effectively, differential voting systems can incentivise Members to contribute meaningfully to the sport's development, aligning governance with strategic objectives (Chappelet, 2021). However, poorly designed criteria, such as reliance on unverifiable data or easily manipulated metrics, can compromise the credibility and effectiveness of an IF's governance framework (Cabello-Manrique & Puga-González, 2023).

The Importance of Robust, Verifiable Metrics

To maintain integrity, IFs should ensure that the voting system is:

1. Aligned with IF Strategic Goals: Governance structures must reflect the long-term development of the sport, ensuring that grassroots engagement, competitive excellence, and inclusivity are rewarded (Forster, 2016).
2. Verifiable and Transparent: IFs must prioritise objectively measurable criteria to prevent data manipulation and enhance accountability. For instance, ranking data, tournament participation, and national Member development programs could provide a stronger basis for awarding votes than self-reported membership figures (Schubert & Könecke, 2015).
3. Flexible and Adaptive: As participation models evolve, including digital engagement, para-sport inclusion, and emerging forms of play, voting criteria must be reassessed periodically to ensure continued relevance (Henry, 2013).

A data-driven approach to voting allocation, as seen in FIFA's ranking-based funding model and World Athletics' participation-weighted voting system, can enhance decision-making equity while preventing dominance by wealthier or more politically influential Members (Geeraert, 2018).

However, implementing uniform governance solutions remains challenging, as Ifs must manage a diverse membership with varying cultural contexts, technological access, and administrative capacity (Forster, 2006).

Comparing Differential and One-Member-One-Vote Systems

The differential voting system provides IFs with a dynamic mechanism to encourage Members to engage in the sport, rewarding them for active contributions rather than merely granting equal voting rights (Chappelet, 2021). In contrast, the one-Member-one-vote system, while symbolically democratic, fails to account for disparities in engagement, competition, and financial investment, potentially leading to decision-making inefficiencies (Forster, 2016).

A hybrid model, combining baseline voting rights with additional merit-based votes, could serve as a compromise between pure democratic representation and performance-based governance (Schubert & Könecke, 2015).

The Role of IFs in Defining Contribution Standards

One of the key governance functions of an IF is to establish clear criteria that define what it means for a MAs to contribute most to the sport (Hassan & McCarthy, 2014). This involves:

- Establishing transparent governance benchmarks for Members.
- Ensuring that smaller Members have pathways to increased representation based on developmental efforts.
- Balancing competitive, financial, and grassroots development metrics in determining voting power (Chappelet, 2021).

Continuous Review and Governance Evolution

Given the evolving nature of international sport, it is crucial that IFs periodically review and refine their voting systems. By implementing regular governance audits, IFs can:

- Ensure that voting structures remain relevant, equitable, and free from undue influence.
- Identify new participation trends that should be reflected in governance frameworks (e.g., gender equity requirements, youth development programmes).
- Reinforce commitments to integrity, inclusivity, and democratic governance (Geeraert, 2018).

By maintaining a commitment to transparent and fair voting criteria, IFs can enhance democratic legitimacy, promote equitable representation, and encourage sustained development across their sports. As governance challenges evolve, it is imperative that

IFs continuously refine their voting models, ensuring that representation aligns with contribution, and that decision-making remains inclusive, ethical, and future-proofed (Chappelet, 2021).

References

Bowen, G. A. (2009). Document analysis as a qualitative research method. *Qualitative Research Journal, 9*(2), 27-40.

Bryman, A. (2012). Social Research Methods (4th ed.). Oxford University Press.

Badminton World Federation [BWF] (2024). *BWF Constitution*. Badminton World Federation. https://extranet.bwf.sport/docs/document-system/81/1466/1467/BWF%20Constitution%20-%20April%202024.pdf

Cabello-Manrique, D., & Puga-González, E. (2023). A review of the level of good governance in international sport federations. *Journal of Human Sport and Exercise, 18*(1), 180-193. https://doi.org/10.14198/jhse.2023.181.15

Chappelet, J. L. (2021). *The governance of sport: Managing organization and structure in international sport federations*. Routledge.

Claringbould, I., & Knoppers, A. (2012). Paradoxical practices of gender in sport-related organizations. *Journal of Sport Management, 26*(5), 404-416. https://doi.org/10.1123/jsm.26.5.404

Corbetta, P. (2003). *Social Research: Theory, Methods and Techniques*. SAGE Publications Ltd.

Dowling, M., Leopkey, B. & Smith, L. (2018). Governance in Sport: A Scoping Review. *Journal of Sport Management, 32*(5), 438-451. https://doi.org/10.1123/jsm.2018-0032

Forster, J. (2016). Global sports governance and corruption. *Palgrave Communications*, *2*(1), 1-4. https://doi.org/10.1057/palcomms.2015.48

Geeraert, A. (2016). The governance of international sport: Understanding the sport-specific regime complex. Palgrave Macmillan. Geeraert, A. (2018). *Sports Governance Observer 2018: An assessment of good governance in five international sports federations*. Play The Game.

InsideTheGames (2018). *ISF introduces new digital membership system to enhance governance transparency*. InsideTheGames. https://www.insidethegames.biz/articles/1071885/world-squash-federation-selects-club-locker-as-technology-partner

Hassan, D., & McCarthy, P. (2014). *Sport governance: International case studies*. Routledge.

Henry, I. (2013). Athlete representation in IFs: Towards democratic legitimacy? *Sport in Society, 16*(2), 182-201.

Hoye, R., & Cuskelly, G. (2007). *Sport governance*. Routledge.

James, T. S., & Garnett, H. A. (2023). The Voter Experience Around the World: A Human Reflexivity Approach. Representation, 60(2), 231–252. https://doi.org/10.1080/00344893.2023.2290714

Kang, Y. (2011). Life is Learning. Daekyo Publishing.

Mills, E. A., Deng, Z., Zhong, Z., & Li, J. (2024). Data-driven prediction of soccer outcomes using enhanced machine and deep learning techniques. *Journal of Big Data, 11,* 170. https://doi.org/10.1186/s40537-024-01008-2

Parent, M. M., Haye, R., Taks M., Thompson, A., Naraine, M. L., Lachance, E. L. & Séguin, B. (2021). National sport organization governance design archetypes for the 21st century. *European Sport Management Quarterly, 23*, 1115. https://doi.org/10.1080/16184742.2021.1963801

PlayTheGame. (2022). *New research: Alternative voting systems may lead to better governance in sport.* PlayTheGame. https://www.playthegame.org/news/new-research-alternative-voting-systems-may-lead-to-better-governance-in-sport/

Schubert, M., & Könecke, T. (2015). Governance structures of international sport organizations and their influence on election outcomes. *International Journal of Sport Policy and Politics*, 7(3), 353–375.

Thompson, A., Lachance, E.L., Parent, M. M., & Haye, R. (2023). A systematic review of governance principles in sport. European Sport Management Quarterly, 23, 1863. https://doi.org/10.1080/16184742.2022.2077795

Yin, R. K. (2018). *Case Study Research and Applications: Design and Methods* (6th ed.). SAGE.

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