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Indistinguishability of Racket and Body Kinematics during Different Table Tennis Serves for International Elite and Intermediate Players

Indistinguibilidad de la cinemática de la raqueta y del cuerpo en diferentes servicios de tenis de mesa en jugadores internaciones de élite e intermedios

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Abstract

Table tennis serves are strokes in which disguise and deception skills are important. This study aimed to investigate whether international elite table tennis players can make their racket and body kinematics more indistinguishable than intermediate players during three different serve types. Five former international elite and 8 intermediate players performed 3–12 trials of each serve type. The kinematics of the server's body and the racket was determined using a motion capture system. The time instant of racket-ball impact was determined using a high-speed video camera with the motion capture system. Misclassification rates when the serve type was classified using the racket and body kinematics were determined using linear discriminant analysis. Elite players showed higher misclassification rates for the racket kinematics than intermediate players during the early swing and follow-through phases. The body kinematics suggested that the elite players made their racket kinematics more indistinguishable using different approaches between the early swing and follow-through phases. The elite players tended to make the racket's angular velocity more similar and make the wrist rotational variables more indistinguishable in different serves compared to the intermediate players during the early swing phase. In contrast, the elite players made the racket's linear motion more variable within individual serve types than the intermediate players during the follow-through. The results suggest that intermediate players are recommended to practice making wrist angular motions more similar during the early swing phase and making racket linear motions more variable during the follow-through in order to improve the disguise skill in table tennis serves.

Keywords: *linear discriminant analysis, disguising motion, machine learning, table tennis, serve.*

Resumen

Los servicios en el tenis de mesa son movimientos en los que las habilidades para enmascarar y engañar son importantes. El objetivo de este estudio fue investigar si los jugadores de tenis de mesa de élite internacionales pueden hacer que la cinemática de su raqueta y cuerpo sea más indistinguible que los jugadores intermedios durante tres tipos de servicio diferentes. Cinco exjugadores internacionales de élite y 8 jugadores intermedios realizaron de 3 a 12 intentos de cada tipo de servicio. La cinemática del cuerpo y de la raqueta del servidor fue determinada a través de un sistema de captura del movimiento. El momento del impacto raqueta-pelota fue determinado usando una videocámara de alta velocidad con sistema de captura de movimiento. Las tasas de

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clasificación errónea cuando el tipo de servicio fue clasificado usando la cinemática de la raqueta y del cuerpo fueron determinadas por medio de un análisis discriminante linear. Los jugadores de élite mostraron tasas de clasificación errónea más altas en la cinemática de la raqueta que los jugadores intermedios durante la fase inicial del swing y la fase de terminación. La cinemática del cuerpo sugirió que los jugadores de élite hicieron su cinemática de la raqueta más indistinguible al usar diferentes enfoques entre la fase inicial del swing y la de terminación. Los jugadores de élite tuvieron una tendencia a hacer que la velocidad angular de la raqueta fuera más similar y las variables de rotación de la muñeca fueran más indistinguibles en diferentes servicios comparados con los jugadores intermedios durante la fase inicial del *swing*. En contraste, los jugadores de élite hicieron que el movimiento lineal de la raqueta fuera más variable en tipos de servicio individual que los jugadores intermedios durante la terminación. Los resultados sugieren que los jugadores intermedios deberían hacer movimientos angulares de muñeca más similares durante la fase inicial del swing y hacer que los movimientos lineares de la raqueta sean más variables durante la terminación para mejorar la habilidad para enmascarar los servicios de tenis de mesa.

Palabras clave: *análisis discriminante linear, movimiento para enmascarar, aprendizaje automático, tenis de mesa, servicio.*

INTRODUCTION

In table tennis, servers have the advantage over receivers in scoring points (Tamaki & Yoshida, 2020; Tamaki, Yoshida, & Yamada, 2017; Yoshida, Yamada, Tamaki, Naito, & Kaga, 2014; Zhang, Liu, Hu, & Liu, 2013). A recent study (Djokic, Malagoli Lanzoni, Katsikadelis, & Straub, 2020) has reported a significant association between the serve outcome and match outcome in elite player's matches, demonstrating the importance of the serve for winning a match. The importance of disguise and deception skills in the serve are highlighted in table tennis textbooks. Specifically, serve effectiveness is dependent on the opponent's difficulty judging the shot's spin and placement (Geske & Mueller, 2010), and players are recommended to learn to deceptively vary the spin, speed, and placement (Seemiller & Holowchak, 1997). Theoretically, deception and disguise in action have the intent either to mislead the opponent's anticipation or to keep the opponent in suspense about the real intention (Helm, Munzert, & Troje, 2017). In table tennis games, a player can widely vary the spin, pace, and placement of the serves. Thus, keeping the opponent in suspense about the server's real intention as long as possible would be an approach to performing effective serves. Evaluating such a skill in the serve and revealing possible differences between advanced and intermediate players would add insight into improving the skills. Previous studies on table tennis serves quantified the ball spin rates in international elite players (Lee & Xie, 2004; Yoshida, Yamada, Tamaki, Naito, & Kaga, 2014), revealed that a top player can perform two different serves with similar upper limb joint linear velocities (Wang, Zhou, Li, & Li, 2008) and demonstrated the squat serve needs higher lower limb drive than the standing serve in short serves (Yu, Shao, Baker, & Gu, 2018). However, to our knowledge, the racket and body kinematics have not yet been investigated in detail in terms of the skill of disguising table tennis serves.

Linear discriminant analysis was recently used to classify kinematic patterns into different characteristic groups (Benson et al., 2018; Fox, Ferber, Saunders, Osis, & Bonacci, 2018), to reveal what body parts provide a clue for discriminating the throw direction (Maselli et al., 2017), and to identify the kinematic variables that provide a clue for discriminating between disguised and non-disguised throws in handball (Helm et al., 2017). The present study attempted to assess the indistinguishability of the serve types by the racket and body movements in different table tennis serves using linear discriminant analysis. The racket movement is produced by the kinematic chain of the trunk and upper limb joints. By doing so, we can infer what parts of the body movements are associated with the indistinguishability by the racket movement.

A player may make the racket kinematics indistinguishable by keeping the different serve types the same as possible as he/she can or increasing the variability of the racket kinematics within individual serve types. By taking the latter approach, one may be able to remove the features of each serve type that can be used to distinguish the serve type. Determining the similarities of the racket kinematics between different serve types and their variability within individual serve types would give us insight into how players make the racket kinematics indistinguishable.

Using linear discriminant analysis, this study aimed to investigate whether elite table tennis players can make their racket and body kinematics more indistinguishable than intermediate players in three different types of serves. The present study hypothesized that elite players can make their racket and body kinematics more indistinguishable than intermediate players.

METHODS

Participants

Five former international elite (2 male, 3 female) and 8 collegiate (4 male, 4 female) table tennis players participated in the study. The mean (range) age, height, and body mass were 37.0 (30.9–54.7) years, 1.61 (1.55–1.68) m, and 56.7 (48.4–65.1) kg, respectively, for the elite players and 20.9 (19.2–21.6) years, 1.62 (1.51–1.73) m, and 57.7 (50.7 –64.7) kg, respectively, for the collegiate players. Two elite players were medalists at the Olympic Games and all elite players were medalists at the International Table Tennis Federation World Championships competitions. The elite players were retired players with high-level serve skills. Three elite players had been within three years from retirement, one elite player had retired six years ago and the remaining one player was an active elite table tennis coach. Please note that active elite players are not willing to have their serving techniques scrutinized even though the data are anonymized. All collegiate players were Kanto (a region including Tokyo) Collegiate Table Tennis League Division II or III players and categorized as intermediate players. One elite player used a Chinese penholder grip racket, while all other elite and collegiate players used shake-hands grip rackets. All participants had no recent injuries that could affect the serve performance. All participants provided written informed consent before participating in the study. The study procedure was approved by a local ethics committee.

Protocol

The participants wore tight-fitting pants and shirts and their own table tennis shoes. A total of 52 retro-reflective markers were attached to the body surface of each participant. Four markers were also attached to the lateral aspects of each participant's racket; every participant used his or her racket. After the individual warm-up, each participant was asked to perform three types of serves to a right-handed receiver, who was an experienced table tennis coach (the fourth author). The order of serve types was randomized. The last author instructed the participants regarding the next serve type before each trial by showing them a sheet on which the order was written. The receiver was not informed about the next serve type. Each participant determined three types of serve he or she considered the best set in terms of disguise in advance. The participants were asked to vary spin, pace, and/or location of the three serve types. The techniques, spins, and aimed locations of the ball's second bounce on the table as well as the number of trials for each participant are listed in Table 1. The number of trials was varied among the participants based on the time allowed for each player to participate in the experiment as well as the total time allowed for the experiment. Three-star plastic balls with 40mm diameter (Nippon Takkyu, Tokyo, Japan) were used in all trials.

Data collection

The three-dimensional coordinates of the reflective markers during serves were collected using a 16-camera motion capture system (MAC3D System; Motion Analysis, Santa Rosa, CA, USA) at 200 Hz. Images of the racket around the ball-racket impact were recorded using three high-speed video cameras (1×Phantom VEO 710, 2×Phantom MiroLC; Vision Research, Wayne, NJ, USA) at 2,000 Hz. Trigger signals for the high-speed video cameras were also recorded using the motion capture system for synchronization.

Data Analysis

Racket kinematics

The three-dimensional coordinates of the racket markers were smoothed with a zero-lag 2nd-order Butterworth low-pass filter. The filter cut-off frequencies were determined with the residual analysis. Considering the small trial-to-trial variation of the server's standing position, the position of the racket tip was determined as the position relative to the midpoint of the left and right anterior superior iliac spines at the time when the racket's resultant velocity exceeded 0.2 m/s and used for later analysis. The velocity of the racket's tip was determined using the central finite difference method. The orientation of the racket relative to the laboratory coordinate system was determined using unit quaternions, which do not suffer from singularities as Euler angle parametrization does. A unit quaternion that represents rotation through an angle θ around the axis represented by the unit vector $\boldsymbol{n}$ can be written as:

$$\hat{q} = [q_0, \boldsymbol{q}] = [q_0, q_1, q_2, q_3] = [\cos\frac{\theta}{2}, \sin\frac{\theta}{2}\boldsymbol{n}]$$

Only the imaginary part of the unit quaternion $[q_1, q_2, q_3]$ was used in the calculation of misclassification rates because only three components of a unit quaternion are independent and were deemed significant for discrimination. The X-axis of the laboratory coordinate system was directed rightward from a server's view (Figure 1). The Y-axis was directed forward from the same view. The Z-axis was perpendicular to the X- and Y-axes pointing upward. The racket's coordinate system was determined as shown in Figure 1, while its angular velocity was determined from its rotation matrix.

Kinematic dissimilarity of racket kinematics among different serve types and its variability within individual serve types

We assessed the dissimilarity of the racket kinematics among different serve types and its variability within individual serve types during each swing phase. Then, we determined the Euclidean distances of the mean position vectors among the three serve type pairs and averaged them as follows:

$$\textit{Averaged distance} = \frac{||\overline{\mathbf{X}^{s1}}(t_k) - \overline{\mathbf{X}^{s2}}(t_k)|| + ||\overline{\mathbf{X}^{s1}}(t_k) - \overline{\mathbf{X}^{s3}}(t_k)|| + ||\overline{\mathbf{X}^{s2}}(t_k) - \overline{\mathbf{X}^{s3}}(t_k)||}{3},$$

where $\overline{\mathbf{x}^{s1}}(t_k), \overline{\mathbf{x}^{s2}}(t_k), \overline{\mathbf{x}^{s3}}(t_k)$ are the mean racket position vectors at a time t_k for each serve type (s1, s2, and s3). The averaged Euclidean distance was further averaged for each swing phase, which represents the dissimilarity of the racket position among the different serve types for each phase. We determined the position deviation vector of each trial from the mean vector. Then, the root-mean-square norm of the deviation vectors for each serve type was averaged for three serve types as follows;

$$\mathrm{RMS}_d(t_k) = \frac{\sum_j \sqrt{\left[\frac{\sum_{i=1}^{N_j} || \mathbf{X}_i^j(t_k) - \overline{\mathbf{X}^j}(t_k) ||^2}{N_j}\right]}}{3}, \quad (j = s1, s2, s3)$$

where $X_i(t_k), \overline{X^j}(t_k), N_j$ are the position vector of the racket tip at the time t_k, the mean position vector at t_k and the number of the trial for serve type j, respectively. The root-mean-square values were further averaged for each swing phase, which represents the variability of the position vector for each phase. The averaged Euclidean distances and the root mean squares of the norm of the deviation vectors for the racket linear velocity, quaternion, and angular velocity were similarly determined.

Upper trunk and racket arm kinematics

The right-handed coordinate systems for the upper trunk, upper arm, forearm, and hand segments were defined in the same way as in the study of Iino (2017). The upper trunk angles with respect to the laboratory coordinate system were determined using Euler angles (Grood & Suntay, 1983) with the rotational sequence of longitudinal rotation, lateral flexion, and anteroposterior bending. The shoulder, elbow, and wrist joints angles were also determined using Euler angles with the sequence of rotations about the mediolateral axis, anteroposterior axis, and superior-inferior axis.

The angular velocities of the body segments were determined from the rotation matrices of the respective segments. The shoulder, elbow, and wrist joint angular velocities were calculated by subtraction of the angular velocity of the proximal segment from that of the distal segment. The joint angular velocity vectors were decomposed into anatomically interpretable components aligned with the joint coordinate systems, which were defined in the same manner as in the study of Iino and Kojima (2009).

Swing phases

Time with respect to the time of ball impact (0 sec) was determined for kinematic data using 2,000Hz video images with a precision of half a millisecond. The swing duration of a table tennis serve was defined as the time from when the racket's resultant velocity exceeded 0.2 m/s to the time of ball impact. One elite player (E3) varied the initial swing motion within each serve type, and the swing duration varied widely within each serve type if it was defined as stated above. Thus, for this player, the swing duration was from the time of the peak resultant racket velocity during the initial swing motion to the ball impact. Time was first normalized to the swing duration of each serve for each participant. We then rescaled the normalized time to the unit of seconds by multiplying the mean duration of the three serves for each participant. These rescaled data were sampled at 200 Hz using cubic spline interpolation such that the data would include 0-sec data. The swing motions were then divided into three phases: early swing, -0.7 s to -0.15 s; pre-impact, -0.15 s to 0 s; and follow-through, 0 s to 0.2 s. We defined the early swing phase by not using the time when the racket's resultant velocity exceeded 0.2 m/s because we thought we needed to standardize the phase durations when comparing the linear discriminant analysis results among the different players; it is relatively easy to make different serves indistinguishable before accelerating the racket just before impact, and the serves with longer durations probably have a higher degree of similarity among the different serves. The time -0.7 sec was selected because all players began the serve motion before this time, while the time -0.15 sec was selected because all players increased the racket speed substantially after this time.

Consideration of hiding the racket behind the body or table

Several players hid their rackets from the receiver behind their body or the table. Although a receiver can estimate the server's racket motion even when he or she cannot see it, its reliability is severely degraded. Thus, we excluded the data over the duration when the receiver was thought not to be able to see the racket completely in the calculation of the misclassification rate, which will be explained in the next section. To estimate that duration, we created movies of each server's motions from the receiver's viewpoint using the marker coordinates and Matlab 3D graphics functions. In creating the movies, we assumed the receiver's viewpoints by referring to video footage because we did not determine the exact positions of the receiver. Furthermore, we considered this viewpoint as fixed throughout the swing phase. The movies did not accurately express the outline of the body segments as they were depicted as simplified geometric objects. We confirmed that ±5 cm lateral shifts of the assumed receiver's viewpoint affected the estimation of the duration by ±5 ms at most by creating multiple movies with the viewpoint shifted laterally by ±5 cm and ±10 cm. Furthermore, we treated the data equally for both groups of players. Thus, despite the limitations, we believe that the inaccuracy estimating the duration did not substantially affect the intergroup comparison.

Table 1.
Technique, spin, placement and number of trials for three types of services performed by each player.

Player	Technique			Serve 1			Serve 2			Serve 3		
	Racket side	Motion	Height of ball toss	Spin	Placement	# of trials	Spin	Placement	# of trials	Spin	Placement	# of trials
Elite												
E1	FH	standing	middle	back+side	LB	11	side	SF	11	back+side	SF	11
E2	FH	standing	middle	top+side	LB	10	top	LF	10	back	SF	12
E3	BH	squat	middle	top	LB	10	top	LF	10	back+side	SM	10
E4	FH	standing	middle	back+side	LB	11	side	SF	10	back+side	SF	10
E5	BH	standing	middle	top+side	LB	7	back+side	SF	7	top	SF	7
Intermediate												
I1	FH	standing	low	back+side	SF	5	minimal	SF	5	top	LB	6
I2	BH	standing	middle	back+side	LB	4	back+side	SF	5	side	SF	3
I3	FH	standing	middle	top+side	LB	4	back+side	SF	5	top+side	SF	4
I4	FH	standing	low	back+side	SB	5	top+side	LF	5	top+side	SB	5
I5	FH	standing	middle	side	SF	5	minimal	LB	5	top	LF	5
I6	FH	standing	low	back	SM	5	minimal	SM	5	minimal	LB	5
I7	FH	standing	middle	side	SF	5	side	SF	5	minimal	LB	5
I8	FH	standing	middle	back+side	LB	5	back+side	SF	5	top+side	LB	5

FH, forehand serve; BH, backhand serve. Placement is the aimed indication of the ball´s second bounce on the table: SB, short backhand side; SM, short middle; SF, short forehand side; LB long backhand side; LF, long forehand side for a right-handed player.

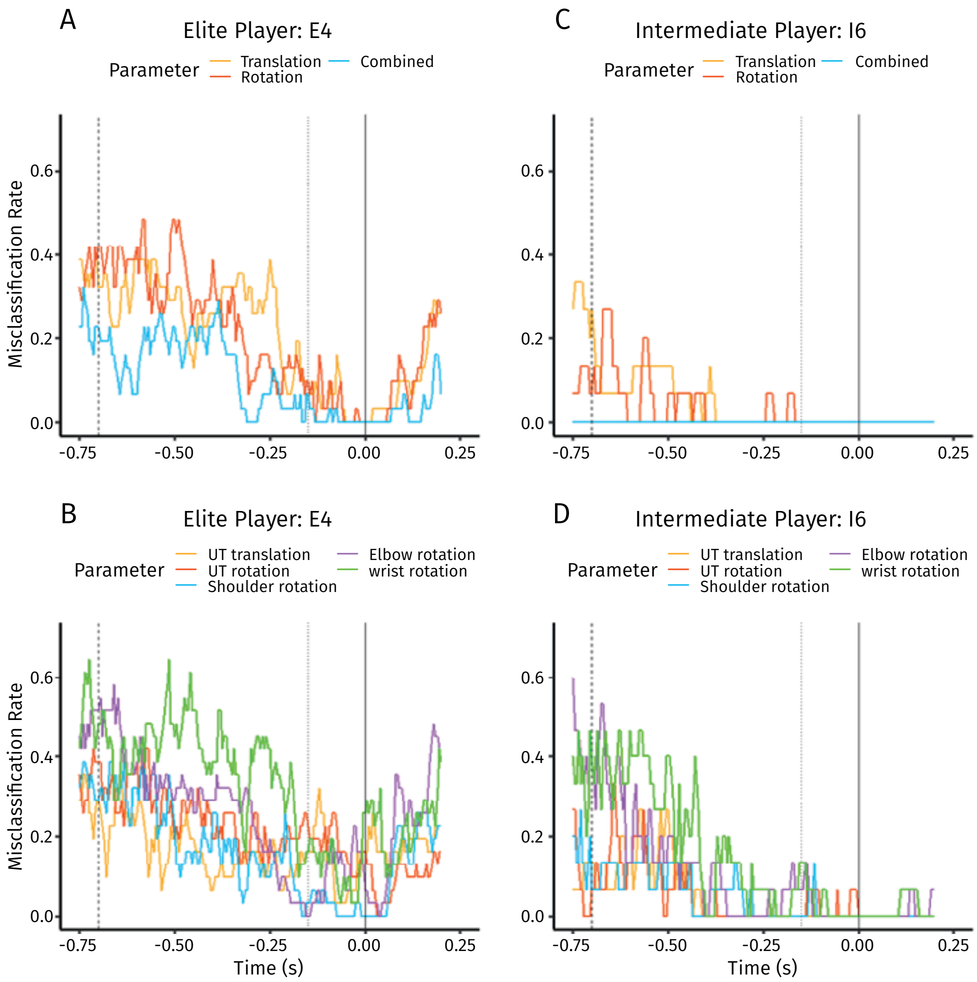

Figure 1.
Misclassification rates determined by the linear discriminant analysis with the racket kinematics and upper trunk and racket arm movements for elite player E4 (A and B, respectively) and intermediate player I6 (C and D, respectively). UT, upper trunk. The vertical lines indicate the beginnings of the early swing.

Linear discriminant analysis

We conducted the linear discriminant analysis using different sets of racket and body kinematics at each time instant. The translational variable of the racket kinematics was the 6 position-velocity coordinates of the racket tip and the rotational variable was the 6 quaternion-angular velocity coordinates of the racket. Thus, the combined variable at each time instant was a 12-dimensional vector. The translational variable of the upper trunk was the 6 position-velocity coordinates of the proximal end of the upper trunk. The rotational variable of the upper trunk was the 6 angle-angular velocity coordinates of the segment. The rotational variables of the shoulder, elbow, and wrist joints were the 6, 4, and 4 angle-angular velocity coordinates of the corresponding joints because we assumed the elbow varus/valgus and wrist longitudinal rotations do not occur. Misclassification rates were determined using a leave-one-out cross-validation procedure. In this procedure, a single data set was classified based on the remaining N-1 training data sets. This process was repeated for all N data sets. Due to the limited number of trials, the resolution of the instantaneous misclassification rate was limited; for an intermediate player with 15 total trials, the resolution was one-fifteenth (about 0.066) and a change by ±0.033 in misclassification rate could not be detected. Thus, we could not assess the misclassification rates at each time instant with high confidence; instead, we determined the mean misclassification rates over each swing phase for each set of kinematic variables by totaling the misclassification rates during each phase and dividing the answer by the number of data points during that phase.

The indistinguishability of the serve types was assessed using the misclassification rates determined by the linear discriminant analysis in the present study. This approach enabled us to assess the indistinguishability due to each of racket and body variables separately. On the other hand, the indistinguishability of the serve types to the receiver's eyes is important in a table tennis match. Separate research is required to reveal how the indistinguishability assessed by linear discriminant analysis is related to the indistinguishability to the player's eyes, which would vary among different performance levels.

Statistical analysis

Shapiro-Wilk test was used to test the normality of the misclassification rates, the mean Euclidean distances of the four racket variables, and the root-mean-square norms of the deviation vectors of the four variables. If the normality was rejected for the data set of either player group, the Wilcoxon rank-sum test was used to compare the data set between the elite and intermediate players; otherwise, a two-tailed t-test was used. In consideration of multiple testing issues, the significance level should be adjusted to reduce type I errors. It is also important to balance type I and type II errors. Thus, the level of statistical significance was set at 0.01. Linear discriminant analysis and all statistical tests were performed using R (R Core Team, 2018).

RESULTS

Results of Shapiro-Wilk normality test indicated that the following data were not normally distributed: the misclassification rates for racket translational and rotational variables during the pre-impact phase for the Intermediate players ($W = 0.689$, $p < .01$ and $W = 0.711$, $p < .01$) and for racket combined variable during all three phases for the Intermediate players (early swing: $W = 0.640$, $p < .001$; pre-impact: $W = 0.418$, $p < .001$; follow-through: $W = 0.465$, $p < .001$), the misclassification rates for shoulder rotation during the pre-impact phase for the Intermediate players ($W = 0.660$, $p < .001$) and for upper trunk translation ($W = 0.680$, $p < .01$), elbow and wrist rotations during the follow-through phase for the Intermediate players ($W = 0.732$, $p < .01$ and $W = 0.740$, $p < .01$), the root-mean-square norms of the deviation vector for the racket quaternion (orientation) within the individual serve types during the early swing phase for the Elite players ($W = 0.636$, $p < .01$), for the racket quaternion during the pre-impact and follow-through phases for the Intermediate players ($W = 0.684$, $p < .01$ and $W = 0.620$, $p < .001$), and for racket angular velocity during the pre-impact phase for the Intermediate players ($W = 0.750$, $p < .01$). Thus, Wilcoxon rank-sum test was used to compare these data set between the two groups of players.

The mean Euclidean distances of the four racket parameters upon ball impact among the three pairs of serve types did not differ significantly between both groups (Position: Elite = 0.138 ± 0.034 m, Intermediate = 0.135 ± 0.027 m, $p = .427$, Cohen's $d = 0.11$; Velocity: Elite = 3.93 ± 0.82 m/s, Intermediate = 2.84 ± 0.90 m/s, $p = .026$, Cohen's $d = 1.25$; Quaternion (Orientation): Elite = 0.423 ± 0.178, Intermediate = 0.394 ± 0.239, $p = .404$, Cohen's $d = 0.13$; Angular Velocity: Elite = 10.7 ± 4.2 rad/s, Intermediate = 12.3 ± 2.1 rad/s, $p = .240$, Cohen's $d = 0.51$).

The root-mean-square norm of the deviation vector for the racket position within the individual serve types was significantly larger for the elite players than the intermediate players during the follow-through phase (Table 2). The Euclidean distances between the mean racket kinematic variables averaged for three pairs of the three different serves were not significantly different for all variables and all swing phases between the elite and intermediate players (Table 2).

Two elite and two intermediate players hid their rackets behind their bodies or the table. Data over the duration when a player hid the racket in all trials (100%) for all serve types, which typically ranged from 0.1 sec to 0.2 sec, were excluded in the calculation of the misclassification error.

The misclassification rates for translational and rotational racket variables and the combined variable tended to decrease toward ball impact and increase after impact for elite players (Table 3 and Figure 1) whereas the misclassification rates tended to decrease towards ball impact and remained low values after impact for intermediate players (Table 3 and Figure 1). The misclassification rates for the body kinematic variables showed similar time-varying patterns as for the racket kinematic variables (Figures 1).

The mean misclassification rates for the combined racket variable during the early swing phase of the elite players were significantly higher than those of the intermediate players (Table 3). The misclassification rates during the pre-impact phase for the racket kinematic variables did not differ significantly between the elite and intermediate players. The misclassification rate for the translational racket kinematic variable during the follow-through phase was significantly higher for the elite players than for the intermediate players (Table 3). For the body kinematic variables, the misclassification rate for the wrist rotational variable during the pre-impact phase was significantly higher for the elite players than the intermediate players and the rate tended to be significantly higher for the elite players during the early swing and follow-through phases. The misclassification rate for the elbow rotational variable also tended to be higher for the elite players than the intermediate players during the follow-through phase (Table 3).

The present study aimed to examine whether elite table tennis players can make the racket and body kinematics more indistinguishable than intermediate players during three different serves. For that purpose, linear discriminant analysis was performed on the different sets of racket and body kinematic variables. The results supported the hypothesis that elite players can make their racket and body kinematics more indistinguishable than intermediate players.

The mean Euclidean distances of all racket parameters among the three pairs of serve types at ball impact did not differ significantly between the elite and intermediate players (Table 2). The mean distances for the linear velocity tended to be larger for the elite players than the intermediate players. This indicates that the elite players varied the racket kinematics at impact for the three serves at least to a similar extent compared to the intermediate players. Therefore, it is very unlikely that the higher misclassification rates for the elite players than the intermediate players observed in the present study (Table 3) were due to the variation of the three serves being smaller for the elite players than the intermediate players.

Table 2.
Root-mean-square norm of the deviation vectors of four racket variables within individual serve types averaged for three serve types and euclidean distance between the mean racket kinematic variables averaged for three pairs of three different serves in elite and intermediate players.

	Early swing				Pre-impact				Follow-though			
	Elite	Intermediate	*p*-value	Cohen´s d	Elite	Intermediate	*p*-value	Cohen´s d	Elite	Intermediate	*p*-value	Cohen´s d
Root-mean-square norm of the deviation vectors within individual serve types averaged for three serve types												
Position (m)	0.095 ± 0.073	0.074 ± 0.044	0.578	0.35	0.093 ± 0.041	0.071 ± 0.030	0.334	0.61	**0.137 ± 0.021**	**0.096 ± 0.024**	**0.009**	**1.85**
Velocity (m/s)	0.61 ± 0.47	0.56 ± 0.29	0.839	0.13	0.91 ± 0.26	0.82 ± 0.51	0.698	0.21	1.71 ± 0.29	1.24 ± 0.39	0.032	1.36
Quaternion	0.19 ± 0.19	0.12 ± 0.06	0.833	0.47	0.20 ± 0.10	0.20 ± 0.19	0.622	-0.01	0.28 ± 0.16	0.23 ± 0.18	0.524	0.29
Angular Velocity (rad/s)	2.38 ± 1.69	1.57 ± 0.74	0.359	0.62	2.95 ± 0.63	2.95 ± 1.81	0.284	0.02	6.90 ± 2.70	5.23 ± 1.55	0.258	0.76
Euclidean distances between the mean racket kinematic variables averaged for three pairs of three different serves												
Position (m)	0.11 ± 0.10	0.074 ± 0.044	0.59	0.36	0.19 ± 0.07	0.16 ± 0.04	0.42	0.52	0.25 ± 0.17	0.19 ± 0.09	0.504	0.44
Velocity (m/s)	0.58 ± 0.33	0.56 ± 0.29	0.671	-0.26	2.14 ± 0.50	1.83 ± 0.51	0.324	0.59	2.68 ± 0.50	2.73 ± 1.14	0.908	-0.06
Quaternion	0.17 ± 0.12	0.12 ± 0.06	0.823	-0.13	0.46 ± 0.08	0.49 ± 0.22	0.704	-0.2	0.47 ± 0.19	0.48 ± 0.24	0.962	-0.03
Angular Velocity (rad/s)	1.75 ± 0.19	1.57 ± 0.74	0.138	-0.84	6.43 ± 0.71	7.74 ± 2.11	0.138	-0.84	8.63 ± 3.62	9.04 ± 3.68	0.848	-0.11

Table 3.
Misclassification rates for racket and body kinematics during three phases of three serve types of elite and intermediate players.

	Early swing			Pre-impact			Follow-thorugh		
	Elite	Intermediate	*p*-value	Elite	Collegiate	*p*-value	Elite	Intermediate	*p*-value
Racket									
Translation	0.183 ± 0.108	0.089 ± 0.070	0.132	0.016 ± 0.021	0.013 ± 0.022	0.848	**0.105 ± 0.043**	**0.022 ± 0.031**	**0.008**
Rotation	0.206 ± 0.119	0.067 ± 0.047	0.058	0.035 ± 0.050	0.014 ± 0.023	0.288	0.073 ± 0.028	0.035 ± 0.028	0.044
Combined	**0.078 ± 0.085**	**0.001 ± 0.002**	**0.002**	0.006 ± 0.010	0.001 ± 0.004	0.417	0.014 ± 0.010	0.003 ± 0.007	0.012
Body									
UT translation	0.115 ± 0.039	0.098 ± 0.051	0.503	0.042 ± 0.053	0.048 ± 0.046	0.836	0.060 ± 0.070	0.043 ± 0.037	0.645
UT rotation	0.156 ± 0.064	0.095 ± 0.043	0.103	0.064 ± 0.071	0.027 ± 0.022	0.314	0.067 ± 0.048	0.030 ± 0.044	0.062
Shoulder rotation	0.136 ± 0.055	0.098 ± 0.045	0.238	0.010 ± 0.010	0.023 ± 0.035	0.644	0.064 ± 0.047	0.033 ± 0.033	0.233
Elbow rotation	0.198 ± 0.066	0.190 ± 0.105	0.868	0.058 ± 0.029	0.044 ± 0.031	0.445	0.159 ± 0.052	0.077 ± 0.088	0.045
Wrist rotation	0.302 ± 0.066	0.173 ± 0.086	0.012	**0.116 ± 0.024**	**0.038 ± 0.042**	**0.001**	0.142 ± 0.051	0.069 ± 0.088	0.030

UT: Upper trunk; Values are shown as mean ± standard deviation. Number in bold face indicate significant differences between elite and intermediate players.

DISCUSSION AND IMPLICATIONS

The elite player made their racket kinematics more indistinguishable during the early swing and follow-through phases than the intermediate players (Table 3). The results of the misclassification rates during the pre-impact phase (Table 3) suggest that the elite players could perform three types of serves with more indistinguishable wrist motions than the intermediate players although the indistinguishability of the racket kinematics was not significantly different between both players group. Thus, the results suggest that receivers may be recommended to focus on the racket motion rather than the wrist motion during the pre-impact phase for judging the serve type.

The results also revealed that the elite players made their racket kinematics more indistinguishable using different approaches between the early swing and follow-through phases. This is explained below. In the early swing phase, the elite players made the combined racket variable more indistinguishable than did the intermediate players (Table 3). The variability of the racket variables within individual serve types in this phase was similar in the elite and intermediate players (Table 2), suggesting that making the racket kinematics more variable within individual serve types was not an approach of the elite players to making the racket variables more indistinguishable in this phase. Though the mean Euclidean distances between the racket variables for the three serve types were not significantly different between both groups, the effect size of the difference was large for the angular velocity and the distance was smaller for the elite players (Table 2). It is possible that a more similar angular velocity among the different serves contributed to a more indistinguishable racket variable for the elite players. A tendency toward a more indistinguishable wrist rotational variable for the elite players (Table 3) indicates that the wrist motion may be related to the more indistinguishable racket kinematics of the players.

During the follow-through, the racket linear position was more variable within individual serve types for the elite players than the intermediate players. This likely contributed to the more indistinguishable translational racket motion during this phase for the elite players. The elite players tended to make the elbow and wrist motions more indistinguishable than the intermediate players during the follow-through phase. Thus, a more variable racket position for the elite players may be attributed to their elbow and wrist motions. Based on the results, intermediate players are recommended to practice serves with variable follow-through motions for each serve type, which is not addressed in table tennis textbooks (Geske & Mueller, 2010; Seemiller & Holowchak, 1997) although the importance of disguising and deceptive serve motions is highlighted there.

Some limitations exist in this study. First, the elite players were retired players, and the number of elite players was low. Five elite players are not enough to make generalization about international elite players. Thus, the findings obtained in the present study should be considered with these in mind. Second, the elite group included a pen holder grip user whereas all intermediate players were shake-hands grip users. The present study could not reveal whether differences exist in racket and body kinematics distinguishability between pen holder and shake-hands grip types or between male and female players. Then, the players performed a low number of trials, which prevented us from assessing the instantaneous values of the misclassification rate. Finally, the indistinguishability of the different serves was only assessed by linear discriminant analysis. Future studies are needed to clarify how the assessment by linear discriminant analysis is related to the judgment by players' perceptions with different performance levels.

CONCLUSION

We compared the indistinguishability of racket and body kinematics during three different table tennis serves between elite and intermediate players. Specifically, the misclassification rates when the serve type was classified using the racket and body kinematics were determined using linear discriminant analysis. Elite players showed significantly higher misclassification rates for the racket kinematics than intermediate players during early swing and follow-through phases. The elite players tended to make the racket's angular velocity more similar in different serves compared to the intermediate players during the early swing phase. In contrast, the elite players made the racket's linear motion more variable within individual serve types than the intermediate players during the follow-through. In short, the results suggest that the elite players made their racket kinematics more indistinguishable using different approaches between the early swing and follow-through phases. Furthermore, the elite players showed a higher misclassification rate for the wrist motion during the pre-impact phase than the intermediate players, suggesting a higher ability of the elite players to make the wrist motion more indistinguishable immediately before impact.

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The relationship between service performance and physical strength focusing on speed and spin rate in Japanese elite junior tennis players

La relación entre el desempeño en el servicio y la fuerza física enfocada en la velocidad y la tasa de rotación de la pelota en jugadores jóvenes de élite japoneses

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Abstract

The service is the most powerful and potential shot in tennis. To reach global elite status, Japanese players, being generally inferior in height, must overcome the limitations in service performance. If their height is insufficient, they must improve their service performance speed while maintaining the spin rate. Therefore, in this study, we aimed to examine the relationship between service performance according to the speed and spin rates and physical factors among national-level male and female junior tennis players. Twenty-eight elite tennis players participated in this study. Service tests were completed using the TrackMan tennis radar device. A total of 12 services per player were collected. Physical strength tests were conducted according to the Japan Tennis Association methods. Based on a previous study, 16 measurement variables related to service performance were selected. Among the male players, both the 1st and 2nd services showed significant correlations of service speed with physique and physical strength. On the other hand, no correlation was observed between service spin and physique or physical strength. Among female players, there was a significant correlation between service speed and physique, but not physical strength. In contrast to male players, there were significant correlations between service spin and some parameters of physical strength. As described above, the results were different for males and females. It is recommended that male players should focus intensively on muscular strength and power during training, whereas female players should focus on acquiring the skills needed to increase the spin rate, with strength as their secondary focus. Additionally, the increased drive from the legs can be converted to increased service speed. Therefore, male and female players should be coached on service from different perspectives.

Keywords: *tennis; service performance analysis; physical analysis; gender difference; principal component analysis.*

Resumen

El servicio es el golpe más potente y fuerte del tenis. Para llegar a un nivel de élite mundial, los jugadores japoneses, que suelen ser inferiores en cuanto a altura, deben superar las limitaciones en el desempeño del servicio. Si su altura es insuficiente, deben mejorar su desempeño en la velocidad del servicio al mismo tiempo que mantienen la tasa de rotación de la pelota (spin). Por lo tanto, el objetivo de este estudio es analizar la relación entre el desempeño en el servicio según la velocidad y la tasa de rotación y los factores físicos de jugadores juveniles hombres y mujeres de tenis de nivel nacional. Veintiocho jugadores de tenis de élite participaron en el estudio. Las pruebas en el servicio se realizaron con el dispositivo de radar TrackMan para tenis. Cada jugador realizó 12 servicios en total. Se llevaron a cabo pruebas de fuerza física según los métodos de la Asociación

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Japonesa de Tenis. Con base en un estudio previo, se seleccionaron 16 variables de medida relacionadas con el desempeño en el servicio. Entre los jugadores hombres, tanto el primer como el segundo servicio mostraron correlaciones importantes entre la velocidad del servicio y el físico y la fuerza física. Por otro lado, no se observaron correlaciones entre la tasa de rotación y el físico o la fuerza física. Entre las jugadoras mujeres, se encontró una correlación significativa entre la velocidad del servicio y el físico, pero no la fuerza física. A diferencia de los jugadores hombres, las mujeres presentaron correlaciones significativas entre la rotación en el servicio y algunos parámetros de fuerza física. Como ya se mencionó, los resultados fueron diferentes entre hombres y mujeres. En conclusión, los jugadores hombres deberían enfocarse intensivamente en la fuerza muscular y la potencia durante el entrenamiento, mientras que las mujeres deberían enfocarse en adquirir las habilidades necesarias para aumentar la tasa de rotación; con la fuerza como su enfoque secundario. Adicionalmente, el aumento en impulso de las piernas puede convertirse en un aumento en la velocidad del servicio. Por lo tanto, los jugadores hombres y mujeres deberían ser entrenados en el servicio desde diferentes perspectivas.

Palabras clave: *tenis; análisis del servicio; análisis físico; diferencia según el sexo; análisis de componentes principales.*

INTRODUCTION

The modern game of tennis has evolved from a technical-based sport to a more dynamic and explosive sport as a result of higher stroke and service velocities, bolstered by the improvement of rackets and strings (Ulbricht et al., 2016). Above all, service is the most powerful and important shot in tennis. After the toss-up, while moving the power from the lower half to the upper half of the body using the whole-body movement chain, the racket speed is increased toward impact (Kibler, 2009). This racket motion can create a mix of ball speed and spin. A clear trade-off between the ball spin and horizontal ball speed has been reported in tennis (Sakurai et al., 2013). Theoretically, the speed decreases when spin is applied and vice versa. Elite tennis players generally stroke a flat or power service first, reducing the spin rate and focusing on speed, then select a slice or spin as the second service (Douglas, 1992; Bahamonde, 2000; Whiteside et al., 2013). When the first service fails, it is common for players to slow down and increase the spin rate on the second service, which increases the likelihood of the ball successfully landing in the service box. This technique increases accuracy without losing points (Chow et al., 2003). To achieve higher speeds during service, the player must account for the net height, position of the service line, and height of the hitting point. Brody (1987) reported that a minimum height of 2.74 m on the baseline is required to eliminate gravity and ball aerodynamics concerns. For athletes who are not tall enough, spinning is essential; however, at the same time, speed is also required to some extent. As of July 2020, the average height of the top 50 players in the International Tennis Federation ranking was 188.73 cm (ITF, 2021). However, the average height of the four Japanese players in the top 100 was 176.50 cm (ITF, 2021). Japanese players, who are generally inferior in height, must overcome the technical hurdle associated with service performance to reach global elite status.

A significantly high correlation between service speed and the percentage of points won has been shown. Service reportedly influences the game outcomes for both male and female players; in particular, service speed is highly correlated with an athlete's competition level (Ulbricht et al., 2016). Fett et al. (2017) reported significant differences between junior Davis cup and regional level players in service speed and upper body strength. According to Fett (2018) and Kramer (2017), maximal service speed is the most appropriate on-court predictor of player performance. Thus, the importance of service speed in an athlete's competition level is widely known in the tennis world. Moreover, various researchers have reported the relationship between service speed and physical factors. In a study on German National junior tennis players, Ulbricht et al. (2016) reported that the upper limb muscular strength, power, and service velocity were interrelated in both male and female players, and there was a strong relationship between service speed and level of competition. In a study emphasizing the importance of transmitting power in the kinetic chain from the lower body to the upper body, Girard et al. (2005) examined the earlier activities in the lower leg muscles in high level players and suggested that for hitting, the power of not only the upper body but also of the whole-body kinetic chain is vital. Hence, it is important to acquire a service form that links the whole-body as well as muscle activity. Many studies of these services have been historically centered on adult, male players and, consequently, the mechanics characterizing the female and junior serves is underpinned by emulation, rather than the objective data that have guided instruction of the adult male serve (Whiteside et al., 2013). Even when we consult tennis-coaching books from each country, no gender-specific coaching methods on the technical instruction of service are found. Although many researchers have reported a relationship between service velocity and physical strength factors (Ferrauti and Baestiaens, 2007; Knudson et al., 2004; Cardoso, 2005), no studies have so far explored the correlation between service spin rate and physical strength. There are some reports on the spin rate in service. However, these did not elucidate its relationship with physical strength (Murakami et al., 2016; Muramatsu et al., 2015; Muramatsu et al., 2010; Sakurai et al., 2007). As mentioned above, there is a trade-off between the speed and the spin rate of service. However, it has been reported that the world's top-level players could hit the speed service while maintaining a high spin rate (Muramatsu et al., 2015). It is important for Japanese athletes, who are inferior in height, to learn to improve both spin rate and speed.

Although muscle strength or strength power is thought to play a role in service speed, only a few studies have clarified the effects of physical strength on service spin. This study aimed to examine the relationship between performance in tennis service, based on speed and spin rates, and physical factors among national-level male and female junior tennis players.

MATERIAL AND METHODS

Participants

Forty-one elite tennis players (30 men; mean ± standard deviation [SD] age, 15.03 ± 2.58 years; height, 170.64 ± 7.06 cm; mass, 60.39 ± 7.72 kg and 11 women; age, 16.73 ± 2.65 years; height, 163.56 ± 5.35 cm; mass, 55.56 ± 6.45 kg) participated in this study. These were either top-level junior players of each generation in Japan or candidates who participated in the Universiade tournament. These players were selected by the National Federation's coaching staff based on competitive performance. All players had at least 10 years of tennis training. Under the Institutional Review Board's policies for the use of human participants in research in accordance with the Declaration of Helsinki, the investigator informed all participants about the benefits and possible risks associated with participation in the study. All participants signed a written informed consent document indicating voluntary participation. Self-reported medical histories were received from all participants. We confirmed their medical history of injuries and determined that there was no effect on this study.

Design & Procedures

An attempt was made to examine whether there was a relationship between service performance (speed, spin, impact height when hitting a ball, impact depth), anthropometry (player's height, mass, skeletal muscle mass), and physical condition (grip strength, isokinetic peak torque (PT), jump, sprint, medicine-ball throw). Variables were categorized as service speed, service spin, impact height, impact depth, physique, and physical strength. We set 3 independent variables of physique and 15 independent variables of physical strength. Independent physique and physical strength variables were converted into the principal component analysis (PCA) score, and the correlation with service performance (speed, spin, impact height, impact depth) was analyzed. Furthermore, we examined whether there was a difference by sex in the above correlation

Service performance test

The service tests were conducted using the TrackMan tennis radar device (TrackMan Inc., Vedæk, Denmark). This device is an advanced radar that utilizes the Doppler effect to capture the behavior of an object; in this case, the full three-dimensional flight of a tennis ball (speed, spin, spin axis). The Doppler effect is a phenomenon in which the relative velocity between a generation source and an observer result in the shifting of sound or radio wave frequencies (Murata and Takahashi, 2020). If a ball in flight reflects a radio wave, the frequency of the reflected wave shifts, depending on the velocity and spin of the ball, and is calculated by a dedicated software (Martin, 2012). Doppler effect-based measurement devices are superior to other devices in terms of immediacy and user-friendliness and are used in golf coaching and baseball (Murata and Takahashi, 2020). The accuracy of the TrackMan system is equivalent to that of conventional high-speed cameras or speed radar devices, as reported in recent studies (Martin, 2012; Murakami et al., 2016; Murata and Takahashi, 2020; Sato et al., 2017). That allows for real-time measurements and an analysis of parameters such as spin rate, ball speed, ball direction, impact location (height, depth), net clearance, and landing position. In this study, the TrackMan was set at approximately 4 m behind the center mark, which allowed the radar to visualize the service box (Fig.1).

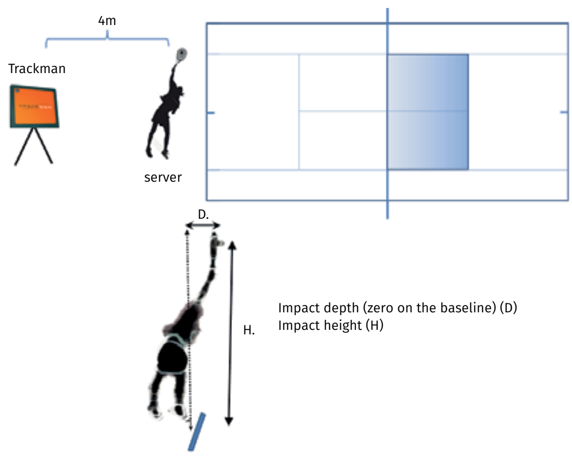

Figure 1. Experimental set up for service performance test and service impact items.

Service impact was defined as the moment when the ball hit the racket, and the height and depth of the hitting point at that moment were measured.

The impact depth was analyzed with the baseline set to zero, with the forward direction closer to the net considered as positive (+) and backward direction away from the net as negative (–) (Fig.1). The tests were conducted on an indoor tennis court. After a brief warm-up consisting of serves with increasing velocities, players were instructed to perform the first service as fast as possible and the second service with as much spin as possible, with both directed at the T of the service box. No returner was placed. They performed three sets of service tests, hitting the 1st and 2nd serve from the deuce side and then hitting the same from the advantage side. Details of a total of 12 services per player were collected. For the analysis, the average of the six services was used for each variable. Services such as fault and net were excluded, and only successful services were used.

Physical strength tests

Based on the published literature, 15 measurement variables related to service performance were selected (Delgado et al., 2019; Kramer et al., 2017; Signorile et al., 2005; Koya et al.,2018). In addition to height, weight, and grip, the following physical condition variables were measured using the Japan Tennis Association protocols (Koya et al., 2014; Koya et al., 2015):

1. Skeletal muscle mass: Data were obtained via impedance methods using a body composition analyzer (In Body 730, BioSpace Inc., Los Angeles, CA, USA).
2. Isokinetic peak torque (knee and hip): Isokinetic muscle strengths of the legs and trunk were measured using the Biodex (Biodex Medical Systems, Inc., Shirley, NY, USA). The knee joint was tested at 1.05 rad $\cdot$ s^{-1} and 3.14 rad $\cdot$ s^{-1} and the hip joint was tested 1.05 rad $\cdot$ s^{1} and 2.10 rad $\cdot$ s^{-1}. The peak torque of extension and flexion was recorded, and both legs were measured. Total value of flexion and extension was used.
3. Squat jump: This test was performed using a mat-switch (Multi Jump Tester, DKH Inc., Tokyo, Japan). The players completed a jump test from a squat position with the hands on the waist. The best value was used.
4. Vertical jump: This test was also measured using the mat-switch. Players were required to jump using an arm action. The best value was used.
5. Rebound Jump-Index (RJ-Index): The players performed six consecutive rebound jumps with their hands on their waists. This test serves to measure ankle joint stiffness. The RJ-Index was calculated by dividing the jumping height by the landing time and was used as a criterion for the stretch-shortening-cycle (SSC) function. The best value was used.
6. 5-m sprint and 20-m sprint: The participants were instructed to sprint in a straight-line for 20 m; the times from the starting line to the 5-m and 20-m marks were measured using a photocell (Timing Systems by Brower Timing Systems, Draper, UT, USA). In the analysis, the speed was calculated (m/s) based on the time. The best value was used.
7. Medicine ball throw (MBT): Players performed three types of forward throws (overhead, right side, and left side) and backward overhead throws in an open stance, with both legs fixed whilst throwing a 2 kg medicine ball. The best value was used.

All those variables were highly related to the ability to hit the service (Delgado et al., 2019; Kramer et al., 2017; Signorile et al., 2005; Koya et al.,2018). Test reliability was confirmed by performing a retest.

Analyses

Partial correlations (controlling for age) were conducted to assess the association between the service performance variables (speed, spin rate, impact height and impact depth) and anthropometrics variables (physique and physical strength) for each gender (Table 1). Age was used as a control variable to exclude the influence of growth and maturity (Fett et al., 2018). We performed principal component analysis (PCA) using the physical strength test variables and then extracted the first principal component score as a comprehensive index of physical general strength (strength PCA) to comprehensively evaluate each player's physical strength. Correlation analyses were conducted to assess the relationship between strength PCA and service performance within sex. Statistical analyses were performed using IBM SPSS Statistics for Windows, version 27 (IBM Corp., Armornk, N.Y., USA). Statistical significance was set at $P < 0.05$.

RESULTS

Table 1 shows physique and strength test results of players in each group. The partial correlation coefficients for males and females are shown in Tables 2-1 and 2-2, respectively. Among male players, correlation analyses revealed some significant relationships of 1st and 2nd service with physique and physical strength; however, service speeds were not correlated with isokinetic PT (knee), squat jump, vertical jump and the 5-m sprints. A significant correlation was observed between the service speed and grip strength, isokinetic PT (hip), broad jump, 20 m sprint, MB throw, and physique. As for service spin, in the 2nd service, a significant correlation was observed between grip strength, isokinetic PT (hip), and broad jump. In both 1st and 2nd services, speed was more correlated than spin with physique and physical strength. As for impact, there was a significant correlation between impact height and isokinetic PT (hip) and RJ-index, but not between impact depth and the other items (Table 2-1). The results among the female players were entirely different compared to the male players. We found a significant correlation between the 1st service speed and forward overhead MB throw; however, no correlation was observed between both service speeds and the other tests. As for service spin, in both services, there were significant correlations with isokinetic PT. Regarding impact (height, depth), neither physique nor physical strength items showed any correlation (Table 2-2).

Table 3 shows the factor loading of physique PCA and strength PCA (Table 3).

Table 1.
Physique and strength test results of players in each group.

		Male players (30)	Female players (11)
Physique	Age (years)	15.03 ± 2.58	16.73 ± 2.65
	Height (cm)	170.64 ± 7.06	163.56 ± 5.35
	Mass (kg)	60.39 ± 7.72	55.56 ± 6.45
	Skeletal muscle (kg)	30.96 ± 4.36	24.46 ± 3.17
Strength	Grip strength (kg)	43.23 ± 7.70	33.85 ± 4.27
	Isokinetic PT / Knee at 1.05 rad•s-1 (Nm)*	534.59 ± 113.14	389.82 ± 201.81
	Isokinetic PT / Knee at 3.14 rad•s-1 (Nm)*	406.09 ± 86.71	260.82 ± 136.37
	Isokinetic PT / hip at 1.05 rad•s-1 (Nm)**	405.47 ± 135.94	309.55 ± 162.92
	Isokinetic PT / hip at 2.10 rad•s-1 (Nm)**	369.97 ± 132.81	252.00 ± 147.75
	Squat Jump (cm)	33.57 ± 6.82	30.72 ± 3.73
	Vertical Jump (cm)	41.56 ± 8.33	37.52 ± 4.01
	RJ-index (m/sec)	1.94 ± 0.41	2.20 ± 0.32
	Broad Jump (m)	2.24 ± 0.24	2.03 ± 0.17
	5m sprint (m/sec)	4.50 ± 0.28	4.35 ± 0.23
	20m sprint (m/sec)	6.12 ± 0.31	5.81 ± 0.26
	MBT overhead backward (m)	11.71 ± 2.32	8.78 ± 1.11
	MBT overhead forward (m)	8.25 ± 1.66	6.36 ± 1.21
	MBT forehand (m)	10.17 ± 1.70	7.80 ± 0.85
	MBT back hand (m)	9.47 ± 1.73	7.50 ± 0.85
Service	1st service speed (km/h)	171.51 ± 15.10	151.68 ± 8.79
	1st service spin (rpm)	1409.58 ± 380.06	1415.02 ± 240.74
	1st service impact H (m)	2.61 ± 0.12	2.53 ± 0.09
	1st service impact D (m)	0.03 ± 0.19	0.05 ± 0.19
	2nd service speed (km/h)	131.75 ± 15.63	129.68 ± 4.32
	2nd service spin (rpm)	3514.24 ± 501.49	2200.37 ± 452.99
	2nd service impact H (m)	2.56 ± 0.15	2.54 ± 0.08
	2nd service impact D (m)	-0.18 ± 0.25	-0.11 ± 0.13

PT = peak torque; RJ = rebound jump; MBT = medicine ball throw; H = height; D = depth.
* : Total value of flexion and extention of both knee joints.
** : Total value of flexion and extention of hip joint.

Table 2-1.
The partial correlation coefficient of physique and physical strength versus service performance in male players.

			1st service				2nd service			
	Measured item		Speed (km/h)	Spin (rpm)	Impact H	Impact D	Speed (km/h)	Spin (rpm)	Impact H	Impact D
Physique	Height (cm)	r	0.27	-0.22	0.77	0.02	0.49	-0.19	0.76	-0.10
		p	0.16	0.26	0.00	0.90	0.01	0.32	0.00	0.61
	Mass (kg)	r	0.61	-0.26	0.33	0.23	0.42	0.40	0.30	0.14
		p	0.00	0.18	0.08	0.24	0.02	0.03	0.12	0.48
	Skeletal muscle (kg)	r	0.65	-0.26	0.52	0.21	0.51	0.29	0.50	0.14
		p	0.00	0.18	0.00	0.26	0.00	0.13	0.01	0.48

Table 2-1.
The partial correlation coefficient of physique and physical strength versus service performance in male players (Continuation).

Strength	Grip strength (kg)	r	0.71	-0.41	0.24	0.14	0.43	0.39	0.22	-0.05
		p	0.00	0.03	0.22	0.46	0.02	0.04	0.25	0.78
	Isokinetic PT/Knee at 1.05 rad • s^{-1} (Nm)	r	0.34	-0.17	0.41	0.16	0.19	0.19	0.35	0.16
		p	0.07	0.37	0.03	0.40	0.31	0.32	0.06	0.40
	Isokinetic PT/Knee at 3.14 rad • s^{-1} (Nm)	r	0.36	-0.28	0.38	0.15	0.14	0.25	0.30	0.08
		p	0.06	0.14	0.04	0.43	0.48	0.19	0.11	0.68
	Isokinetic PT/hip at 1.05 rad • s^{-1} (Nm)	r	0.39	-0.12	0.42	0.06	0.21	0.41	0.40	0.04
		p	0.03	0.52	0.02	0.76	0.26	0.03	0.03	0.85
	Isokinetic PT/hip at 2.10 rad • s^{-1} (Nm)	r	0.30	-0.02	0.25	0.18	0.26	0.29	0.26	0.15
		p	0.11	0.92	0.20	0.35	0.18	0.13	0.17	0.44
	Squat Jump (cm)	r	0.29	-0.23	0.16	0.26	0.29	-0.01	0.16	0.17
		p	0.13	0.22	0.42	0.18	0.13	0.96	0.42	0.38
	Vertical Jump (cm)	r	0.32	-0.20	0.03	0.32	0.23	-0.03	0.06	0.21
		p	0.09	0.30	0.89	0.09	0.23	0.89	0.76	0.27
	RJ - index (m/s)	r	0.21	-0.37	0.50	-0.22	0.08	0.06	0.44	-0.37
		p	0.26	0.05	0.01	0.24	0.66	0.76	0.02	0.05
	Broad Jump (cm)	r	0.62	-0.34	0.38	0.11	0.37	0.38	0.31	0.00
		p	0.00	0.07	0.04	0.59	0.05	0.04	0.10	0.98
	5m sprint (m/s)	r	0.24	-0.19	0.11	-0.09	0.10	0.01	0.00	-0.08
		p	0.21	0.33	0.57	0.65	0.59	0.95	0.99	0.69
	20m sprint (m/s)	r	0.41	-0.23	0.23	0.00	0.30	0.08	0.14	0.01
		p	0.03	0.23	0.23	0.99	0.11	0.68	0.48	0.96
	MBT overhead backward (m)	r	0.65	-0.09	0.37	0.29	0.67	0.14	0.42	0.28
		p	0.00	0.65	0.05	0.13	0.00	0.48	0.02	0.14
	MBT overhead forward (m)	r	0.60	-0.06	0.25	0.14	0.52	0.17	0.26	0.16
		p	0.00	0.75	0.20	0.47	0.00	0.38	0.18	0.40
	MBT forehand (m)	r	0.58	-0.23	0.34	0.35	0.56	0.16	0.34	0.23
		p	0.00	0.23	0.07	0.07	0.00	0.41	0.08	0.23
	MBT backhand (m)	r	0.65	-0.30	0.51	0.28	0.65	0.04	0.54	0.23
		p	0.00	0.12	0.01	0.14	0.00	0.84	0.00	0.22

r : partial corelation coefficient; $p<0.05$
PT = peak torque; RJ = rebound jump; MBT = medicine ball throw; H = height; D = depth.

Table 2-2.
The partial correlation coefficient of physique and physical strength versus service performance in female players.

			1st service				2nd service			
	Measured item		Speed (km/h)	Spin (rpm)	Impact H	Impact D	Speed (km/h)	Spin (rpm)	Impact H	Impact D
Physique	Height (cm)	r	0.69	-0.21	0.76	0.74	0.47	0.44	0.75	-0.18
		p	0.08	0.65	0.05	0.06	0.29	0.32	0.05	0.70
	Mass (kg)	r	0.79	-0.02	0.06	0.35	0.19	0.70	-0.12	-0.41
		p	0.03	0.97	0.91	0.44	0.68	0.08	0.80	0.37
	Skeletal muscle (kg)	r	0.88	-0.05	0.31	0.74	0.58	0.50	0.24	-0.39
		p	0.01	0.92	0.50	0.05	0.17	0.25	0.60	0.38

Table 2-2.
The partial correlation coefficient of physique and physical strength versus service performance in female players (Continuation).

Strength	Grip strength (kg)	r	0.41	0.29	0.18	0.26	0.12	0.54	0.10	-0.32
		p	0.36	0.53	0.71	0.57	0.80	0.21	0.83	0.48
	Isokinetic PT/Knee at 1.05 rad・s^{-1} (Nm)	r	0.25	0.80	0.48	-0.08	0.19	0.50	0.36	0.44
		p	0.59	0.03	0.27	0.87	0.69	0.25	0.42	0.33
	Isokinetic PT/Knee at 3.14 rad・s^{-1} (Nm)	r	0.53	0.46	0.43	0.46	0.55	0.34	0.41	0.06
		p	0.22	0.30	0.33	0.30	0.20	0.45	0.36	0.90
	Isokinetic PT/hip at 1.05 rad・s^{-1} (Nm)	r	0.03	0.65	-0.06	-0.48	-0.31	0.56	-0.27	0.15
		p	0.96	0.12	0.91	0.28	0.50	0.19	0.56	0.75
	Isokinetic PT/hip at 2.10 rad・s^{-1} (Nm)	r	0.04	0.54	0.15	-0.41	-0.46	0.77	-0.08	-0.04
		p	0.94	0.21	0.75	0.37	0.30	0.04	0.87	0.93
	Squat Jump (cm)	r	0.00	0.61	0.25	0.16	0.19	0.29	0.16	-0.08
		p	1.00	0.15	0.59	0.73	0.68	0.53	0.74	0.86
	Vertical Jump (cm)	r	0.25	0.64	0.76	0.27	0.46	0.28	0.76	0.44
		p	0.58	0.12	0.05	0.56	0.30	0.55	0.05	0.33
	RJ - index (m/s)	r	-0.24	0.23	-0.57	0.00	0.32	-0.63	-0.45	0.07
		p	0.60	0.62	0.18	1.00	0.49	0.13	0.31	0.88
	Broad Jump (cm)	r	0.36	0.28	0.69	0.58	0.45	0.32	0.72	-0.08
		p	0.42	0.55	0.08	0.18	0.31	0.48	0.07	0.87
	5m sprint (m/s)	r	-0.38	0.39	-0.04	0.11	0.39	-0.59	0.11	0.27
		p	0.40	0.39	0.94	0.82	0.39	0.17	0.82	0.56
	20m sprint (m/s)	r	-0.28	0.51	0.22	0.16	0.29	-0.23	0.31	0.14
		p	0.55	0.24	0.63	0.17	0.53	0.62	0.49	0.76
	MBT overhead backward (m)	r	0.63	-0.28	-0.08	0.22	0.33	-0.01	0.01	0.13
		p	0.13	0.54	0.87	0.64	0.47	0.99	0.99	0.78
	MBT overhead forward (m)	r	0.92	-0.28	0.01	0.50	0.41	0.39	-0.03	-0.28
		p	0.00	0.55	0.98	0.26	0.36	0.39	0.95	0.55
	MBT forehand (m)	r	0.61	-0.03	0.58	0.44	0.08	0.75	0.50	0.36
		p	0.14	0.94	0.17	0.33	0.87	0.05	0.25	0.43
	MBT backhand (m)	r	0.38	0.02	0.63	0.00	-0.20	0.69	0.54	0.08
		p	0.39	0.96	0.13	1.00	0.67	0.08	0.21	0.86

r : partial corelation coefficient; $p<0.05$
PT = peak torque; RJ = rebound jump; MBT = medicine ball throw; H = height; D = depth.

Table 3.
Factor loading in physique PCA and strength PCA

		Factor loading in PCA	
		Male players (30)	Female players (11)
Physique PCA	Height (cm)	.789	.981
	Mass (kg)	.931	.851
	Skeletal muscle (kg)	.960	.858
Strength PCA	Grip strength (kg)	.770	.551
	Isokinetic PT/Knee at 1.05 rad・s^{-1} (Nm)	.844	.773
	Isokinetic PT/Knee at 3.14 rad・s^{-1} (Nm)	.839	.807
	Isokinetic PT/hip at 1.05 rad・s^{-1} (Nm)	.861	.672
	Isokinetic PT/hip at 2.10 rad・s^{-1} (Nm)	.829	.776
	Squat Jump (cm)	.757	.084
	Vertical Jump (cm)	.776	.577
	RJ-index (m/s)	.697	-.485
	Broad Jump (m)	.907	.431
	5m sprint (m/s)	.529	-.498
	20m sprint (m/s)	.787	-.055
	MBT overhead backward (m)	.900	.617
	MBT overhead forward (m)	.775	.757
	MBT forehand (m)	.897	.910
	MBT backhand (m)	.899	.838

PCA: the first principal component analysis score.

We analyzed the correlation of service (speed, spin) with strength PCA and physique PCA as well as service speed with impact height and impact depth. Male players showed a significantly high correlation of service speed with physique PCA and strength PCA (Figure 2), but there was no significant correlation between service spin and either of the PCA scores (Figure 3). A significant correlation was found between service speed and both impact height and depth (Figure 4).

In contrast, female players showed a significant correlation between the 1st service speed and physique PCA, and between the 2nd service spin and physique and strength PCA. As for impact, there was no correlation between service speed and impact height. However, there was a significant correlation between the service speed and impact depth in the 1st service alone.

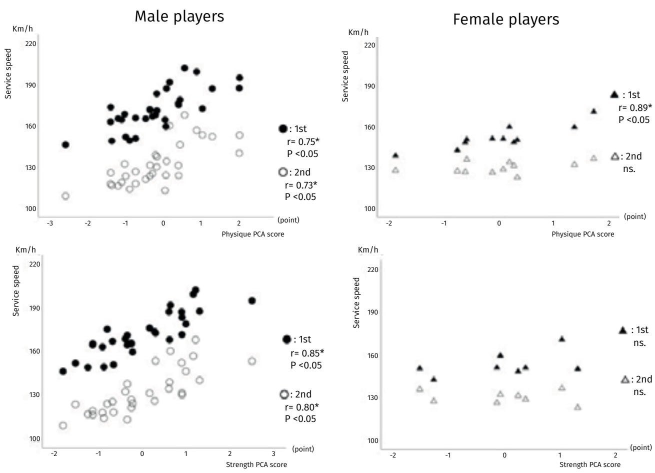

Figure 2. Correlation between service speed and physique PCA (upper row), and between service speed and physical strength PCA (bottom row) in male and female players. PCA: the first principal component analysis score.

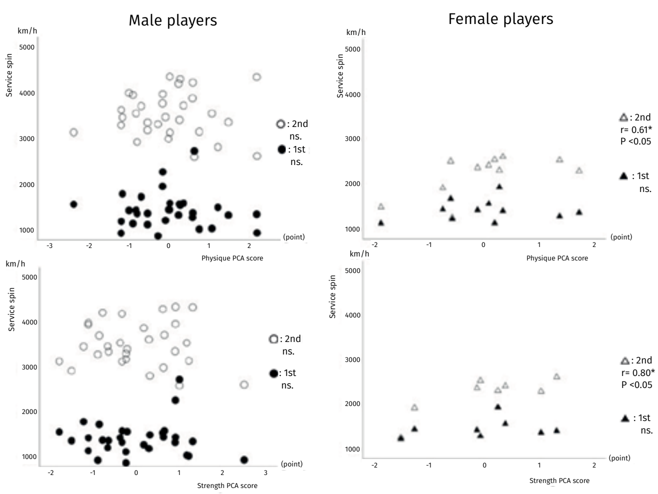

Figure 3. Correlation between service spin and physique PCA (upper row), and between service spin and physical strength PCA (bottom row) in male and female players. PCA: the first principal component analysis score.

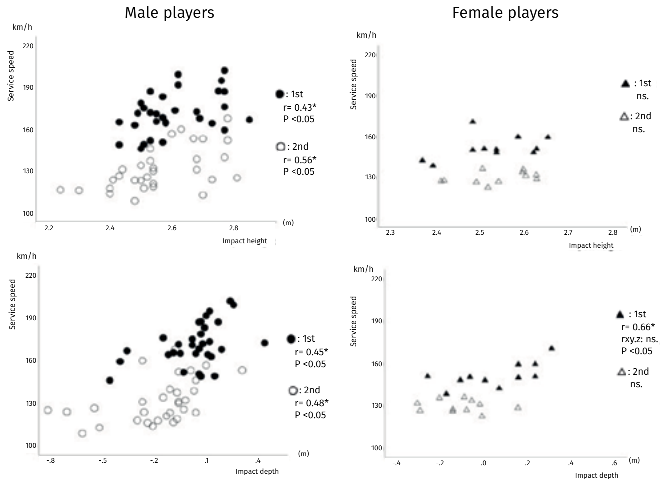

Figure 4. Correlation between service speed and impact height (upper row), and between service speed and impact depth (bottom row) in male and female players.

DISCUSSION

The results of this study support findings from previous studies regarding male players (Kovacs and Ellenbecker, 2011; Ulbricht et al., 2016). Although these studies have reported a relationship between physical strength and service speed, female players could not utilize their physical strength for service speed. It is possible that female players in this study could not emphasize service speed, even if they could hit the service at maximum effort. In other words, their effort may be directed more towards spin, and not speed. The tennis service motion has three distinct phases: preparation, acceleration, and follow-through (Kovacs and Ellenbecker, 2011). The acceleration phase involves physical factors through ball impact, starting with the preparation for power loading. Timing begins in this phase when physical strength is involved in service speed. When the server initiates knee flexion during service for power loading, a natural stretch-shortening cycle and combination of eccentric and concentric contraction of the leg muscles help store elastic energy (Girard et al., 2005). This elastic energy can assist the leg drive (Elliott et al., 2009). Service speed is correlated with a forceful leg drive created by greater muscle forces (Bahamonde, 1997). It is said that this leg drive increases the propulsive force of the ball, which is reflected in the service speed. According to a previous study, the pushing action, which uses a backward-to-forward sequence with higher horizontal forces as seen in elite-level servers, may be of the greatest importance in generating high-speed serves (Girard et al., 2005). In the current study, we did not analyze service motion but collected data regarding impact height and impact depth, which could be indices of service performance. In this study, among male players, there was a significant correlation between service speed and physical strength, as well as between service speed and impact height and impact depth (Figure 2 and 4). These observations suggest that in male players, physical strength is important to take the impact point much higher and more forward to develop service speed. This was consistent with previous reports (Girard et al., 2005). On the other hand, service spin was not correlated with impact height and impact depth. As of July 2020, the average height of the top 50 players in the International Tennis Federation ranking was 188.73 cm, but the average height of the four Japanese players in the top 100 was 176.50 cm (ITF, 2021). Japanese players who are disadvantaged in terms of height should develop service speed without reducing the amount of spin. Considering this, in addition to increasing the impact height, it is also important to take the impact depth forward from the baseline. If they could swing the racket with much greater impact height and depth, it may be possible to hit a service that improves the speed while maintaining the spin. As a technique for improving service speed without reducing the spin rate, it is expected that the service speed could be further increased by directing the leg drive in the vertical and horizontal directions instead of only the vertical direction. Female players did not show a significant correlation between service performance (speed, spin) and physical strength as male players. No correlation was found between the impact height and service speed. However, a significant correlation was observed between the impact depth and the 1st service speed. This result was similar to that of males taking the hitting point forward. Furthermore, another significant correlation was found between the impact depth and physique only at the 1st service speed. These results indicated that female players who were tall and hit the service at high speed could take their impact point inside the court. Since no correlation was found between physical strength and service speed, we inferred that this is due to the effect of service form of hitting or height. Even players with a low physical strength could speed up by taking the impact point forward.

In this study, since the number of female players was limited compared to that of males, the insights related to the characteristics of female participants might be inadequate to draw relevant conclusions. In the future, it is necessary to increase the number of participants and further investigate the differences from male players. Spin rate is important for Japanese players who are disadvantaged in physique. The female players in this study showed a significant correlation between spin rate and physique and physical strength. In contrast, male players showed no such correlation. Thus, a player with enough height could hit an effective service, emphasizing speed without focusing on the spin. It would be important for players with low service impact points to increase their spin rates so that the service goes over the net rather than selecting a flat service that emphasizes speed. However, female players in this study showed lower spin rates in the 2nd service than male players, despite male players being taller. This suggests that female players can improve their spin rates to enhance service performance. Previous studies reported that tall top-tier male players have a wide range of fluctuations in the spin rate of the 1st service (Muramatsu et al., 2010). Variations in spin rate affect speed and trajectory, making it difficult for the receiver to predict the return. Therefore, to achieve effective service performance from a tactical point of view, it would be important not only to increase the speed but also to increase spin rate.

CONCLUSION

The present study found that the relationship between physical strength and service performance in terms of speed or spin rate varied between male and female elite tennis players. Among male players, muscular strength and power should be considered indispensable for improving service speed without decreasing the spin rate, and it is important to set the impact point high and take it forward. Female players should first consider focusing on improving their spin rate and then on service speed in order to find a physical factor. Achieving this would require them to examine how to take service impact points much higher and more forward. In the future, it is necessary to clarify the relationship between physical strength and swing speed of racket, which may be directly related to spin rate and speed. These results suggest a need to consider service coaching that is suitable for the different characteristics of male and female players in the future.

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Analysis of the effectiveness of technical-tactical elements during the serve-receive phase in youth female table tennis athletes

Análisis de la efectividad de los elementos técnico-tácticos durante la fase de servicio-recepción en jóvenes atletas de tenis de mesa

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Abstract

The aim of the current study was to record and compare the technical and tactical elements of the strokes during serve, receive and winning shots between winning and defeated female table tennis athletes, belonging to the cadet leagues and to study their relation with the outcome of the match. The sample for this study was 36 official table tennis matches (2487 rallies) of cadets (14 ± 1.48 years). The technical and tactical analyses was concerned with the type and direction of the serve and receiving the ball, the success rates of the player serving and receiving, as well as the process of winning a point after an offensive shot. In order to record and analyze the matches, the method of video analysis was used and for the statistical treatment of the data the non-parametric X^2 test was implemented. The results revealed that the forehand grip was mainly used for the execution of a serve and the serve of the young female winners was statistically superior to the losers, regarding the score and the rates of successfully receiving the ball. Statistically significant differences were also observed in the first return of the ball after the execution of the serve, where the winners preferred mostly the forehand-push, backhand-topspin and forehand-topspin, making even more winning shots compared to the losers. The findings of the current study could be used by coaches in Cadet Leagues to improve training methods and help them to provide feedback to the athletes during the matches.

Keywords: *serve, receive, winning shots, video analysis.*

Resumen

El objetivo de este estudio fue grabar y comparar los elementos técnicos y tácticos de los golpes en el servicio, la recepción y los golpes ganadores (*winner shots*) entre atletas de tenis de mesa mujeres ganadoras y derrotadas que pertenecen a ligas cadetes, y estudiar su relación con el resultado del partido. La muestra para este estudio fue de 36 partidos oficiales de tenis de mesa (2487 *rallies*) de cadetes (14 ± 1.48 años). Los análisis técnicos y tácticos estaban relacionados con el tipo y dirección del servicio y la recepción, las tasas de éxito de la jugadora al servir y recibir, así como el proceso de ganar un punto luego de un golpe ofensivo. Con el fin de grabar y analizar los partidos, se usó el método de análisis de video y para el tratamiento estadístico de los datos se usó la prueba no paramétrica X^2. Los resultados revelaron que el agarre *forehand* era usado principalmente para la ejecución de un servicio, y el servicio de las mujeres ganadoras jóvenes fue estadísticamente superior al de las perdedoras en cuanto al puntaje y las tasas de recepción exitosa. También se observaron diferencias significativas estadísticamente en la primera devolución de la pelota luego de la ejecución del servicio, cuando las ganadoras prefirieron principalmente el *forehand-push*, el *backhand-topspin* y el *forehand-topspin* lograron más golpes ganadores comparadas con las perdedoras. Los hallazgos del presente estudio pueden ser útiles para los entrenadores en las ligas cadetes para que mejoren sus métodos de entrenamiento y puedan brindar una mejor retroalimentación a las atletas durante los partidos.

Palabras clave: *servicio, recepción, disparo ganador, análisis de video.*

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INTRODUCTION

Table tennis, due to the small dimensions of the court and the high speed of the ball, along with the small size of the racket, requires high level technique quality and accuracy of movements (Fayt et al., 2003).

Match analysis provides coaches and athletes with useful information, which can determine to a considerable extent the result of a match (Wu Xiao, Z., & Escobar, 2007). In racket sports and especially in table tennis, the serve and receiving the ball are the most significant factors affecting the outcome of a match. Learning how to serve requires many hours of practice and is characterized as a special indicator of performance, which is related to technical and tactical parameters (Bahamonde, 2000).

The winning outcome in table tennis matches is related to successful the serve and receiving the ball activities (Djokic, Malagoli-Lanzoni, Katsikadelis & Straub, 2020). Also, the quality of serve activities is an important differentiator between winners and losers in table tennis (Djokic, Malagoli-Lanzoni, Katsikadelis & Straub, 2020). Winning athletes score more points when serving, in comparison with the defeated athletes (Djokic et al., 2017; Djokic, 2002; Katsikadelis et al., 2013) and according to Yu et al. (2015), when an athlete serves and then attacks earns higher rate of points, compared to the case where he/she attacks after receiving the opponent's serve. As it is noticed by Liu et al. (2015) and Tong & Xiao (2015), rallies are also important and the winners are more accurate. Although Malagoli-Lanzoni et al. (2010), reported that the most common stroke during serving is the Forehand, followed by the Topspin, it varies depending on the type of the racket grip, the direction of the ball, the type of spin and length, and the strategy followed is a determinant factor for the outcome of the match (Drianovski & Otcheva, 2002).

Yet, although the technical and tactical characteristics of top level table tennis athletes have been examined in the past, there is a lack of relevant data regarding young table tennis athletes (Mulloy, Glynn, Rusga, Moore, Hartley, Williams & Irvin, 2014). Due to the fact that, the athletes' technique is developed during the early years of training and is essential for their evolution (Malagoli-Lanzoni et al., 2013), the aim of the current study was to record and compare the technical and tactical elements of the strokes during serve, receiving the ball and winning shots between winning and defeated female table tennis athletes belonging to the cadet leagues and to study their relation with the outcome of the match. In general, research on female table tennis athletes is limited, especially for young female athletes. Also, the technique and tactics of young athletes play a very important role in their subsequent development. It was hypothesized that the winners would be superior in all the technical and tactical elements assessed in the current study.

METHODS

Participants

A total of 36 table tennis matches (2487 stages) of cadet Greek female athletes, were recorded and analyzed. These matches were quarter-finals, semi-finals and final games of the official cadet leagues, but also from the pan-Hellenic championship of the season 2016-17. The participants were 24 young female table tennis players (20 right-handed, 4 left-handed, 19 pimple-in rubber, 5 pimple-out BH-rubber, all of them offensive) with an average age of 14 ± 1.48 years, who belonged to the 26 best athletes of the official ranking list of the Hellenic Table Tennis Federation.

Measuring Instruments

All matches were recorded by the researcher with a Nikon Coolpix B500 camera and a professional tripod. The video was recorded at 120fps, with a resolution 640 x 480. The shooting angle was such that the search variables were clearly visible throughout the matches. In order to achieve the reliability of the research, two very experienced table tennis coaches took part in the recording and analysis of the research data. The researcher then watched the videos and registered the analysis data (point-to-point) in the Spss 20 program where the analyzes were performed.

Process

Video recordings started immediately after athletes' warm-up and ended when the final point was won. The observed parameters regarding the serve and the receiving of the ball were categorized as follows: a) female athlete serving: winner - defeated athlete, b) serve grip: forehand (FH), backhand (BH), c) area where serve was executed: backhand-short, middle-short, forehand-short, back-hand-inside/out, middle-inside/out, forehand-inside/out, backhand-long (BH-Long), middle-long, forehand-long, d) result of the point made by the serving athlete: point won-point lost, e) female athlete receiving: winner-defeated athlete, f) outcome of the serve and the receiving of the ball: successful, unsuccessful, g) way of receive: backhand-push, forehand-push, backhand-flick, forehand-flick, backhand-topspin, forehand-topspin, backhand-drive, h) final shot: successful, missed.

Statistical Analysis

For the statistical treatment of the data the non-parametric chi-square (χ) test was used for each categorical dependent variable to identify statistically significant differences between the classifications within each variable. For selected pairs of the categorical dependent variables chi-square (χ) test of independence was also applied to examine statistically significant relationships between them. The level of significance was set as $p < 0.05$.

RESULTS

Regarding the grip used for the execution of the serve, the chi-square (χ) test of independence revealed that both winning and defeated young female athletes executed more serves using the FH in comparison with the BH grip [$\chi_{(1)}$= 0.009 p= 0.926], without significant differences between them (Table 1).

Table 1.
Racket grips for the execution of a serve.

	Forehand grip	Backhand grip
Winning athletes	67.00%	33.00%
Defeated athletes	67.10%	32.90%

Moreover, both winning and defeated young female athletes execute statistically significant more serves in the area of BH-Long [$\chi_{(8)}$= 27.116; p< 0.05], while for both groups, the second choice was the FH-short area (Table 2).

FH-Long	Middle-Long	BH-Long
FH-Inside/Out	Middle-Inside/Out	BH- Inside/Out
FH-Short	Middle-Short	BH-Short

Figure 1. Service areas.
Source: Luini, Fuchs, Djokic, Malagoli-Lanzoni & Munivrana (2021)

As far as the final outcome of the match in relation to the point earned or the point lost after serving is concerned, there was found a statistically significant difference between winning and defeated female athletes [$\chi_{(1)}$= 84.819; p< 0.05]. The winning athletes earned points on two of the three serves they had executed, while, on the contrary, the defeated athletes won less than half of the executed serves (Table 3).

Concerning the first return of the ball after the execution of a serve, it was observed that winning athletes showed statistically significant higher rates of successfull return of the ball [$\chi_{(1)}$ =27.179;p< 0.05], compared to the defeated athletes (Table 4).

Statistically significant differences [$\chi_{(6)}$ = 69.281; for p< 0.05] were also found between winning and defeated female athletes concerning the first return of the ball after the execution of the serve, where both showed greater percentages of the BH-Push, but the winners showed in addition greater values for the FH-push, the BH-Topspin and the FH-Topspin. (Table 5).

Concerning the final ball, the winners showed statistically significant [$\chi_{(1)}$=57,098 p<.05] more successful shots compared to the defeated young female players (Table 6).

DISCUSSION

The results of the present study are very important and rare as most research in performance analysis has to do with top-level male athletes. The findings of the current study revealed significant differences between the winning and defeated female athletes in almost all variables under consideration. The only exception was the grip used for the execution of the serve, where both showed similar rates for the FH grip, which were significantly greater in comparison with the use of the BH grip. Similar with the present research are the findings of Malagoli- Lanzoni, Lobietti & Mermi (2010) according to which the most common service is with FH grip. The same result was found in a study of young male athletes. (Nikolakakis, Mavridis, Gourgoulis & Pilianidis, 2020). Especially in the reception and in the acquisition of a point by service the results were almost the same. In the service grip, the majority of young boys again chose the FH grip but with higher percentages compared to the young girls. egarding the receipt of the ball there is a similarity in the BH-PUSH and FH-Push movements, while differences are spotted in the BH-Flick and FH-Flick movements, where the young female athletes do not perform them so often. Regarding the area where a serve is executed, it was found that not only the winners, but also the defeated young female athletes prefer mainly the BH-Long area. However, as far as their second choice is concerned, despite the fact that both prefer the FH-Short area, the rates observed in this particular area were higher for the winners. Moreover, the winners chose to serve less in the BH-Short and FH-Long spot, compared to the defeated young female athletes. Findings of a similar research on young athletes show that services in the areas near to the net specially in the places Middle and FH shorts belong to the first choices of athletes (Mulloy et al., 2014). From a survey of Luini, Fuchs, Djokic, Malagoli-Lanzoni & Munivrana (2021) in female elite European table tennis players, various results arise in the execution of the service. The elite European athletes perform services mainly in the Middle-Short area while the Greek athletes choose the BH-Long area. However, similarities were observed in the reception as the FH-Push and BH-Push movements are the most common choice of both European elite girls and Greek female table tennis players.

Table 2.
Area where a serve is executed by the winning and defeated female athletes.

Area where a serve is executed	BH-Short	Middle-Short	FH-Short	BH-Inside/Out	Middle-Inside/Out	FH-Inside/Out	BH-Long	Middle-Long	FH-Long
Winning Athletes	8.70%*	7.40%*	23.60%*	2.70%	1.90%	8.60%	36.10%	3.80%	7.30%
Defeated Athletes	12.40%*	5.60%*	18.40%*	4.00%	2.80%	8.80%	35.00%	3.60%	9.30%

Table 3.
Relationship of the point earned or lost when executing a serve with the final outcome of the match.

Point earned when serving	Point Won	Point Lost
Winning athletes	66%*	34%*
Defeated athletes	47.7%*	52.3%*

Table 4.
Relationship between the success of the first return of the ball, after the execution of a serve receive, with the final outcome of the match.

Receive of a serve	Successful Return	Failure to Return
Winning athletes	82%*	18%*
Defeated athletes	73.2%*	26.8%*

Table 5.
Relationship of the way a serve is received among winning and defeated

Way of receiving a serve	BH-Push FH-Push	BH-Flick	FH-Flick	BH-Topspin	FH-Topspin	BH-Drive
Winning athletes	37,90% 30,60%*	1,10%	2,10%	8,00%*	16,90%*	11,60%*
Defeated athletes	36,20% 24,00%*	1,30%	2,00%	1,70%*	10,00%*	16,30%*

female athletes.

Table 6.
Relationship between the success of the final ball and the final outcome of the match.

Final shot	Successful	Missed
Winning athletes	64,2%*	46,8%*
Defeated athletes	35,8%*	53,2%*

Due to the fact that serving and receiving the ball offer a considerable advantage that could lead to win, the winning table tennis athletes become more effective when serving, in relation to the defeated athletes. The current findings highlight that the winners earned more points when serving themselves, in comparison with the defeated athletes. The results of the research of Yu et al. (2015) were similar, who claimed that the winners gain an advantage when they serve as they earn a point directly from the service or gain an advantage in the third ball. Concerning the rates of success in receiving the ball it showed that winning athletes successfully received the ball more frequently, contrary to the defeated athletes, who made more errors. All the aforementioned results are in line with a relevant survey conducted by Djokic et al. (2017), who claimed that winning athletes obtain an advantage when serving by immediately winning points or winning an advantage in the third ball. Consequently, this means that winning athletes present The quality of receiving the ball also plays when executing a serve or receiving. As Ma et al. (2015) stated, the first three strokes of a game are considered as an important factor that could directly affect the outcome of the game.

The quality of the receives execution also plays a major role in the outcome of the match. Regarding the receipt of the ball and more specifically the strokes used to receive it, it was found that winning young female athletes use technically more complex and offensive strokes, compared to defeated athletes, a fact that offers them an advantage in the acquisition of the point. Both winning and defeated female athletes used the Backhand-push as their first choice, followed by the Forehand-push. There are statistically significant differences in Backhand-topspin and Forehand-top-spin, which are mainly executed by winning athletes. Coaches and athletes should therefore, integrate to a greater extend the elements of serve and receive in their training, in order to achieve an effective improvement of their technique, as well as optimized outcomes during games.

Concerning the final hits, statistically significant differences were found between winners and defeated female table tennis players. The winners executed more successful winning shots compared to the defeated players, and consequently earned more points. It was impressive that slightly over half of the winning shots executed by the defeated athletes were missed, pointing out the low level of these athletes. Apart from the hits that lead to win a direct point, avoiding errors is also or more important (Wenninger & Lames, 2015).

Although the aforementioned findings could help table tennis players and coaches to increase the efficiency of their serves and receives, they were restricted to cadet leagues and should be generalized with caution. Future studies could examine in detail the technical and tactical features in other categories and apart from serve, receive and winning shots, could also focus on other parameters, for instance leg movements. A detailed study of the technical and tactical parameters could provide valuable information to table tennis coaches to improve their athletes' performance and to develop a stable background especially for the young table tennis players.

CONCLUSION

The current study showed that both the winners and the defeated female athletes used mainly the forehand grip for serving, and their first choice for the area where the serve was executed was the same, corresponding to the BH-Long area. However, their second and third choices were different. Moreover, winning female athletes earned more points immediately after their own serve and they win also more points directly from their serve (ace). Last but not least, crucial differences were observed regarding the receiving of an opponent's serve and the wining shots. Winning female athletes performed receives with better-quality and more successfully, making fewer errors compared to defeated athletes.

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Early talent identification in tennis: A retrospective study

Identificación temprana de talento en tenis: un estudio retrospectivo

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Abstract

Talent identification often begins at the age of entry into a sport: even under the age of 9 years old (U9). However, the success of such early talent identification is questionable. Therefore, the aim of this long-term retrospective study is to examine whether today's more successful junior tennis players already differed from today's less successful junior tennis players in terms of physical fitness and motor competence when both groups were U9. If significant differences in performance characteristics between successful and less successful tennis players were already apparent at this young age, such characteristics could be used to forecast talent at an early stage. Based on their current tennis success, a total of 174 junior tennis players were divided into national *ranked players* (n = 16: players who achieved a place in the official national junior tennis ranking list of the German Tennis Federation) and *non-ranked players* (n = 158). All of these players had already participated in two anthropometric and nine physical fitness and motor competence tests at U9 (e.g., sprint, endurance run, ball throw). Using a MANCOVA and a correlation analysis, we retrospectively examined whether the two current performance groups had differed significantly in their U9 test scores and whether these athletes' U9 test performance scores correlated with their current playing success. No significant ($p < 0.05$) differences were found between ranked and non ranked junior players in terms of U9 body weight and height. However, with the exception of flexibility, all physical fitness tests and motor competence tests showed significant results. The ball throw was the most relevant test parameter, as it showed the highest prognostic validity (effect size $\eta^2 = .157$ and $r = .360$). This test was followed by the two test tasks standing long jump (effect size $\eta^2 = .081$ and $r = .287$) and endurance run (effect size $\eta^2 = .065$ and $r = .296$). Overall, the U9 findings are in line with the results from other studies of U12–U18 tennis players. Therefore, it can be assumed that talent specific characteristics remain stable over a certain period of time and that U9 test performances may provide an early indication of later playing success.

Keywords: *talent, tennis, performance testing, prognosis, success.*

Resumen

La identificación de talentos a menudo suele comenzar desde la edad de entrada al deporte, es decir, incluso por debajo de los 9 años (U9). Sin embargo, el éxito de dicha identificación de talento temprana es cuestionable. Por lo tanto, el objetivo de este estudio retrospectivo a largo plazo es analizar si los jugadores juveniles de tenis más exitosos hoy en día ya eran diferentes de los jugadores juveniles de tenis menos exitosos hoy en día en términos de aptitud física y competencia motora cuando los dos grupos eran U9. Si a esta temprana edad ya eran notables diferencias significativas en las características de desempeño entre los jugadores de tenis exitosos y menos exitosos, dichas características podrían usarse para predecir el talento desde una etapa temprana. Basados en su actual éxito en el tenis, un total de 174 jugadores juveniles de tenis fueron divididos en jugadores de clasificación nacional (n= 16: jugadores que obtuvieron un lugar en la lista oficial de clasificación nacional juvenil de tenis de la Federación Alemana de Tenis) y jugadores por fuera de la clasificación (n=158). Todos estos jugadores ya habían participado en dos pruebas antropométricas y nueve de aptitud física y competencia motora en U9 (ej. sprint, carrera de resistencia, lanzamiento de balón). Usando un análisis de correlación y el MANCOVA, analizamos retrospectivamente si los dos grupos de desempeño actual diferían

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significativamente de los puntajes en sus pruebas en U9, y si esos puntajes de las pruebas de rendimiento en U9 de estos atletas se correlacionaban con su éxito de juego actual. No se encontraron diferencias significativas ($p < 0{,}05$) entre los jugadores juveniles dentro la clasificación y por fuera de ella en términos de peso y altura en U9. Sin embargo, exceptuando la flexibilidad, todas las pruebas de aptitud física y competencia motora presentaron resultados significativos. El lanzamiento de balón fue la prueba más relevante ya que demostró la mayor validez pronóstica (tamaño del efecto $\eta 2 = .157$ y $r = .360$). A esta prueba le siguieron dos actividades de prueba, salto de longitud de pie (tamaño del efecto $\eta 2 = .081$ y $r = .287$) y carrera de resistencia (tamaño del efecto $\eta 2 = .065$ y $r = .296$). En general, los resultados en U9 están en línea con los resultados de otros estudios de jugadores de tenis en U12-U18. Por lo tanto, puede asumirse que las características de talento específicas permanecen estables durante cierto periodo de tiempo y que el desempeño en las pruebas en U9 puede ser un indicador temprano de futuro éxito en el juego.

Palabras clave: *talento, tenis, prueba de desempeño, pronóstico, éxito.*

INTRODUCTION

With over 1.2 billion fans and more than 80 million players, tennis is one of the most popular sports in the world (International Tennis Federation, 2021). Tennis is also a highly complex sport that requires not only general endurance but also speed, agility, upper body power, and coordination (Filipcic & Filipcic, 2005; Kramer et al., 2017; Robertson et al., 2018). Apart from professional tennis players needing these performance prerequisites to defend their top positions in the world (Reid & Schneiker, 2008), it is also necessary to understand which performance characteristics are already relevant for tennis players at an early age. This may not only contribute to a successful future tennis performance (Till & Baker, 2020); it may also orientate a *best mover* to this particular sport according to the particular strengths of his or her individual performance profile. Importantly, the better the individual talent characteristics match the (future tennis) demands, the higher the chances that the beginners will achieve success and satisfaction in this complex sport. This assumption is underlined by Suppiah et al. (2015), who state that a wrong choice can never be compensated for by training. Engaging in an unsuitable sport might not only be detrimental to fun but also lead to drop outs ahead of time. Conversely, if children like a recommended sport, the talented athletes could transform their physical, physiological, and psychological gifts through a long term process of diligent learning, deliberate practice, and an extended amount of high quality training into optimal achievements (Davids & Baker, 2007; Pion, 2015).

With the help of physical fitness and motor competence tests, young athletes are analyzed and their future potential is assessed (Kramer, Huijgen, Lyons, et al., 2016; Ulbricht et al., 2015). These so called sports orientation and talent identification (TID) campaigns have become increasingly common in recent years (Johnston et al., 2018). This is also due to national sports organizations investing more and more effort into the systematic identification of talented young players. In a professionalized competitive environment, a relaxed approach no longer appears acceptable (De Bosscher et al., 2008), and talent identification could become the key to national elite sport performance. Therefore, TID is designed to identify promising young athletes at an early stage (Hohmann & Seidel, 2003; Pion, 2015). Thus, the testing and scouting of athletes begin as soon as they enter a sport. On average, the general sport entry age of professional athletes is about 9 years (8.5 ± 2.5 years: Güllich & Emrich, 2014; 9.1 ± 3.7 years: Vaeyens et al., 2009). In this context, tennis and other racket sports are known to have an early starting age (5–8 years) (Faber et al., 2016). Studies by Li et al. (2020) have shown that 75% of all Top 300 tennis players began playing tennis between 3 and 7 years of age, and only 4% of the Top 300 tennis players started after the age of 10. This might be related to the fact that, firstly, the former group of athletes had more time to freely gain competitive experience, and secondly – particularly before puberty – there are sensitive learning phases that promote motor learning and thus offer the opportunity for the acquisition of technical skills (Knudsen, 2004). In addition, a tennis education starting at a young age gives the coaches a longer observation period; this reduces *talent selection* errors during early adolescence and enhances practitioners' talent identification decisions. Accordingly, it is not surprising that the evaluation of young athletes begins when they are under nine years (U9) of age (Potočnik et al., 2020; Tomkinson et al., 2017). However, because in many cases these young athletes have only little technical experience so far, these TIDs often consist of several generic test items rather than specific, more technically demanding skill tests (Hohmann et al., 2018; Niessner et al., 2020). This approach is supported by studies by Faber et al. (2020), who found a small but significant correlation between more sport specific, coordinative technical skills (e.g., speed while dribbling or aiming at a target) and previous training hours in racket players aged between 8 to 10 years old. In contrast, generic tests such as sprinting or standing long jump had no significant relationship with training volume.

While there are already some studies on the success of TID in other sports, such as soccer (see Sarmento et al., 2018), in tennis it is still questionable whether TID campaigns in the U9 age group (Hohmann et al., 2018; Pion, 2015) can provide any information whatsoever about later tennis performance. Although there are many studies on TID in junior tennis (U12–U18) and in professional tennis (Baiget et al., 2016; Van Den Berg et al., 2006), there are either no studies or hardly any on younger age groups (e.g., U9). This might be related to the fact that for this young age group, which lacks a developed tournament and ranking system, no proper differentiation of better and weaker performance groups can be established (Siener & Hohmann, 2019). The assessment of different tennis performance groups usually arises with the entrance into the junior ranking system of the U12 and is then often determined by the ranking position (Ulbricht et al., 2016). For this reason, it has been common practice to use as a template for TID in youth professional adult tennis players' profiles, collected from cross sectional studies (Hohmann & Seidel, 2003). This assumes that the same invariant skills are crucial for tennis success in both age groups. However, this has not yet been adequately demonstrated by long term studies (Baker et al., 2020). Therefore, for a prognostically valid evaluation of U9 test performances, either a prospective study design must be employed or these test performances must be considered retrospectively (see also Mostaert et al., 2020; Till et al., 2015). Either way, both approaches are highly time consuming and only possible in a longitudinal study.

The present study starts at the earliest possible point in time at which a distinction between different performance groups in tennis can be made. From U12, tennis players are able to qualify for the national junior tennis rankings of the German Tennis Federation and thus stand out from other athletes. These junior tennis rankings cover the age range up to U18 (Deutscher Tennis Bund [DTB], 2020). Within the group of junior tennis players, two performance groups – junior ranked players (RPs) and non ranked players (NPs) – can be distinguished. Based on these two performance groups, it is possible to retrospectively analyze the performance shown in the physical fitness and motor competence tests of the U9. Thus, the aim of this long-term retrospective study was to compare the initial U9 physical fitness and motor competence test performances of today's junior ranked and non–ranked tennis players from the national tennis ranking list of the German Tennis Federation (U12–U18) and, based on this, to address whether TID in U9 seems at all possible. Overall, this study makes the first attempt to close the gap in research on TID at U9 and to investigate the validity of talent prediction by physical fitness testing at this young age. If it transpires that at this young age, there are already significant differences in performance characteristics between later successful and less successful tennis players, these characteristics can be used to make a talent forecast for players when they are only 8 years old.

MATERIALS AND METHODOLOGY

General study design

In this retrospective (long-term) study, we examined whether there is a relationship between the playing success achieved by junior tennis players (U12–U18) and this cohort's general childhood performance (U9). For this purpose, 174 junior tennis players were divided into two groups based on their current playing success: (A) 16 players who have achieved a position in the official national tennis ranking lists of the German Tennis Federation (RPs); and (B) 158 players who have not achieved a position on the rankings (NPs).

All these players (A+B) had already been tested in the U9 category in two anthropometric tests, six physical fitness tests, and three motor competence tests (Fig. 1). This now allows us to analyze whether the two performance groups had already showed differences in their performance characteristics at the age of 8 and, if so, in which generic tests the differences were particularly evident. The results can then indicate whether certain characteristics/predictors detectable as early as U9 may point to later success at junior age and thus make TID worthwhile at this earlier stage.

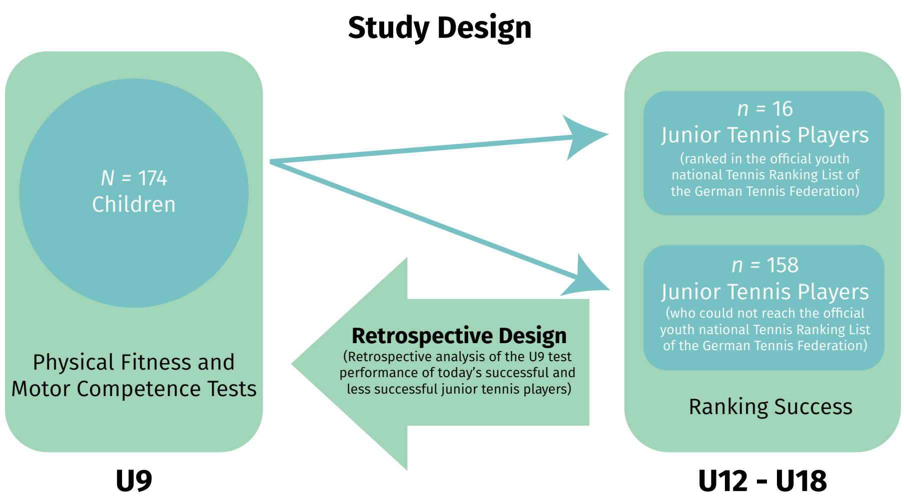

Figure 1. Study Overview

Participants

A total of 174 junior tennis players (U12–U18; *M* = 156.3 months, *Min* = 132 months, *Max* = 206 months) were included in this study. The sample consists of 62 girls (♀) and 112 boys (♂). Among these junior tennis players, 16 RPs (n♂ = 11, n♀ = 5) achieved a place in the official national junior tennis ranking list of the German Tennis Federation (DTB, 2020). To be included in this junior ranking, a player must have at least 10 wins in junior ranking matches or have already earned a position in the adult rankings. All other junior tennis players (NPs; n = 158, n♂ = 101, n♀ = 57) were registered in clubs and actively participated in regional and local club competitions and tournaments but did not achieve the necessary number of wins in official ranking matches to earn a place on the official national junior ranking list of the German Tennis Federation.

As part of the study, all participants and their parents were fully informed about the content of the testing and the resulting studies, and their consent was obtained before the study began. The study and research design were in line with the Declaration of Helsinki and was approved by the ethics committee of the Municipality of Fulda (Germany), as well as the State Office of School Education of Fulda (Germany).

Measurements

Physical Fitness and Motor Competence Tests of U9 Testing

All junior tennis players were already tested at U9 with a test battery of two anthropometric (body weight and height) tests; six physical fitness tests (sprint, flexibility, arm and upper body strength, leg power, and endurance performance); and three mixed motor competence tests (coordination, balance, and ball throw performance). Each of the standardized tests was performed according to existing test protocols, which include a detailed description of the test items, the exact test set up, the demonstration of the test item, the execution of the test phases, and the measurements (Bös et al., 2009; Siener et al., 2021):

20-m Sprint

The sprint performance was recorded using a 20-m sprint (~21.9 yards). In each of the two possible attempts, the test persons started 0.3 m before the starting line. The time was stopped by means of light gates (Brower Timing Systems; Draper, USA). The test met an objectivity value of .86 and a reliability value of .96 (Bös et al., 2009).

Sideward Jumping

The number of two-legged jumps that a participant could perform between two 50-cm x 50-cm (1 cm ≈ 0.4 inches) squares within 15 s was measured. Only jumps where none of the boundary lines was touched counted. In total, two attempts were made, with a break of at least 2 min. between each attempt. The mean value of both tests was used for further calculations. The objectivity of this test is .99 and the reliability is .89 (Bös et al., 2009).

Balancing Backwards

The participants balanced backwards on a 6-cm, 4.5-cm, and 3-cm wide wooden beam. Two attempts were made on each beam, and the number of steps (feet fully raised) before leaving the beam was counted. A maximum of eight steps/points could be achieved per beam, so that the total maximum number of points for this test task is limited to 48. The test achieved an objectivity of .99 and a reliability of .73 (Bös et al., 2009).

Standing Forward Bend

In this flexibility test, the participants have to try to reach as low as possible with their hands. The ground height is evaluated as 0 cm, and everything that goes beyond that (below ground level) is entered as a positive value. The achieved value had to be held for at least 3 sec. in each of the two attempts. The test achieved an objectivity of .99 and a reliability of .94 (Bös et al., 2009).

Push-Ups

In this test, the participants had to perform as many push-ups as possible over 40 sec. An execution was only evaluated if the technique was correct and the test person subsequently lay back down in the starting position. Only one attempt was performed. Bös et al. (2009) rated the objectivity with .98 and the reliability with .69.

Sit-Ups

The sit-up test also evaluated the number of correctly performed sit-ups in 40 sec. Only one attempt was performed. The objectivity of this test was .92 and the reliability was .74 (Klein et al., 2012).

Standing Long Jump

In the standing long jump test, the jumping distance was measured in centimeters. Each test person had two attempts, of which the better attempt was recorded. Between both attempts, a complete break was ensured. The test achieved an objectivity of .99 and a reliability of .89 (Bös et al., 2009).

Ball Throw

In the ball throw test, the throw distance was measured in centimeters orthogonal to the line of release. The test persons threw with an 80-gm ball from a standing position three times in a row. As in the previous tests, the best value was evaluated. The test could be evaluated in our own studies (n = 1800) with a reliability of .77.

6 min Endurance Run

In the endurance test, the participants tried to run as many laps as possible around a 9-m x18-m volleyball field in 6 min. The achieved distance was noted in meters. The test was carried out by a total of 15 people at the same time. The objectivity of this test is .87 and the reliability is .92 (Bös et al., 2009).

All tests were conducted by qualified personnel during regular school hours (8–12 am), and a uniform warm-up was held before starting. The 6-min endurance run was always the last test in the test series.

STATISTICAL ANALYSES

For all analyses, the software SPSS (version 26; SPSS Inc, Chicago, IL, USA) was used.

A univariate ANOVA found that age affects the data and that the performance of U9 players increased significantly with age. In order to avoid this age bias, bivariate regressions to age in months were used to z standardize the test value residuals separately for both genders (Siener et al., 2021). Since this procedure poses the risk that in homogeneous groups certain test values are distorted by the group composition, the results of about 4000 children predominantly not from sporting clubs (see Hohmann et al., 2018; Tomkinson et al., 2017) were additionally used for z standardization. Thus, all data are available as age and gender independent z values. To ensure a better comparison of the sprint data, the z values were additionally multiplied by "–1", thus turning the better sprint results into positive z values.

T-Tests and a MANCOVA were used to check whether the test results differed significantly between the gender and tennis success groups. A covariate weight was chosen. Effect sizes for *partial eta squared* (η^2) smaller than 0.01 are interpreted as trivial, effect sizes between 0.01 and 0.059 are small, between 0.06 and 0.139 are moderate, and values higher than 0.14 are large.

To gain a better insight into the influence of the individual test items on later tennis success, *bivariate correlations* were also calculated. The Spearman correlations were classified according to the following pattern: trivial (0 – 0.1), small (0.1 – 0.3), moderate (0.3 – 0.5), and large (0.5 – 0.7).

RESULTS

The initial U9 test results of the junior tennis players show that in almost all test tasks, RPs perform significantly better than NPs (Table 1). Particularly noteworthy here are the standing long jump, the sideward jumping, the balancing, the endurance run, and the ball throw, which all have values of $p < 0.001$ (t-Tests). In sideward jumping, the maximum value of the RPs was five jumps (12.5%) higher than the maximum value of the NPs. In the ball throw and the standing long jump, the later better athletes had a clear advantage in their youth. In both tests, approximately 84% of the NPs did not reach the average test result of RPs. In the sideward jumping, the balancing, and the endurance run, 84% of the RPs were also above the average result of the weaker performance group. For the forward bend test task (p = 0.158) and body weight (p = 0.910), no significant differences in the two performance groups could be found. In addition, the later ranked players are on average 4 months older than their weaker tennis colleagues ($p < 0.01$).

In examining the raw scores of the two performance groups separately by gender, it is notable that no significant group difference can be found for boys ($n_{♂}$ = 112) in the test scores for body weight (p = 0.149), height (p = 0.8), sprint (p = 0.106), push-ups (p = 0.065), and forward bends (p = 0.111). All other test results showed significant group differences ($p < 0.01$). *Girls* ($n_{♀}$ = 62) showed comparable results. Only the test results for body height (p = 0.044) and sprint (p = 0.013) were also significant in contrast to the results for boys.

Also, after eliminating the age effect, RPs achieved better z-values than the NPs in all test items (Fig. 2). Except for the 20-m sprint, however, the ascending order of the single tests was almost identical in both groups. Also, in regard to the order of the RPs' tests, the ball throw (M_z = 2.03) was in first place, followed by the standing long jump (M_z = 1.53), the endurance run (M_z = 1.42), and sideward jumping (M_z = 1.41). For the ball throw, female tennis players (M_z = 2.95, n = 5) performed significantly better ($p < 0.05$) than their male counterparts (M_z = 1.61, n = 11). The same holds true for body height ($M_{z♀}$ = 0.92, $M_{z♂}$ = 0.07) and the standing long jump ($M_{z♀}$ =1.88, $z_{♂}$ = 1.37). The anthropometric measures of the RPs were M_z = 0.34 (body height) and M_z = −0.30 (body mass). RPs at U9 were, therefore, on average slightly taller and lighter than the NPs. However, while in a t-test comparison, significant differences between the two performance groups can be found in almost all generic test items (with the exception of $p_{\text{Forward bends}}$ = 0.086), there are no significant differences in the anthropometric test values of body mass (p = 0.078) and height (p = 0.234).

Table 1.
– *Descriptive statistics for the former U9 test results of the junior tennis players.*

	Groups	N	M	SD	95% CL		Min	Max	*p*
					LL	UL			
Calendar age (months)	NPs	158	93.8	5.0	93.0	94.6	83	110	0.007
	RPs	16	97.5	6.4	94.1	100.9	88	112	
				Test results					
Body height (cm)	NPs	158	129.1	5.7	128.2	130.0	117	145	0.034
	RPs	16	132.3	4.5	129.8	134.7	127	143	
Body mass (kg)	NPs	158	27.2	4.1	26.6	27.9	20.0	39.3	0.910
	RPs	16	27.3	1.9	26.3	28.3	23.4	30.6	
Sideward jumping (repeats)	NPs	157	27.3	6.1	26.3	28.2	6.5	40.5	0.001
	RPs	16	33.0	5.1	30.3	35.7	27.0	45.0	
Balance backward (steps)	NPs	158	30.3	8.5	28.9	31.6	8	48	0.001
	RPs	16	38.3	5.7	35.2	41.3	28	48	
Standing long jump (cm)	NPs	157	135.1	16.2	132.5	137.6	82	190	0.001
	RPs	16	153.0	17.2	143.8	162.2	125	178	
20 m sprint (s)	NPs	158	4.45	0.36	4.39	4.51	3.10	5.32	0.011
	RPs	16	4.21	0.34	4.03	4.39	3.50	4.72	
Push ups (repeats)	NPs	158	14.6	3.6	14.0	15.1	4	24	0.041
	RPs	16	17.1	5.2	14.3	19.9	9	25	
Sit ups (repeats)	NPs	158	19.2	5.1	18.4	20.0	2	30	0.002
	RPs	16	23.4	4.1	21.3	25.6	15	29	
Forward bends (cm)	NPs	158	1.98	5.94	1.05	2.92	-11	18	0.158
	RPs	16	4.16	4.90	1.55	6.77	-10	12	
6 min run (m)	NPs	154	959	130.8	938	979	545	1259	0.001
	RPs	16	1078	80.7	1035	1121	891	1200	
Ball throw (m)	NPs	155	13.5	4.03	12.9	14.2	3.8	27.6	0.002
	RPs	16	18.8	5.35	15.9	21.6	9.2	28.3	

M = mean; SD = standard deviation; SE = standard error; CL = confidence limit; LL = lower limit; UL = upper limit; Min = minimum; Max = maximum; NPs = non-ranked players; RPs = ranked players; p = *p*-value of the *t*-test

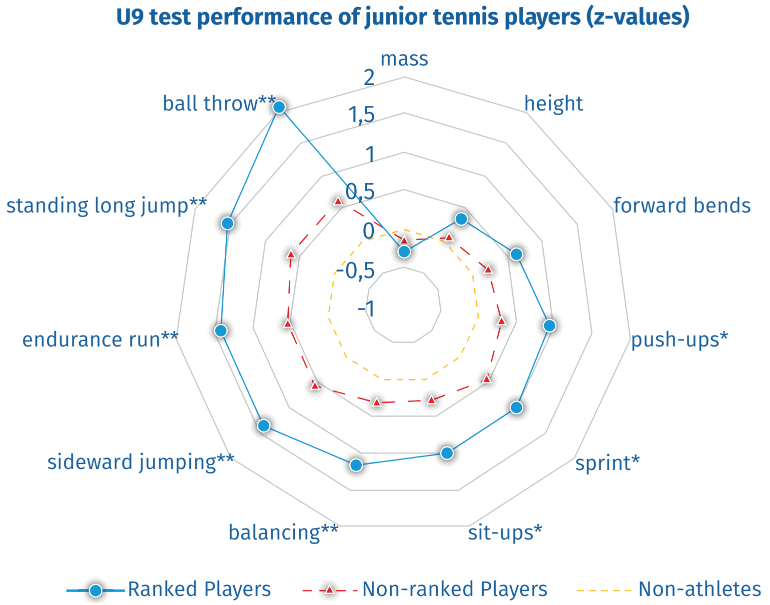

Figure 2. Initial U9 test performances (z-values) of junior ranked tennis players, non- ranked tennis players, and non-athletes (* p ≤ 0.05; ** p ≤ 0.01).

The MANCOVA (Table 2) shows that body mass only had a significant ($p < 0.05$) influence on the test values of balancing, sit ups, and the endurance run. Gender only had a significant influence on the ball throw in the analyses ($p_{Gender} = .012$; $p_{Performance*Gender} = .056$). All other hypotheses concerning a difference between the genders had to be rejected. As already suspected in *Fig. 2*, a *partial Eta squared* of $\eta^2 = .157$ shows the strongest effect size of group differences in the ball throw. The standing long jump, the endurance run, and sideways jumping show moderate effect sizes, while all other effects are small. It is notable that the standard deviation (SD) for the RPs fluctuates strongly. For the NPs, on the other hand, the SD of almost 1, which is usual for z values, is achieved.

Looking at the box plots of RPs and NPs for the different test tasks (*Fig. 3*), it is notable that the RPs have the biggest advantage, especially in the ball throw. Nevertheless, not all of the 16 RPs can show very high values. There is also one athlete with a *z*-value of $z = -1.2$ and three athletes with z values below $z = 1.0$ (range of 6.06). All other RPs show above-average throwing performances. Such large fluctuations in performance cannot be seen in test items the endurance run (range of 2.3) and balancing (range of 2.16). Here the results are comparatively close to each other, and none of the RP values is below a *z*-value of $z = 0$. Also, in body mass, no major fluctuations can be detected in the RPs (range of 1.15). The results show that in the ranked player group 75% (12/16) of the tennis players at the age of 8 yrs achieved a very good test result ($z \geq 1.0$) in the standing long jump, the endurance run, and the ball throw. In addition to the three tests mentioned, more than 50% of the ranked junior tennis players were initially (when U9) able to achieve a very good test score in the sideward jumping (68.8%) and sit ups (56.3%).

Table 2.
– *Results of the MANCOVA for the different former U9 test disciplines*

	NPs (Mean ± SD)	RPs (Mean ± SD)	F	Sig.	Partial Eta Squared (η2)
Ball Throw	0.639 ± 0.999	2.033 ± 1.553	29.943	.0001	.157
Standing Long Jump	0.634 ± 0.874	1.532 ± 0.906	14.175	.0001	.081
Sideward Jumping	0.558 ± 0.949	1.407 ± 0.773	11.401	.001	.066
Endurance Run	0.537 ± 0.975	1.423 ± 0.564	11.239	.001	.065
Sit-Ups	0.281 ± 0.908	1.010 ± 0.710	9.697	.002	.057
Balancing	0.300 ± 0.938	1.157 ± 0.605	9.542	.002	.056
Sprint	0.440 ± 0.912	0.987 ± 0.851	5.468	.021	.033
Push-Ups	0.288 ± 0.927	0.924 ± 1.360	5.090	.025	.031
Forward Bends	0.198 ± 0.952	0.634 ± 0.564	2.548	.112	.016

SD = standard deviation; NPs = junior non ranked tennis players; RPs = junior ranked tennis players; Effect sizes (η2): 0.01 ≤ small, 0.06 ≤ medium, 0.14 ≤ strong

Apart from the forward bends, no significant results can be seen for the correlations of tennis ranking success with body height or body mass (Table 3). All other test values achieved significant correlations, mostly in the moderate range.

The ball throw reaches the highest correlation value with r = .360, followed by the standing long jump (*r* = .287), and the endurance run (*r* = .296). However, these two values cannot be considered a moderate result. Also, all other test values have small correlation effects.

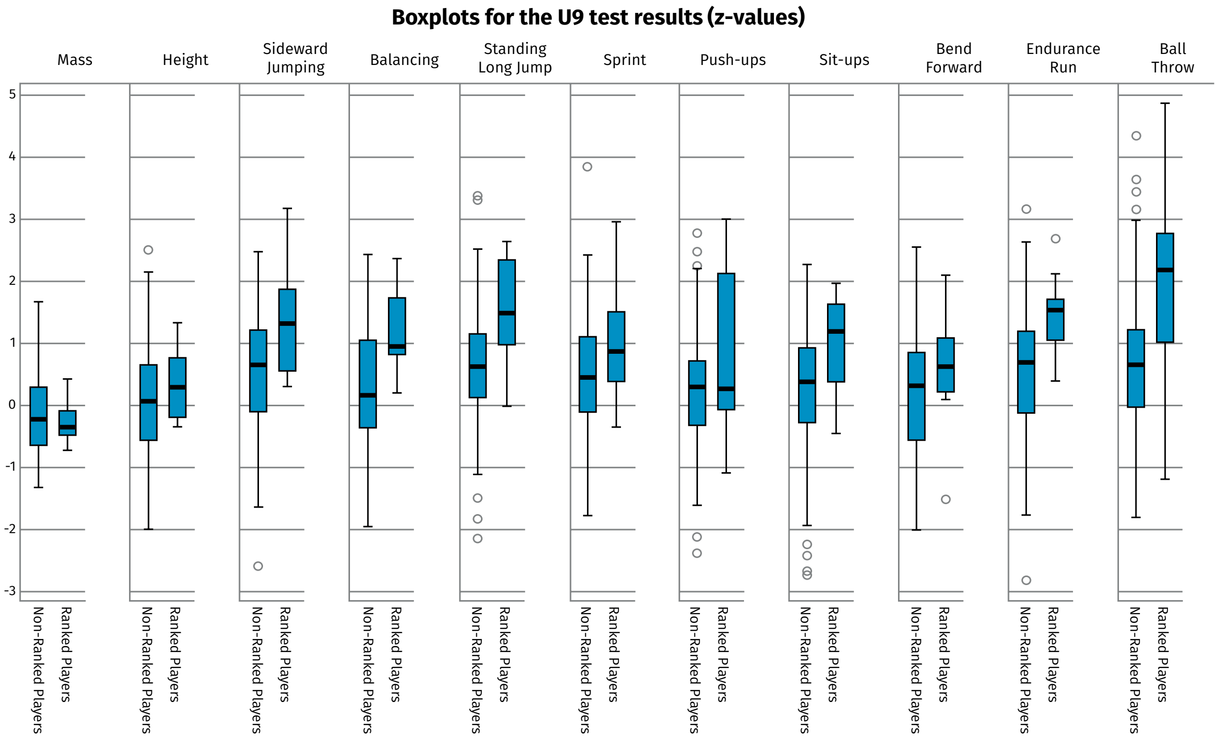

Figure 3. Boxplots of the former U9 test results (z-values) of junior non-ranked tennis players and ranked tennis players.

Table 3.
– Bivariate correlations of the different U9 test results and the chance to achieve a ranking position in the official youth national ranking lists of the German Tennis Federation (p ≤ 0.05; ** p ≤ 0.01).*

	Mass	Height	Sideward Jumping	Balancing	Standing Long Jump	Sprint	Push-ups	Sit-ups	Forward Bends	Endurance run	Ball Throw
Tennis Ranking Success	-.077	.091	.256**	.263**	.287**	.226**	.187*	.231**	.130	.296**	.360**

DISCUSSION

The aim of this study was to investigate whether TID in tennis is already possible in the U9 age group and whether physical fitness tests and motor competence tests provide an early indication of later junior success. For this purpose, a long-term study retrospectively investigated the initial U9 test performances (based on physical fitness and motor competence tests) of today's junior tennis players in the official junior ranking list of the German Tennis Federation, as well as the weaker tennis players without a successful placement in the ranking list. If measurable differences in certain physical fitness and motor competence characteristics/predictors between these two current junior performance groups can already be identified at U9, then conversely, a prediction of later junior success can also be prospectively made at U9 on the basis of these characteristics, and the validity of early TID can be evaluated.

It was shown that the group of junior ranked tennis players were already significantly superior to the group of non ranked players in almost all test items at the age of 8 (U9). Looking at the results of the U9 tests more closely, it is noticeable that the differences are particularly high in test tasks the ball long throw, the endurance run, and the standing long jump, while U9 body height and body weight did not show any significant difference between the two groups of junior tennis players.

In *Table 1*, it can be assumed that the RPs as children (U9) had a clear advantage over their peers. The mean values of all test items are higher for the later group of more successful athletes than for the later group of NPs. With the exception of body weight and flexibility, the raw values already show significant differences between the two performance groups. However, the values still cannot be interpreted well, as age can also have an effect on performance. Considering the age in months, it is also notable that the later RPs are, on average, about 4 months older than the NPs. This is consistent with various studies on the *relative age effect*, according to which older athletes of a given age group have an advantage over their younger peers (Musch & Grondin, 2001). According to the data, this advantage does not seem to vanish even after about 5 years (Smith et al., 2018). Also, comparing the results of similar tests by Tomkinson et al. (2017) and Bös et al. (2009), it is of note that the participants tested in this study performed better in certain test items than the comparison groups of the other studies. Therefore, it can be assumed that regional differences influence performance. For this reason, too, it makes sense to standardize the **raw scores**. For the *z*-value standardization, in addition to the gender and age in months of the tennis players, the data of about 2000 non athletes of the same region were also used. This prevents regional test bias from blurring the results (Hohmann et al., 2018). In addition, **male and female** athletes can be evaluated together, as is usual in talent identification campaigns (Pion, 2015). While the raw scores of female and male tennis players still differ significantly in the four test tasks the sprint, the forward bends, the endurance run, and the ball throw, the MANCOVA of *z*-values only shows significant differences between the genders in the ball throw, with girls scoring comparatively better than boys. Overall, however, it must be noted that with this exception, the sample is still relatively homogeneous at this age (Siener & Hohmann, 2019).

However, the *z*-standardization to the non athletes also has the disadvantage that the *z*-values are comparatively higher than usual. This is especially noticeable in the **ball throw**, where individual tennis players can show *z*-values of z = 4 and more. Therefore, the results must always be seen in relation to the regional non athletes. Nevertheless, the differences in the individual test items now can be better seen. In this study, the ball throw is also the most important U9 test value. Both the NPs and RPs achieved the highest average test values of z = 0.64 and z = 2.03. It is not surprising that the ball throw, as a combined exercise of technique and strength, has such a high influence on subsequent success in tennis, since the two movements, the tennis serve and throwing abilities, have similar characteristics (Fett et al., 2020). The serve is of particular importance in tennis, as it lays the foundation for the rally and can put pressure on the opponent right from the beginning to achieve a point win. As early as 1992, Roetert et al. could prove a significant correlation between national tennis success and striking speed (correlations: $r_{forehand}$ = 0.68, $r_{backhand}$ = 0.59, r_{serve} = 0.57). Similar results have been shown in recent studies by Ulbricht et al. (2016) on the influence of fitness characteristics on tennis performance. They showed that in 902 tennis players aged from 11 to 16 years, serve velocity (correlations: $r♀$ = −0.43 to −0.64, $r♂$ = −0.33 to −0.49) and upper body power (medicine ball throw; $r♀$ = −0.26 to −0.49; $r♂$ = −0.20 to −0.49) have the greatest impact on tennis performance. We were able to demonstrate a significant correlation between the ball throw and the RP of r = 0.360 ($p < 0.01$), which is comparable to the studies described above. *Table 2* also shows the highest effect size for the ball throw, with a *partial eta squared* of $\eta^2 = 0.157$. This is the only one of the various test items that can demonstrate a strong effect. A high influence on tennis performance could be proven not only for the serve but also for the upper body strength in general. In cross-sectional studies by Kramer et al. (2017) on 86 Dutch junior elite tennis players, a significant correlation between the combined upper body strength abilities of the ball throw and two medicine ball throws with the ranking of the male U13 players (Pearson correlation: r = −0.5*) was demonstrated. This is supported in studies by Fett et al. (2017) on U16 *Davis Cup* players and regional squad tennis players, who demonstrated a large effect size (*Cohen's d* = 1.04) for the throwing performance (forehand medicine ball throw) in *t*-tests.

In college tennis competitions, Kovacs (2007) measured an average playing time of about 1.5 hr. With such a long game duration, it is not surprising that due to exhaustion, hitting accuracy can drop as low as 81% (Davey et al., 2002). Thus, **endurance** has an important impact on tennis success and in our study reaches a moderate effect strength of η^2 = 0.065. Box plots also show that the range of results is relatively small, which is also shown in *Table 2* in SD = 0.564. A certain level of endurance seems to be indispensable for achieving rankings. For example, in a study with 40 male RPs (ranked 1 to 40) at the age of 15 years, a 20-m shuttle run (number of laps) correlated significantly with the achieved ranking (Meckel et al., 2015). However, the achieved correlation of r = −0.581* is much higher than the correlation value of r = 0.296** proven here. In addition to Meckel and colleagues (2015), other authors demonstrated the importance of endurance performance for tennis success in the U15 category (Filipcic et al., 2010). While in older athletes good endurance, due to the shifting of the fiber distribution, can have a rather negative effect on sprint ability, at the age of 8 years a significant correlation between the two abilities is still evident (r = 0.331**). Nevertheless, the influence of **sprinting** is weaker compared to endurance and has a correlation value of only r = 0.226** (Sprint–Tennis Ranking Success). The *partial eta squared* also turns out to be only a *small* effect, with η^2 = 0.03. This seems surprising at first sight, since studies by Girard and Millet (2009) on male U15 tennis players showed correlation values between the 20-m sprint performance and the ranking of r = 0.74**. However, their study was based on a small sample, with only 12 participants. Nevertheless, Filipcic et al. (2010) also demonstrated similar results in a larger sample (N = 159, U16–U19). In investigations by Ulbricht et al. (2016), correlations of $r♂$ = 0.31** and $r♀$ = 0.19* were found in the U14 category (N = 431), but in contrast to the serve velocity (r = 0.33 to 0.64 of U12–U16), these values were rather low. Also, the effect size between national and regional athletes was mostly small (d_{Cohen} = 0.00 to 0.21 for U14–U16; exception: d_{Cohen} = 0.63** for ♂ U12). Ulbricht explains the low significance of the classic linear sprint tests by the fact that typical movements in tennis are limited to a radius of 3 to 4 meters. The maximum speed would therefore never be reached. This fact is even more relevant for the U9 players, where the 20-m sprint is more dependent on speed endurance than in older research groups. Therefore, at a second view, the weak performance of the 20-m sprint is understandable.

The two test tasks **sideward jumping** and **standing long jump** have moderate effect size of a *partial eta squared* of 0.066 and 0.081. The standing long jump is also in second place in the overall U9 motor skills profile, and both RPs and NPs were able to achieve very good values at a young age. The explosive power of the leg muscles is also of great importance for short fast starts and quick first steps. Both exercises were investigated in a series of agility tests (see Girard & Millet, 2009; Ulbricht et al., 2016). Roetert et al. (1992) was one of the first to point out the significant correlation between the hexagonal test and the tennis ranking position. Although a classical agility test is missing in our study, the high value in the standing long jump may be an indication of corresponding abilities in tennis.

None of the RPs was extremely light or heavy at the age of 8. Accordingly, no significant results could be found in **body mass** comparing the two performance groups. Also, the **body height** did not lead to a significant result (*t*-test: p = 0.24). This is surprising, since a larger person has an advantage over smaller persons in the serve and also in the range of covered space on the court. Due to the higher hitting position of the ball, the relative field size to be hit in the opponent's field is larger than from a lower hitting position of the ball (Vaverka & Cernosek, 2013). A higher hitting position also allows the ball to be played at greater speed, so it should not be surprising that coaches give larger athletes a higher chance of success (Robertson et al., 2018). Nevertheless, the height of the junior tennis players tested in the U9 had no direct influence on their tennis ranking success.

Overall, U9 results are comparable to results from other performance studies of U11–U16 tennis players (Fett et al., 2017; Ulbricht et al., 2016). Therefore, it can be assumed that talent specific characteristics remain stable over time (Hohmann et al., 2018) and that athletes who tend to perform better later on already emerge in U9. However, the results cannot consistently confirm the prognostic validity of TID in U9, as a high association with later ranking success could be found in only a few test items. Future TID predictions could therefore benefit from more test items or holistic talent assessments (e.g., motivation; Zuber et al., 2016). Nevertheless, for coaches, the results demonstrated can serve for a first cautious assessment of their training groups.

LIMITATIONS

The **test battery** used here covers a wide range of generic motor tests and almost all basic abilities (speed, strength, flexibility etc.). These tests intentionally correspond to the physical fitness and motor competence tests often used in TID campaigns in Europe (Niessner et al., 2020; Pion, 2015; Potočnik et al., 2020). Nevertheless, it should be noted that the results of the study shown here also depend to a large extent on the tests used. According to the retrospective design, the U9 tests here were already given up to 9 years ago; accordingly, it was not possible to draw on the latest test developments of recent years (Faber et al., 2017; Faber et al., 2018; Fernandez-Fernández et al., 2014). However, although Koopmann et al. (2020) were able to highlight the use of sport specific tests in the context of TID for the junior level, it is questionable whether similar successes in TID can be already predicted in U9 through sport specific tests in tennis. This is because the use of sport specific tests can quickly overburden children without many years of sport specific technical experience and, accordingly, would presumably over recommend early specialized athletes. However, specialization as early as 8 years of age is at the same time considered critical in the eyes of many scientists (LaPrade et al., 2016). Therefore, for future testing of the U9 players, sport-specific tests should only be used to a small extent. Nevertheless, the study shown here could have benefited from an additional *change of direction agility test, a stroke velocity test, or* a *handgrip test* (Ulbricht et al., 2016). However, tennis success does not only depend on physical fitness. Zuber et al. (2016) have therefore made initial attempts to integrate *psychological tests* into TID campaigns. In the future, it will be interesting to see how TID develops further.

The small **sample size** is another limitation of the study. With only 174 participants and also only 16 ranked players, the sample is very small. The results shown here are therefore not generalizable and must always be interpreted in relation to group size. Following Gagné (2010), only about every 10th athlete can be described as talented. Accordingly, if a group of 50 ranked players were to be studied, a total sample of approximately 500 participants would be needed. However, investigating such large sample sizes is highly time-consuming and cost-intensive, especially for long-term studies, which is why only a few studies have made this effort (Bergkamp et al., 2019; Gonaus & Müller, 2012; Höner et al., 2017; Höner & Votteler, 2016).

Another problem could be the joint consideration of genders. In Germany, it is common to train girls and boys together at a young age and thus to screen them together in the initial TID. However, various studies (Fernandez-Fernández et al., 2014; Kramer, Huijgen, Elferink-Gemser, & Visscher, 2016; Sannicandro et al., 2012; Ulbricht et al., 2016) suggest that boys' physical fitness and motor competence (in relation to tennis) may differ from that of girls. Usually, these differences do not emerge until puberty (Grosser et al., 2008). In the U9 sample used here, no significant differences in age-adjusted z-scores between the genders were found except for ball throwing (where ranked girls were slightly better than ranked boys). Nevertheless, even the same test values could have a different effect for the different genders later. However, our calculations showed that the results for test items with the strongest effect values were almost identical for both genders. Unfortunately, due to the even smaller sample size (especially for the 62 girls), these results are difficult to evaluate. Therefore, in future studies, the differentiation of the genders should be considered again more intensively.

CONCLUSION

This long-term retrospective study shows that TID appears possible even at U9 and that early test performance can be used to predict later junior tennis success. Today's junior tennis players in the national tennis ranking list of the German Tennis Federation were already superior in U9 to current weaker junior players in almost all early test items. This is especially evident in throwing performance, endurance running, and the standing long jump. Throwing performance is the most important factor. In all analyses (MANCOVA and correlation), it was shown to have the greatest influence. All other test items could only show medium to small effect sizes. Retrospective body height and weight at the time of U9 testing did not show any difference between the groups. Nevertheless, the study demonstrates that a valid talent prognosis seems to be possible even at the U9 level.

PRACTICAL APPLICATION

The results show that TID can be successful as early as U9. Coaches should particularly focus on throwing power in their search for talent, as this has the greatest effect on reaching the national youth rankings later on. Namely, every second person with a throwing performance of $z \geq 2$ reached the rankings. In addition to throwing power, endurance and jumping power were also good indicators of later success. In both parameters, with one exception, later RPs reached above-average values ($z \geq 0$). However, the results also show that even weaker athletes ($z_{ball\ throw}$ = −1.3) can still achieve success. Therefore, physical fitness and motor competence should not be used alone for TID but should be considered in addition to the coach's opinion.

CONFLICT OF INTERESTS

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript. Also, the authors did not conduct any studies with animal participants for this article. As for other studies citied in this article, information on ethical guidelines may be found in the respective sources. All experiments comply with the current laws of the country in which they were performed.

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Predicting Table Tennis Tournaments: A comparison of statistical modelling techniques

Predecir torneos de tenis de mesa: una comparación de técnicas de modelización estadística

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Abstract

There are two main goals of this work: 1) to compare different statistical models, which are applied to historic tournaments to find a suitable statistical model, i.e. the model with the best predictive performance, and 2) to understand which factors are important for good predictions. Every year at least one of four important recurring table tennis tournaments takes place where top players compete. Those tournaments are the World Table Tennis Championships, the Table Tennis World Cup, the Olympic Games and the ITTF World Tour. In other areas of sports, it is common to analyse major tournaments and predict future ones. This work aims to bring this aspect of analysis to the world of table tennis by evaluating recent holdings of the Men's World Cup and the Grand Finals of the Men's ITTF World Tour. The results show that it is indeed possible to apply statistical machine learning methods on table tennis tournaments for prediction with a correct classification rate of around 75% by a random forest and 74% by a penalized generalized linear logit model. Even though both models based their predictive power mainly on the official table tennis rankings and points, variables like age, playing handedness or individual strength were important factors as well.

Keywords: *Tournament analysis, random forest, statistical learning, table tennis, LASSO regression.*

Resumen

Este trabajo tiene dos objetivos principales: 1) comparar los diferentes modelos estadísticos que se aplican a torneos históricos para encontrar un modelo estadístico adecuado, es decir, el modelo con el mejor rendimiento predictivo, y 2) entender cuáles factores son importantes para una buena predicción. Cada año se celebra al menos uno de los cuatro torneos importantes y recurrentes de tenis de mesa en los que compiten los mejores jugadores. Esos torneos son el Campeonato Mundial de Tenis de Mesa, la Copa del Mundo de Tenis de Mesa, los Juegos Olímpicos, y el Circuito Mundial de Tenis de Mesa. En otras áreas del deporte, es común analizar torneos importantes y predecir los futuros. Este trabajo pretende traer ese aspecto del análisis al mundo del tenis de mesa al evaluar las competencias recientes en la Copa del Mundo y las Grandes Finales del Circuito Mundial, ambas en la categoría masculina. Los resultados demuestran que es posible aplicar métodos estadísticos de aprendizaje automático a los torneos de tenis de mesa para predecir con una tasa de clasificación correcta de alrededor del 75% a través de un bosque aleatorio y del 74% con un modelo logit lineal generalizado penalizado. Aunque ambos modelos basan su poder predictivo principalmente en las clasificaciones oficiales de tenis de mesa y puntos, las variables como la edad, la destreza en el juego o la fuerza individual también fueron factores importantes.

Palabras clave: *análisis de torneo, bosque aleatorio, aprendizaje estadístico, tenis de mesa, regresión LASSO.*

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INTRODUCTION

International sports tournaments (most of them periodically held) are usually seen as a highlight for the respective sport due to their extensive nature. Thus, they are attracting a bigger audience and gain temporary more attention than the national counterparts. As the tournaments are often scheduled a considerable time in advance, people try to predict potential outcomes and winners. This is reflected in the countless bets at bookmakers shortly before and during those tournaments, as well as in the general media activity.

With the rise of computational power and the increased popularity of machine learning tools over the last two decades, scientific research began to extend and optimize predictions of tournaments in many sports, e.g., football (Groll A. , Ley, Schauberger, & Van Eetvelde, 2019a) and tennis (Gu & Saaty, 2019). There has evolved a competition of different prediction models with lots of competitors. This also comes with an increased understanding of sports matches. More and more data become available, and once they have been analysed for prediction purposes, they can potentially improve the understanding of why a specific team or player won. Beside the general interest of sports fans, the expected continuing growth of the global sports betting market (Grand View Research, 2021) is motivating research in predicting sports results.

However, table tennis is not yet in the focus of this development. This work aims to bring that aspect of analysis to the world of table tennis by conducting recent holdings of the ITTF (International Table Tennis Federation) Men's World Cup and the Grand Finals of the Men's ITTF World Tour. There are two main goals: 1) to compare different statistical models based on historic tournaments to find the model with the best predictive performance and 2) to understand which factors are important for good predictions in table tennis. The best model can then be used to predict future tournaments. The results should give a first impression of how suitable statistical models are in the context of modelling table tennis. With the expected growth of sports betting, also table tennis bets will most likely gain more popularity. Hence, modelling table tennis matches could become a critical aspect for the betting industry.

The second main goal is first of all simply inspired by scientific curiosity. Moreover, the understanding of the models and the important features indicate what kind of data is most interesting in the context of table tennis prediction. And therefore, the most important features can hint at what sort of data could potentially improve the results.

Since this is the first time that these methods are applied in the area of international table tennis, it is also of interest of how decent the methods work in this context. We answer the question whether results of research with respect to predictions of other sports can be applied in table tennis as well. However, the authors want to state that this work only represents a first modest overview of potential statistical and machine learning models. Furthermore, the selected models were not considerably tuned. Finally, we make use of the best predictive model and analyse what it would have predicted for the 2019 ITTF Men's World Cup.

MATERIAL AND METHODS

Data

For the complete analysis the programming language R was used (R Core Team, 2019). The data set was collected via web scraping from the official web archive (ITTF Archive, 2019). The obtained data was then pre-processed, including manual updating of missing values where the information could be found elsewhere. The final full data set includes 419 matches taken from all World Cups and Grand Finals of the ITTF World Tour held between the years 2010 and 2018, see Table 1. In this manuscript, players' names are encoded as FL (F = first name, L = last name). Individual player statistics are included for each match. Additionally, there were features generated based on this data. Exemplary features are host (whether the tournament is taking part in the players' home country), age, handedness (left or right-handedness), style (attacker or defensive), grip (shake-hand grip or penhold), WTTR-position (WTTR=World Table Tennis Ranking), WTTR-points. The handedness of players was established according to which hand was used to hold the racket (Peters & Murphey, 1992).

Each row in the data set represents a match where two players (player *A* vs. player *B*) compete. For better visibility the transposed version is shown in Table 2, where each column represents a match. The result for a match can either be 1 (player *A* won) or 0 (player *A* lost, i.e., player *B* won). The indications as player *A* and *B* are assigned randomly in the beginning. The covariates then represent the differences between player *A* and player *B*. For example, the WTTR-points of player *B* are subtracted from the WTTR-points of player *A*. The variable age is corrected by the average age (*avgAge*), which is assumed to be the optimal value: $age = | age(B) - avgAge | - | age(A) - avgAge |$. This way, it takes the value 0 when e.g., player *A* is 3 years younger than the average age and player *B* is 3 years older than the average age, i.e., both have the same distance to the optimal age and are assumed to have identical age benefits. For the variable *handedness*, the encoding is 1 if player *A* is right-handed and player *B* is left-handed, -1 if player *A* is left-handed and player *B* is right-handed and 0 if both players play with the same hand. Similarly, the encoding is done for the other variables.

Furthermore, there were several dummy variables defined: A group of dummy variables is representing the continent, where players origin from. It is encoded pairwise, i.e., all possible two-pair-combinations of continents are present, and only the relevant combination for the specific match is set to 1, e.g., *EU_AF* (*Europe/Africa*), while the other combinations remain 0. A unique ID for each player was used that could feature as a strength variable where players that participated for the first time in a tournament were given a rookie ID (999999) for that tournament. For this player strength variable, all available IDs of every player that participated in the conducted tournaments are considered as dummy variables. Then, only the specific IDs for a match are set to 1 (player A) and -1 (player B). Hence, the model can identify all matches of a specific player and evaluate the player's performance. However, this is evaluated over all available matches without considering their chronological order (see also the paragraph *Cross Validation*).

Table 1.
Data set overview. In total there are 419 matches that have been used of which the majority is coming from the World Cups.

Year	World Cup Matches	Grand Final Matches	Total
2010	38	15	53
2011	38	15	53
2012	36	15	51
2013	32	15	47
2014	28	15	43
2015	28	15	43
2016	28	15	43
2017	28	15	43
2018	28	15	43
Total	**284**	**135**	**419**

Table 2.
Overview of the used data set. Note: Shown is artificial data to give an impression of the value ranges. Each column represents a match and each row a variable.

Variable Name	***Observation 1***	***Observation 2***	***Observation 3***	**...**
Winner_is_A	1	0	1	...
Year	2011	2012	2013	...
A_id	999999	123456	324544	...
B_id	123456	452364	999999	...
Host	0	1	0	...
Age	-3.06	4.15	-2.45	...
Hand	1	-1	0	...
Style	0	1	-1	...
Grip	0	1	-1	...
WTTR-position	-15	-66	13	...
WTTR-points	56	155	-50	...
AF_AS	0	-1	0	...
AF_EU	0	0	0	...
⋮	⋮	⋮	⋮	...
EU_LA	1	0	0	...
A_id123456	-1	1	0	...
⋮	⋮	⋮	⋮	...
A_id999999	1	0	-1	...

Statistical Models

The models of choice were a **LASSO:** *Least Absolute Shrinkage and Selection Operator* (Friedman, Hastie, & Tibshirani, 2010; Tibshirani, 1996), and a random forest (Breiman L. , 2001). The LASSO is a penalized version of a generalized linear model (Fahrmeir & Tutz, 2001; McCullagh & Nelder, 1989) in particular of a logit model. It yields a predicted win probability π_i for match i and a coefficient vector $\boldsymbol{\beta}$ corresponding to covariate effects which is well suited for interpretation purposes. The chosen logit model has the form:

$$\pi_i = \frac{\exp(\boldsymbol{x}_i'\boldsymbol{\beta})}{1+\exp(\boldsymbol{x}_i'\boldsymbol{\beta})}.$$

Here, $\boldsymbol{x}_i$ is the vector of covariates for match *i*.

The fitted model is then the solution to the minimization problem

$$\hat{\beta}_{LASSO} = \underset{\beta}{\operatorname{argmin}}\ \mathcal{L} + \lambda \sum_{j=1}^{k} |\beta_j|,$$

where $\mathcal{L}$ is the Bernoulli likelihood (Friedman, Hastie, & Tibshirani, 2010) to which a penalty term is added, whose strength is controlled by a penalization parameter $\lambda \in [0, \infty)$. The penalty term itself is the sum over all j = 1, 2, ..., k regression coefficients.

The chosen L1-penalization allows to potentially shrink estimated coefficients to zero which effectively results in a variable selection process. Non-significant variables implicitly get removed, which yields a more stable model. The R-package `glmnet` (Friedman, Hastie, & Tibshirani, 2010) was used to fit the penalized generalized linear logit model. To find the best penalization parameter λ the implementation utilizes a cross validation via the `cv.glmnet` function.

However, the linear nature of the LASSO comes with limitations when it comes to modelling data of unknown shape. The **random forest** model (Breiman L. , 2001) is very flexible and efficient in modelling any input data. It has been shown (Schauberger & Groll, 2018) that random forests work considerably well for predicting sport results.

A random forest is based on the idea of decision trees (Breiman, Friedman, Stone, & Olshen, 1984; Theodoridis, 2015). The basic concept of a decision tree is to split the data set into chunks based on a properly chosen splitting variable. This is done subsequentially until a stopping criterion is met. The result is a tree-like chunking of the data, where the very bottom (*the leaves*) corresponds to a specifically characterized data chunk. Figure 1 shows an exemplary simplified decision tree based on solely the variables *WTTR-position* and *age*. The algorithm chooses a suitable splitting variable at each step and splits the data accordingly. The predicted probabilities then correspond to the relative frequency of won matches in this branch. This procedure can continue until a perfect separation is obtained, i.e., each observation has its own unique path in the tree. Usually this process is restricted, e.g., by pruning the tree after completion to avoid overfitting. Once the decision tree is generated, the prediction step consists of a simple evaluation of the given covariates on the tree.

A random forest is utilizing many decision trees and introduces randomization steps to decorrelate the single trees and, hence, lower the variance. The resulting ensemble of decision trees is then used with a majority voting to make predictions. This work makes use of the R-package `randomForest` (Liaw & Wiener, 2002). Even though the random forest lacks interpretability one can look at the so-called **variable importance** (Liaw & Wiener, 2002; Breiman L. , 2001) to get a rough impression of the decision process. The process of calculating the variable importance can be described exemplarily as follows: if we want to calculate the variable importance of the variable *age*, we modify the data set by permuting all age values randomly across the data set. Then, the prediction error is calculated based on this altered data set. Finally, the prediction error is compared to the original prediction error (on the non-permuted data set) with the use of the Gini-Index (Ceriani Lidia, 2012). If the error on the permutated data set substantially increased compared to the original data set, the variable importance for our variable *age* will be high. This is then done for each variable separately.

The third model is a **reference model** which solely predicts based on the current rank of the players. The predicted win probability will be 1 if the player *A* has a higher rank than player *B* and 0 otherwise.

Performance Measures

Each model yields a probability for a win of player A denoted by $\hat{\pi}$ for a given match. The true outcome is always denoted by y, which can take the values 0 (player A lost) or 1 (player A won). Based on these prediction probabilities, the performance will be measured with four different approaches.

The **classification rate** represents the proportion of correctly classified matches and is frequently used in classification problems, also in the field of sports see e.g., (Schauberger & Groll, 2018):

$$\mathcal{K} := \frac{1}{n}\sum_{i=1}^{n} \mathbb{1}(y_i = \hat{y}_i), \text{where } \hat{y}_i = \begin{cases} 1, \text{ if } \hat{\pi}_i > 0.5 \\ 0, \text{ if } \hat{\pi}_i \leq 0.5 \end{cases} .$$

A measure that is capturing more information on how accurate the model predictions are is the **Bernoulli likelihood**. It represents the mean probability for the correct prediction see e.g., (Schauberger & Groll, 2018):

$$\mathcal{L} := \frac{1}{n}\sum_{i=1}^{n} \hat{\pi}_i^*, \text{where } \hat{\pi}_i^* = \begin{cases} \hat{\pi}_i, \text{ if } y_i = 1 \\ 1 - \hat{\pi}_i, \text{ if } y_i = 0 \end{cases}$$

The third measure is the **Brier Score** (Brier, 1950). This time the mean is formed over the quadratic difference between the predicted probability $\hat{\pi}$ and the actual outcome y:

$$\mathcal{B} := \frac{1}{n}\sum_{i=1}^{n} (\hat{\pi}_i - y_i)^2$$

Finally, the fourth measure is the **area under the curve (AUC)** (Fawcett, 2006; Robin, 2021). It is measured over the receiver operating characteristics (ROC) curve where the true positive rate is plotted against the false positive rate.

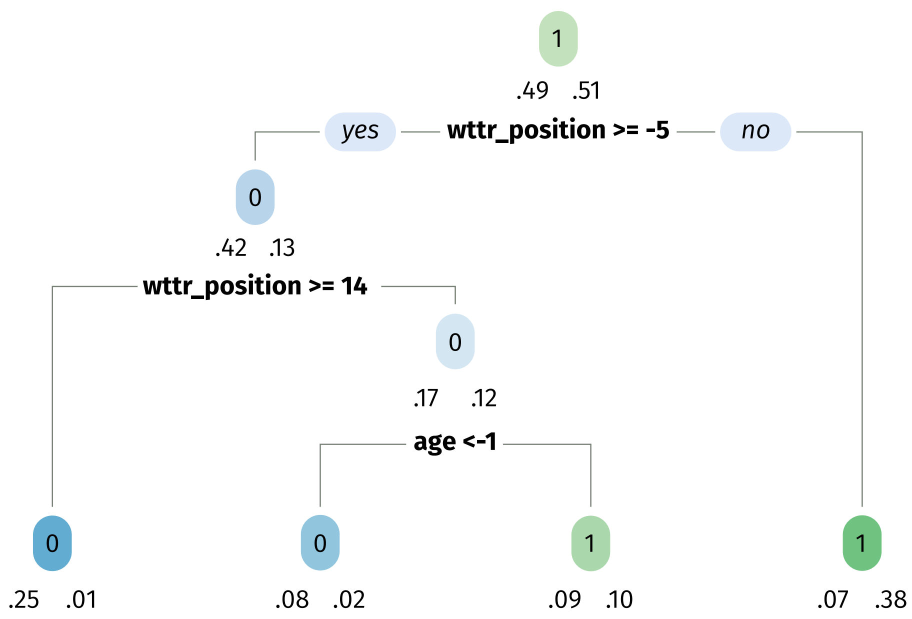

Figure 1. Overview over a simplified decision tree. Recall that the variables wttr_position (WTTR-position) and age are representing differences between the two involved players. It is visible how the probabilities for a win (1) get refined after each split.

All four measures are in a range of 0 to 1. The first two measures and the AUC are goodness-of-fit measures. Therefore, they are desired to be close to 1. The Brier Score, however, is measuring the error and thus it is desired to be close to 0.

To evaluate the performance of the prediction of the ITTF World Cup 2019 the *Tournament Rank Probability Score* (**TRPS**) (Ekstrom, Van Eetvelde, Ley, & Brefeld, 2021) is used. This score takes the whole course of tournament into account by evaluating the predictions and results on every tournament stage, i.e., group stage, round of 16 etc. The TRPS for a full tournament prediction X and the actual outcome O is defined as

$$TRPS(O, X) = \frac{1}{T}\sum_{t=1}^{T}\frac{1}{R-1}\sum_{r=1}^{R-1}(o_{rt} - x_{rt})^2.$$

Here, T represents the number of teams (or players in the present case), R is the worst possible rank and x_{rt} is the cumulative probability that player t reaches at least rank r. The lower the TRPS the better is the prediction, where the ideal prediction has a TRPS of 0. To interpret the TRPS it is advised by the authors to compare the results to a TRPS of a flat prediction, i.e., where each player has equal chances.

Cross Validation

The models are trained, and the errors are calculated via a cross-validation (CV)-type approach. This allows to train and test on the whole data set. The data set is split into a train fold of 7 years and a test fold of 1 year. This is done on all possible combinations of years. The chronological sorting is ignored, and it is assumed that the data is independent, conditioned on the covariates. The prediction on the test fold, i.e., the predicted probability $\hat{\pi}$ of a win for player A, is stored for each fold. Then, the mentioned performance measures are evaluated on the stored $\hat{\pi}$ values.

Analysis

The predictive performance analysis was based on the results of the CV and the performance measures introduced above. Furthermore, both statistical models were trained on the full data set to leverage all available information for the in-depth analysis of important factors. The coefficients of the LASSO as well as the variable importance of the random forest were then interpreted. Finally, the best performing model was used to simulate the (out of sample) ITTF World Cup 2019 and predict the outcome of the tournament.

RESULTS

Performance Comparison

The CV results with respect to different performance measures are shown in Table 3. The last row in Table 3 shows the results of a rank-based model for reference. It solely predicts based on the rank of both participating players. The player with the higher (better) rank is then assigned a 100% winning chance, i.e., if the higher ranked player is player A the prediction is 1, and 0 otherwise.

The random forest outperforms the LASSO approach with respect to every measure that was applied. However, the differences to the LASSO are rather small depending on the considered measure. The classification rate and the AUC are both similar for the different models. This might be due to the rather rough rounding nature of these two measures (probabilities are rounded to 0 or 1). For the Bernoulli likelihood and especially the Brier score, the difference is slightly more remarkable. If one compares the two statistical models (random forest and LASSO) to the ranked-based reference model it is notable that it scores better than both considered statistical models in terms of classification rate and Bernoulli likelihood. However, the Brier score and the AUC show that the random forest is on average making smaller errors in the prediction. Due to the simple prediction method of the rank-based reference model it is always making very confident predictions, which result in very high errors when the prediction is not correct. In comparison to this model, both statistical models are showing a good prediction performance. Due to the lack of comparable work in table tennis competitions it is hard to tell exactly how accurate the prediction is. In a similar work for tennis matches (Brunner & Groll, 2018) a classification rate of 0.79, a likelihood of 0.69 and a Brier score of 0.15 was achieved.

Table 3.
Results of the cross validation. Classification Rate, Bernoulli-Likelihood-Score, Brier Score and area under the curve. Models are LASSO, random forest and the ranking based reference model. Best values in bold typeset.

	CLASS	BLH	BRIER	AUC
LASSO	0.7375	0.6583	0.1844	0.8036
RF	0.7542	0.6842	**0.1781**	**0.8095**
RB	**0.7828**	**0.7828**	0.2172	0.7828

Alternative Models

Even though both statistical models from above incorporate some form of variable selection, due to the large number of covariates the quality of this selection process can not be completely guaranteed. Some variables might still show predictive power just by chance which will not yield a satisfying prediction on unseen data. In particular, the player-specific strength variable which identifies each player individually accounts for 62 variables (players) as a result of the dummy encoding. Hence, the sheer number of variables of this type could be a reason for the models to select some of them. Thus, an alternative version for both models was run with the same CV approach, where both models (random forest and LASSO) were not fed with the player's strength variable. The results are displayed in Table 4. It turns out that the runs without the players' strength variable are even slightly better for both models w.r.t. almost all performance measures. This could be indicating that there are not enough matches for each player to form a reliable strength variable. However, as we are more interested in finding certain player-specific patterns, particularly strong under- or over-performers, than in pure predictive performance, these alternative versions were not studied any further.

Table 4.
Results of cross validation for alternative models without the player's strength variable. Labels are identical to Table 3.

	CLASS	BLH	BRIER	AUC
LASSO	0.7613	0.6583	**0.1656**	**0.8324**
RF	0.7733	0.6871	0.1768	0.8072
RB	**0.7828**	**0.7828**	0.2172	0.7828

Model Interpretation

To interpret the models, they are fitted on the whole data set available. For the random forest, the variable importance is considered for interpretation, while for the LASSO approach the coefficients can be interpreted directly.

The variable importance of the random forest is shown in Figure 2. It turns out that the WTTR-points and the WTTR-position are by far the most important variables. This was to be expected as these two variables contain a lot of (similar) information and are naturally highly correlated. The higher variable importance of the WTTR-points compared to the WTTR-position could be explained by the finer scale of the WTTR-points. The third important variable is the players' age, which suggests that it contains suitable predictive power for the random forest model. The remaining variables have substantially less importance. It is notable though that out of all the available variables, the model selects especially the players' handedness, grip, and the host variable. Additionally, the matches where players from Asia play against European players and matches where Europeans play against Latin Americans show a special character. However, it is not possible to tell from the variable importance whether players from the respective continents perform below average or above average. A look at the specific player IDs reveals that the rookie variable is also considered important by the model. Therefore, there can be a considerable change in the prediction when a new player is part of the match, in contrast to when the same player has played already in a tournament before. The player whose player-specific ability ("strength variable", e.g. A_id108246) has the highest variable importance is VS (BLR). Again, due to the limitation of the measure it is not possible to tell if the player is equipped by the model with a bonus (i.e., performing above average) or with a malus (i.e., performing below average). Nevertheless, it seems that with respect to the other variables this player is standing out when it comes to predicting a match. Similarly, one can observe how much weight the model gives to the other players as seen in Figure 2. The interpretation of this, however, is not to be mistaken with a necessarily good performance of the player. The variable importance represents rather the difficulty of predicting matches when this information is missing. For example, if we would remove the information of whether VS is participating in a match or not (by randomly permuting its values), the predictive power of the model would significantly decrease. In contrast to that it would not change much if we were about to remove the information of whether BS participates in a game or not.

A more in-depth interpretation can be achieved based on the LASSO coefficients. In Table 5 the output of the full LASSO model is displayed. Noticeable is the small number of selected variables. In fact, only the WTTR-points and six player IDs have been selected by the LASSO model. A simple indicator for interpretation purposes is the sign of the coefficients. Recall: The exemplary variable A_id106884 takes the value 1 if player 106884 is player A (all matches are seen from the perspective of player A, the win probability is the probability of a win for player A). The variable A_id106884 takes the value -1 if player 106884 is the opponent (player B). If player 106884 is not part of the match the variable takes the value 0.

For the general interpretation, a positive sign for the coefficient of the players' strength variable results in a higher probability for a win of that player. Likewise, a negative sign lowers the probability of a win for this player.

Table 5 shows that the model assigns three players with a negative sign (SO, CM and AS) and two players are equipped with a positive sign (MK and MM). Because the only other variables considered are the WTTR-points, the resulting LASSO model is rather simple and easy to interpret. Since the WTTR-points have a positive sign, whenever player A has more points than player B, the estimated probability for a win is higher for player A. Roughly speaking the higher the WTTR-points difference is, the higher the win probability. The only exception occurs when one (or multiple) player(s) from the five former mentioned participate(s). Depending on the player, the model would give the player a bonus or malus. This essentially results in a correction of the WTTR-points. Those five players' performance – according to the LASSO model – deviated so far from the expected performance based on the WTTR-points that this was corrected by the model.

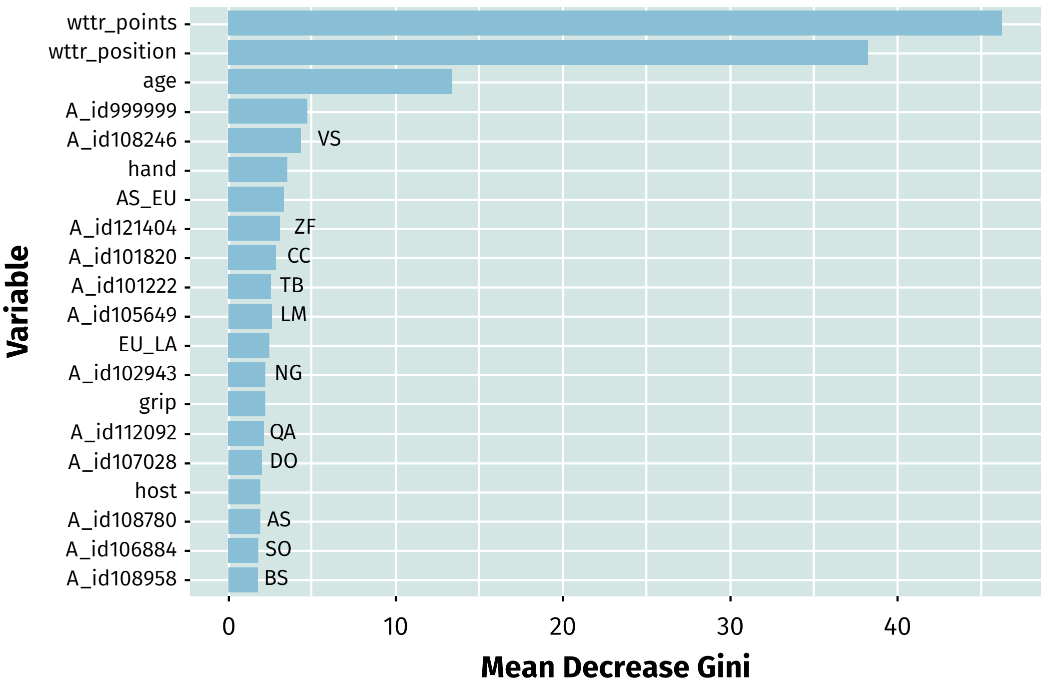

Figure 2. Variable Importance for the Random Forest Model, showing only the top 20 Variables.

Table 5.
Regression coefficients for the selected variables by the LASSO model.

Variable	Coefficient (β)	Player Name
Intercept	0.10952	-
A_id106884	-0.30410	SO
A_id105928	-0.25677	CM
A_id108780	-0.03328	AS
A_id111791	0.02068	MK
A_id105966	0.22670	MM
wttr_points	1.48755	-

PREDICTING THE WORLD CUP 2019

Based on the complete data available the random forest model was superior to the LASSO and was used to simulate the Men's World Cup 2019. Since the drawing of the groups is placed closely to the start of the tournament, the group draws were also simulated. The players YL (TPE), DH (AUT) and SG (IND) were participating in a World Cup for the first time and thus, they were equipped with the rookie variable (ID 999999). The simulation was programmed to follow the official ITTF rules (World Cup Playing System, 2019). The best 8 players (based on their WTTR-points) are bypassing the groups. Thus, only 12 players take part in the group phase. The simulation was made based on 1 million tournament courses. Each match is simulated by taking the predicted winning probabilities returned from the random forest and drawing a Bernoulli random variable with those probabilities.

The results are shown in Table 6. The model is favouring the Chinese top players ZF and LM. The third potential winner is the Japanese player TH. However, with regard to the winning probability he is far behind the former two.

The evaluation with the TRPS is done in the following way: In the simulation no match for place three was considered and thus, the six potential ranking positions were:

1. First Place
2. Second Place
3. Semi-Final
4. Round of 8
5. Round of 16
6. Preliminary Stage (Group Phase)

The TRPS was evaluated for the random forest prediction, for a flat prediction (each participant has equal chances to reach any rank position, i.e., 1/6 for each rank) and for a rank-based prediction (the predicted rank corresponds to the WTTR-Rank, i.e., probability 1 for the corresponding rank and 0 elsewhere). To be fair, the flat prediction is corrected for the first eight players which will always reach the round of 16. Thus, the predictions for those eight players are set to 0 for rank 6 and 1/5 for the other ranks. The results are shown in Table 7. The random forest has the lowest TRPS, almost 3 times smaller than the flat TRPS. The rank-based prediction is closer to the random forest, but the TRPS shows that the random forest is better suited for a whole tournament prediction.

Table 6.
Probabilities for reaching different stages at the 2019 ITTF Men's World Cup for each participant based on the random forest model.

	Player	WTTR-Rank	Round of 16	Round of 8	Semi Final	Final	World Champion	True Position
	ZF	2	100.0000	88.6582	74.8555	62.8887	44.3448	1
	LM	3	100.0000	88.0108	80.2090	67.3938	35.4300	4
	TH	5	100.0000	86.0425	71.5843	23.8240	9.2473	2
	HC	6	100.0000	70.3139	50.5881	14.9690	4.1596	5
	TB	7	100.0000	80.5774	29.6099	11.3912	3.6452	5
	MF	9	100.0000	86.7482	23.8760	6.3742	1.1941	9
	YL	10	100.0000	79.4553	19.4437	4.0668	0.6073	3
	KN	11	100.0000	84.0828	20.7018	3.8581	0.5359	5
	VS	21	91.8613	23.0979	5.8932	1.4128	0.2546	P
	KK	24	94.2586	22.0665	4.9424	1.0431	0.2172	9
	CW	16	95.2743	16.7852	4.2048	0.7404	0.1093	-*
	DO	12	96.7574	18.9190	4.5374	0.7691	0.0984	5
	SL	17	99.0416	15.2372	3.3489	0.5156	0.0648	9
	SG	20	98.3675	14.3511	3.2064	0.4210	0.0537	9
	JG	25	93.6055	15.3979	2.1152	0.2665	0.0325	P
	SG	30	20.0366	1.9689	0.1978	0.0190	0.0018	9
	OA	46	10.2287	1.2564	0.1237	0.0127	0.0015	P
	KJ	27	87.1308	5.6647	0.4403	0.0264	0.0012	9
	DH	40	6.9614	0.8376	0.0797	0.0057	0.0006	9
	HH	66	6.4763	0.5285	0.0419	0.0019	0.0002	P

Note: The true position represents the final ranking after the tournament, where 5 = round of 8, 9 = round of 16, and P = preliminary stage.
*CW was injured before the tournament and replaced by QA, who reached the round of 16.

Table 7.
Results of Tournament Rank Probability Score for the prediction of the world cup 2019. RF is the random forest, Flat refers to the flat prediction (equal chances for everyone) and RB is the rank-based reference prediction (higher ranked player wins).

	RF	***Flat***	***RB***
TRPS	**0.5478**	1.4338	0.7158

DISCUSSION

The two models compared in this work were chosen because of their previous performance in other sports (Groll, Schauberger, & Tutz, 2015; Groll A. , Ley, Schauberger, & Van Eetvelde, 2019a; Groll A. , Ley, Schauberger, Van Eetvelde, & Zeileis, 2019b; Groll, Heiner, Schauberger, & Uhrmeister, 2020). However, there is an abundance of modelling techniques that could have been used. Thus, this work can only give a first impression of how well a statistical model can perform.

In fact, as part of the initial research for this work other models were considered as well. A standard generalized linear model (Fahrmeir & Tutz, 2001) as well as a decision tree (Breiman, Friedman, Stone, & Olshen, 1984) were utilized. Since they belong to the same class of models like the LASSO and the random forest, respectively, only the latter – better performing – variants are shown here.

Additionally, instead of predicting the binary outcome of a match (win or loss), it was also considered predicting the difference in sets. This would allow to involve the notion of high wins or close matches, respectively. However, this approach yields a non-binary classification. The response variable (the difference in sets) is ordinal valued with results from the set {4, 3, 2, 1, -1, -2, -3, -4}. The results of this approach were all outperformed by the binary approach shown in this work and thus, not included here.

For comparing the statistical models to a reference, it is common to look at the bookmarker scores. Since in contrast to highly popular sports like football or tennis, for table tennis those were not freely accessible, a simple rank-based reference model was utilized. Alternatively, one could create a reference model that makes predictions based on the history of the two players and predicts according to the relative win frequency, e.g. with a history of 5-2 wins and losses for player A, the prediction would be 5/7. This would potentially result in probabilities that are not always 1 or 0, which would make it better to compare with the statistical model predictions. However, this approach was not suitable for the given data set, since it contained only very few match constellations that appeared frequently enough.

Both of the used R-functions (`glmnet` and `randomforest`) support multiple hyperparameters that can be tuned. This was not the focus of this work and thus, the standard settings have been used. For the two models it is expected that these are sufficient to compare the models appropriately, however, particularly the random forest's performance might further improve by performing a sophisticated and extensive tuning.

Data

In terms of the available data, one must state that the dataset in use is not very exhaustive. Only 419 matches are available. In future research, potentially other matches of tournaments like the Olympics or the World Table Tennis Championships could be incorporated as well. Here, it was avoided due to their slightly different tournament structure. Similarly, the available covariates are limited because of the lack of more detailed data. In other sports (e.g., football) there is a growing data pool of statistics. The amount of publicly available data in table tennis is rather small though. For example, it was not possible to get any data about betting odds for table tennis matches. This is unfortunate as these incorporate a considerable amount of information and are often regarded as a benchmark for predictions (Groll A. , Ley, Schauberger, & Van Eetvelde, 2019a). Nevertheless, more data about the players would already be of use for a better predictive performance. This data could include statistics like e.g., games played for the national team, participation in high level tournaments, number of attacks per set, points scored after serves or average match length for a specific player.

However, regarding the covariates that are present in the dataset, one can state that the most relevant information is included in the WTTR-points and WTTR-position. However, the results showed that the age also carries some predictive information. Furthermore, the models made use of individual player scores which act like a correction of the WTTR-points.

CONCLUSION

This work aimed to give a first overview over the predictive performance of two well-known modelling techniques for predicting table tennis matches. The linear regression approach, incorporated by the LASSO, yielded solid results, and allowed for a detailed interpretation of covariates. The random forest on the other hand, performed slightly better with respect to prediction and allowed also for an insight in the important covariates. Both models based their predictive power on the WTTR-points and WTTR-position which essentially represent the same information. And both models showed that other covariates like age and individual scores were also of importance. Out of the other available covariates, especially the handedness, grip and two continental combinations showed the most impact within the model.

Alternative versions of both models where the player-specific strength variable was removed yield slightly better results in terms of predictive performance. This renders our findings regarding over- and under performers inconclusive, albeit interesting. On a larger sample size, i.e. with more matches per player this variable could potentially become more reliable.

This work shows, that generally, it is possible to exploit available data for predicting table tennis matches. In the present case, the difference between the well interpretable LASSO and the more sophisticated random forest is not substantial. This allows for a detailed insight into the linear model (LASSO) without losing too much predictive power. The random forest shows a good performance in predicting table tennis matches and was able to predict the World Cup 2019 better than the rank-based reference with respect to the TRPS. This gives confidence that statistical methods for predicting table tennis matches have high potential. However, this potential will highly depend on the availability of more data regarding the table tennis sport.

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Monitoring technical tennis performance under increasing physical intensity by the PTTF-test

Supervisión del desempeño técnico en tenis cuando la intensidad física es cada vez mayor mediante la prueba PTTF

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Abstract

Monitoring technical skills under increasing physical intensity is important for determining a player's performance level in tennis. Therefore, the aim of this study was to determine to what extent the new Physical Technical Tennis-specific Field test (PTTF-test) was able to capture fluctuations in technical skill under increasing physical intensity in adolescent talented tennis players. Forty adolescent players (21 males, 19 females, mean age = 15.4 yrs) performed the PTTF-test until exhaustion (i.e., when they were not able to hit two subsequent oncoming balls with an adequate technique). Technical skills (stroke velocity, stroke accuracy, VA-index and percentage errors) were compared between physical intensity levels, age categories and genders. For all age categories and genders, physical intensity (heart rate) increased between the 'BASELINE'-situation and the 'FINAL'-situation (p<.001). All technical skills, i.e. stroke velocity, stroke accuracy, VA-index and percentage errors, decreased when comparing the FINAL intensity level to the BASELINE intensity level (p<.001). Players in older age categories (16+) reached a higher PTTFlevel and exhibited lower mean heart rates than players in the youngest age category (U14) in both the 'BASELINE'-situation and the 'FINAL'-situation depending on the level players reached (p<.010). These findings show that the PTTF-test is able to analyse and monitor the performance of technical skills under increasing physical intensity in adolescent talented tennis players.

Keywords: *Racket sports, field test, physical fitness, technical skills, tennis players, youth sports.*

Resumen

Supervisar las habilidades técnicas cuando la intensidad física es cada vez mayor es importante para determinar el nivel de desempeño de un jugador en tenis. Por lo tanto, el objetivo de este estudio fue determinar hasta qué punto la nueva prueba de campo físico-técnica específica para el tenis (prueba PTTF) puede capturar las variaciones en la habilidad técnica en jugadores talentosos de tenis adolescentes cuando la intensidad física es cada vez mayor. Cuarenta jugadores adolescentes (21 hombres, 19 mujeres, edad media = 15,4 años) completaron la prueba PTTF hasta el fallo (cuando en recepción no eran capaces de golpear dos pelotas sucesivas con una técnica adecuada). Las habilidades técnicas (velocidad del golpe, precisión del golpe, velocidad y precisión de la pelota y el porcentaje de error) fueron comparadas entre los niveles de intensidad física, las categorías por edad y el sexo. Para todas las categorías de edad y sexos, la intensidad física (frecuencia cardíaca) aumentó entre la situación BASE y la situación FINAL (p<.001). Todas las habilidades técnicas, i.e. velocidad del golpe, precisión del golpe, velocidad y precisión de la pelota y porcentaje de error, disminuyeron al comparar el nivel de intensidad FINAL con el nivel de intensidad de BASE (p<.001). Los jugadores en las categorías de mayor edad (16+) alcanzaron

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un nivel PTTF más alto y mostraron frecuencias cardíacas menores que los jugadores en la categoría más joven (U14) tanto en la situación BASE como en la FINAL dependiendo del nivel que los jugadores alcanzaban (p<.010). Estos hallazgos muestran que la prueba PTTF es capaz de analizar y supervisar el desempeño de las habilidades técnicas cuando la intensidad física es cada vez mayor en jugadores adolescentes de tenis talentosos.

Palabras clave: *deporte de raqueta, prueba de campo, estado físico, habilidad técnica, jugadores de tenis, deporte juvenil.*

INTRODUCTION

"You need to be constantly playing well throughout five hours if you want to win a match like this. I guess there is an endurance part." (Novak Djokovic about his win in 2019 over Roger Federer in the longest Wimbledon final in history (Amako, 2019)). This quote reflects the importance of maintaining high performance in tennis up to the end of every match. Even more, it reflects the importance of maintaining high performance under physically demanding situations, in which decrements of performance might be expected. Tennis performance is directly related to a player's technical skills. They are crucial for discriminating tennis players of various performance level (Baiget, Fernandez-Fernandez, Iglesias, Vallejo, & Rodriguez, 2014; Baiget, Iglesias, & Rodriguez, 2016; Del Villar, Garcia Gonzalez, Iglesias, Perla Moreno, & Cervello, 2007; Kolman, Huijgen, Kramer, Elferink-Gemser, & Visscher, 2017; Lyons, Al-Nakeeb, Hankey, & Nevill, 2013; Vergauwen, Spaepen, Lefevre, & Hespel, 1998; Vergauwen, Madou, & Behets, 2004). Though the importance of technical skills is undisputed, it seems especially important to persevere technical performance throughout the match. Also, under the prolonged physical demands towards the end of matches players need to retain their technical skills at a high level (Kovacs, 2004; Kovacs, 2007). Measuring technical skills under increasing physical intensity is difficult and no tests so far captured all relevant components.

Tennis is a sport with an intermittent profile (Kovacs, 2006). The aerobic and anaerobic energy demands are high throughout these intermittent profiled matches (Bangsbo, 1994; Kovacs, 2007). During long and high-intensity rallies, heart rates of 70-80% of the maximum heart rate and peak heart rates of 100% of the maximum heart rate are elicited (Baiget et al., 2014). The aerobic and anaerobic capacity of a tennis player may therefore highly influence individual performance and match outcome. Consequently, the monitoring of technical and physical skills under increasing physical intensity in a tennis-specific setting is valuable for determining a tennis player's performance level.

Technical skills may be evaluated based on stroke analysis (which captures the mechanical aspects of strokes), as well as based on stroke outcomes (such as stroke accuracy and stroke velocity). Further on, we continue using the term technical skills to describe the stroke outcomes. Technical tennis skills that are most often studied are stroke velocity and stroke accuracy. Stroke velocity (Kolman et al., 2017; Landlinger, Stöggl, Lindinger, Wagner, & Müller, 2012; Vergauwen et al., 1998; Vergauwen et al., 2004) and stroke accuracy (Baiget et al., 2014; Baiget et al., 2016; Del Villar et al., 2007; Kolman et al., 2017; Lyons et al., 2013; Vergauwen et al., 1998; Vergauwen et al., 2004) discriminate between players of different performance levels with better players reaching higher stroke velocities and being more accurate. Not surprisingly, a combination of stroke velocity and stroke accuracy, the VA-index also distinguishes tennis players of different performance levels (Kolman et al., 2017; Vergauwen et al., 1998). Moreover, higher ranked tennis players make fewer stroke errors than their lower ranked counterparts (Kolman et al., 2017; Vergauwen et al, 1998). Therefore, the proposed set of technical skills should contain stroke velocity, stroke accuracy, the VA-index and percentage of errors (PE).

The development of a player's tennis performance is influenced by individual, environmental and task constraints (Newell, 1986). Over time these constraints may change and therefore influence tennis performance. Especially within youth athletes, in which individual constraints change rapidly due to changes in biological development and training (Malina, Rogol, Cumming, Coelho e Silva, & Figueiredo, 2015), improvements but also stagnation in tennis performance are quite common. For instance, physical fitness has a uniform rapid development for male youth tennis players, whereas the development flattens out at the age of 14-15 years old for female youth tennis players (Faff, Ladyga, & Starczewska-Czapowska, 2000; Kramer, Huijgen, Elferink-Gemser, & Visscher, 2016). Although studies measuring technical skills over age are scarce, it has been established that forehand stroke velocity and backhand stroke velocity are positively correlated with age for male youth tennis players (González-González, Rodríguez-Rosell, & Clavero-Martin, 2018). Still, the lack of information regarding the development of the remaining technical skills over age shows the need for new studies. Therefore, capturing the differences of physical and technical skills between male and female tennis players over age will be an important topic within this study.

The interaction between a tennis player and its opponent makes individual tennis performance difficult to determine in matches, as the opponent influences a player's performance as well. Therefore, to capture a player's performance at a certain moment or to monitor progress over time, fixed field test protocols are valuable to measure tennis skills (Kolman et al., 2017; Landlinger et al., 2012; Lyons et al., 2013; Vergauwen et al., 1998; Vergauwen et al., 2004). Fixed field test protocols are essential to compare a player to another player or with performance benchmarks for performance discrimination purposes. Monitoring technical skills under increasing physical intensity is important for determining a tennis player's performance level in tennis. Test protocols including a tennis-specific execution of strokes in incremental stages to induce higher intensities and fatigue have been developed, such as the modified specific endurance field test and the TEST-protocol (Baiget et al., 2014; Brechbuhl, Girard, Millet, & Schmitt, 2016; Smekal et al., 2000). Yet, this specific endurance field test protocol lacks rest intervals given the intermittent character of tennis (Baiget et al., 2014) and the technical performance of strokes is no outcome measure of interest in the TEST protocol (Brechbuhl et al., 2016). Additionally, in these test protocols oncoming ball direction was alternately between the forehand and backhand side of the participant, leading up to a back-and-forth running protocol between the sidelines of the court. Such a back-and-forth running protocol is neglecting the importance of tennis-specific footwork between the strokes. Randomization of oncoming ball direction could solve this problem.

In order to successfully monitor technical tennis skills under increasing physical intensity in a maximized tennis-specific setting, a suitable field test protocol is required. Therefore, the TEST-protocol and specific endurance field test protocol (Baiget et al., 2014; Brechbuhl et al., 2016) will form the basis, and will be modified with respect to abovementioned required adjustments. The current study introduces the new Physical Technical Tennis-specific Field test (PTTF-test) protocol and aims to determine to what extent the PTTF-test is able to capture fluctuations in technical skill under increasing physical intensity in adolescent talented tennis players. The study aims to capture decreasing technical performance under increasing physical intensity. In addition, we will compare performance in the PTTF-test between age categories and between boys and girls. We hypothesize that the PTTF-test succeeds in capturing decreasing technical performance under increasing physical intensity for adolescent talented tennis players.

MATERIALS AND METHODOLOGY

Participants

The minimum age for participation was 12 years old. Participants were excluded in case of a health condition or injury that would make them unable to perform a physical test, or if they were not allowed by the trainer or medical staff. A total of 21 male tennis players (age 15.5 ± 2.5 yrs) and 19 female tennis players (age 15.2 ± 2.2 yrs) from the Netherlands participated in this study. They were considered elite players, as they were the nationally highest ranked performers within their age categories: U14, U16 and 16+ (see also Table 1).

Before the measurements, participants and their parents were fully instructed on the objective, design, method and risks of the test by an information letter. Both the participants and parents (if the participant was under the age of 16) provided written informed consent prior to inclusion within the study. The local ethical committee of the psychology department of the University of Groningen approved the study (PSY-1819-S-0262) that was performed consonantly to the ethical standards derived from the Declaration of Helsinki.

PTTF-test set-up

The measurements for this study took place on a hardcourt indoor tennis court. This court has a Playsight Smartcourt for video-review and analytics and as such is equipped with 10 on-court cameras. The system allows for the valid registration of stroke velocity and ball placement and the registration of session video material. To measure stroke accuracy, target areas were presented on-court to which participants were instructed to direct their strokes. Two target area's (squared plastic of 100.6 x 68.7 cm) were placed near the intersections of the baseline with both singles sidelines, precisely 100.6 cm from the baseline and 68.7 cm from the sidelines, as presented in Figure 1. Set-up of the target area's was based on the D4T test (Kolman et al., 2017), but exact dimensions were slightly adjusted to the pre-specified dimensions of the line system that is available in the Playsight Smartcourt software. During the PTTF-test protocol the participants were fed with regular tennis balls (Dunlop Fort Max TP) by a manually programmed ball machine (Promatch SmartShot Xtra). The ball machine was located in the middle of the court between the singles sidelines and 100.6 cm behind the baseline, as shown in Figure 1. Participants used their own tennis racket during the test protocol and wore a pulse monitoring belt (Polar Team² Pro) for heart rate registration.

PTTF-test protocol

Prior to the PTTF-test protocol, the participants performed a 5-min specific warming-up session, including running, arm rotations, lunges, squat jumps, sprints and 30 practice strokes fed by the ball machine. This warming-up session was created by and performed under the supervision of physical staff members. In the PTTF-test protocol the participants were fed with oncoming balls by the ball machine and instructed to hit both forehand and backhand strokes crosscourt towards the presented targets in an incremental physical intensity level design.

Participants were instructed to hit balls with "the best possible velocity-accuracy ratio", whereby slice strokes were not permitted. Physical intensity levels consist of 60 s activity, which are alternated with 30 s rest, as adopted from the TEST protocol (Brechbuhl et al., 2016). This rest period closely approaches the 25 s intervals between points in a tennis match. Oncoming ball frequency at the first intensity level is 12 strokes. min^{-1}. Physical intensity increases for every new level of 60 s. Oncoming ball frequency increases with 2 strokes. min^{-1} up to 18 strokes.min^{-1} at level 4. From level 5 and on, oncoming ball frequency increases with 1 stroke. min^{-1} per level. Oncoming ball direction, velocity and height are randomised within the intensity levels for the participants to evoke tennis-specific footwork between the strokes. Oncoming ball velocity was based on the D4T test and further adjusted during trials to induce more variability (Kolman et al., 2017). Eventually, oncoming ball velocity in the PTTF-test is randomised within the range of 60 and 80 kph. The randomised pattern varies per intensity level as well, to prevent for habituation of the pattern by the participant. The same standardized pattern of oncoming balls is presented to all participants to secure a standardized test protocol. The PTTF-test protocol ends with a participant's voluntary exhaustion or when the participant is not able to hit two subsequent oncoming balls with an adequate technique as determined by experienced coaches (hit the ball with the racket snares instead of the racket frame and hit the ball in a controlled manner in the direction of the net) or when the participant fails in striking three oncoming balls in total within a given intensity level.

Outcome variables PTTF-test

The determination of physical responses by Polar heart rate measurements has been commonly used throughout activity (Baiget et al., 2014; Baiget, Fernandez-Fernandez, Iglesias, Vallejo, & Rodriguez, 2015). This method for the determination of physical responses is a valuable tool in order to secure the ideal rest interval of tennis through the absence of any additional measurements during the rest intervals. The Polar pulse monitoring belts allow for the registration of participants' heart rate during the PTTF-test as a measure for physical intensity. The continuous registered heart rate data are used to calculate mean heart rate for every intensity level that the participant performed. PTTFlevel is the outcome measure of step-out moment from the test protocol.

For technical performance measurements, Playsight Smartcourt allows for the registration of stroke velocity and ball placement for every performed stroke within the PTTF-test. For stroke accuracy, strokes are awarded with a score of 1, 3, 6 or 9 points based on ball placement location as presented in Figure 1. Balls that landed outside of these point awarding zones, but inside the singles tennis field are awarded with a score of 0 points. Finally, strokes that landed outside the singles tennis field or strokes that ended up in the net were given a score of -1 points. With all data it was possible to calculate the outcome variables stroke velocity, stroke accuracy, the VA-index, PE for every intensity level that was performed by the participant. The VA-index is a validated combination score of stroke accuracy and stroke velocity in which stroke velocity is squared and therefore more rewarded due to the harder increment on higher scores (Kolman et al., 2017; Vergauwen et al., 1998). The VA-index is calculated by the following formula whereby stroke velocity is expressed in kph:

$$VA\text{ - }index = \frac{kph^2}{100} \; x \; \frac{\text{sum of achieved points for ball accuracy}}{\text{number of strokes } x \text{ (9)}}$$

PE is expressed by the number of errors as a percentage of the total strokes within a level. Strokes in the net, off-court or sliced strokes are counted as errors.

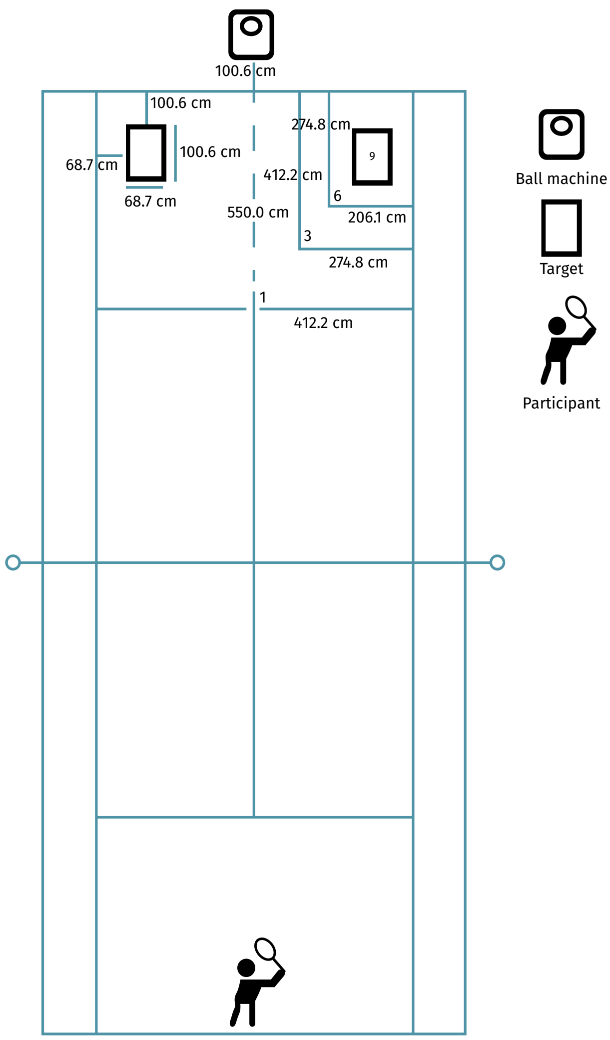

Figure 1. PTTF-test protocol set-up including the dimensions and location of the targets and the point awarding for stroke accuracy based on ball bounce location.

Statistical Analysis

Outcome variables are compared between situations with low physical intensity (LOW-Phys. Int.) and with higher physical intensity (HIGH-Phys. Int.). The 'BASELINE'-situation (LOW-Phys.Int.) is represented by the mean value of the outcome variables from intensity level 2 and intensity level 3 for every participant. Intensity level 1 is not included within the 'BASELINE'-situation, as it is a way for the participants to conform with the test protocol. The 'FINAL'-situation (HIGH-Phys.Int.) is participant-dependant and represented by the mean value of the outcome variables from the final two intensity levels that the participant performed during the PTTF-test.

The statistical analysis was executed with the software IBM SPSS statistics 23.0. The accuracy scores inter-rater reliability was determined with Cohen's kappa and by the examining of four full test protocols by two observers. Cohen's kappa for inter-rater reliability showed an excellent consensus between two observers for accuracy score determination based on ball bounce location, κ = .85 (p<.001).

At first, Analysis 1 was performed to compare the mean heart rates, PTTFlevel and the technical skills in both intensity situations between age categories and genders. A MANOVA analysis with age category and gender as grouping factors and with heart rate, stroke velocity, stroke accuracy, VA-index and percentage errors of both intensity situations and PTTFlevel all as dependant variables was performed as a basic comparison between groups. Analysis 2 assessed the increase in physical intensity between these situations by mean heart rate applying a repeated measures ANOVA with grouping factors age category and gender, and with the 'BASELINE'-situation and the 'FINAL'-situation as repeated measures. Analysis 3, a repeated measures MANOVA with grouping factors age category and gender, and with the 'BASELINE'-situation and the 'FINAL'-situation as repeated measures, was used to assess the effect of physical intensity on the set of outcome variables mean stroke velocity, mean stroke accuracy, the VA-index, and percentage errors. Follow-up univariate analyses are performed to check for the effect of physical intensity on the outcome variables separately. The combination of analysis 2 and analysis 3 will be used to determine the criterion validity of the PTTF-test for capturing decreasing technical performance under increasing physical intensity.

Checks for the normality of distribution, independence of measures, the homogeneity of covariance matrices and sphericity are performed. Sphericity is checked by Mauchly's test. In the case that sphericity assumption is violated, a Greenhouse-Geisser correction is used to adjust. The Bonferroni correction is performed for all post-hoc testing. Effect sizes in the data analysis are classified as large (η^2>0.14), medium (0.06<η^2<0.14) or small (0.01<η^2<0.06) (Cohen, 1988). For all data analysis the level of significance is set at an alpha of 5%.

RESULTS

Participants characteristics, and the PTTFlevel ('FINAL'-situation) for each age category and divided by gender, are presented within Table 1.

Table 1.
Participants characteristics (mean ± SD) and their final reached intensity level (PTTFlevel) per age category group, divided by males (♂, n=21) in 1a. and females (♀, n=19) in 1b.

1a. ♂	**U14 (n=7)**	**U16 (n=7)**	**16+ (n=7)**	**Total (n=21)**
Age (yrs)	13.2 ± 0.4	15.0 ± 0.5	18.3 ± 2.2	15.5 ± 2.5
Height (m)	159.8 ± 6.0	179.5 ± 6.0	189.4 ± 6.8	176.2 ± 13.9
Body Mass (kg)	43.1 ± 4.1	64.6 ± 7.5	81.3 ± 5.6	63.0 ± 16.9
Training background (y)	7.7 ± 1.0	7.9 ± 1.7	12.4 ± 1.8	9.3 ± 2.7
Tennis volume (h*week^{-1})	11.0 ± 1.4	12.6 ± 3.2	16.3 ± 4.3	13.3 ± 3.8
Physical volume (h*week^{-1})	4.3 ± 1.1	3.6 ± 0.6	5.0 ± 0.6	4.3 ± 1.0
PTTFlevel	7.8 ± 0.7	8.6 ± 1.2	10.0 ± 1.0	8.8 ± 1.3

1b. ♀	**U14 (n=7)**	**U16 (n=7)**	**16+ (n=5)**	**Total (n=19)**
Age (yrs)	13.2 ± 0.5	15.1 ± 0.6	18.3 ± 1.0	15.2 ± 2.2
Height (cm)	162.1 ± 4.9	171.1 ± 7.2	170.2 ± 7.2	167.5 ± 7.5
Body Mass (kg)	47.0 ± 6.1	61.1 ± 6.7	64.2 ± 4.0	56.7 ± 9.5
Training background (y)	7.3 ± 1.6	9.6 ± 1.7	11.4 ± 2.1	9.2 ± 2.4
Tennis volume (h*week^{-1})	9.9 ± 2.0	12.1 ± 1.4	16.6 ± 3.5	12.5 ± 3.5
Physical volume (h*week^{-1})	3.4 ± 0.9	4.5 ± 1.7	6.6 ± 1.1	4.6 ± 1.8
PTTFlevel	8.4 ± 1.3	8.4 ± 0.8	8.6 ± 1.5	8.4 ± 1.1

Analysis 1: comparison of the PTTF outcome variables in BASELINE and FINAL intensity situations between age categories and gender

The mean heart rates, mean stroke velocity, mean stroke accuracy, VA-index and PE in the 'BASELINE' and 'FINAL' situation and PTTFlevel are presented in Table 2, divided by age category and gender. The MANOVA found a multivariate Age category effect (F(22,48) =3.328, p=.000; Wilks' Lambda = 0.157, partial η^2 = 0.604). Univariate testing showed that the Age category effect was apparent for PTTFlevel (F(2,34) = 4.341, p=.021; partial η^2 = 0.203), mean heart rate in the 'BASELINE'-situation (F(2,34) =5.468, p=.009; partial η^2 = 0.243), mean stroke velocity in the 'BASELINE'-situation (F(2,34) =8.139, p=.001; partial η^2 = 0.324), VA-index in the 'BASELINE'-situation (F(2,34) =10.700, *p*=.000; partial η^2 = 0.386), mean heart rate in the 'FINAL'-situation (*F*(2,34) =6.958, *p*=.003; partial η^2 = 0.290), mean stroke velocity in the 'FINAL'-situation (*F*(2,34) =7.311, *p*=.002; partial η^2 = 0.301) and PE in the 'FINAL'-situation (*F*(2,34) =7.538, *p*=.002; partial η^2 = 0.307). The results derived from the subsequent Bonferroni post-hoc testing described the differences between the groups as illustrated in Table 2. No Gender effect or Age category x Gender interaction effect was revealed.

Analysis 2: The increase of physical intensity in the PTTF-test

The Repeated Measures ANOVA results regarding heart rate are presented in Table 3. Mean heart rate was significantly higher in the 'FINAL'-situation (190.5 ± 8.1) than in the 'BASELINE'-situation (174.1 ± 11.5); *F*(1,34) = 140.269, p=.000; Wilks' Lambda = 0.195, partial η^2 = 0.805. Furthermore, no significant interaction effects were found (Table 3). The mean heart rates in both intensity situations are illustrated in Table 2 for all age categories and divided by gender.

Analysis 3: The effect of physical intensity on technical performance

The repeated measures MANOVA found a significant effect of Intensity situation (*F*(4,31) = 75.931, p=.000; Wilks' Lambda = 0.093, partial η^2 = 0.907) and Intensity situation x Age category interaction effect (*F*(8,62) = 2.441, p=.023; Wilks' Lambda = 0.578, partial η^2 = 0.240).

Further univariate analyses are presented in Table 4 and illustrate that mean stroke velocity was significantly lower in the 'FINAL'-situation (94.3 ± 7.9) than in the 'BASELINE'-situation (101.6 ± 8.1); *F*(1,34) = 100.310, p=.000; partial η^2 = 0.747. Secondly, mean stroke accuracy was significantly lower in the 'FINAL'-situation (1.6 ± 0.6) than in the 'BASELINE'-situation (2,6 ± 0,5); *F*(1,34) = 144.388, *p*=.000; partial η^2 = 0.809. Furthermore, VA-index was significantly lower in the 'FINAL'-situation (16.1 ± 6.4) than in the 'BASELINE'-situation (30.5 ± 7.4); *F*(1,34) = 278.325, *p*=.000; partial η^2 = 0.891. Finally, PE was significantly higher in the 'FINAL'-situation (28.9 ± 9.4) than in the 'BASELINE'-situation (19.2 ± 9.3); *F*(1,34) = 32.353, *p*=.000; partial η^2 = 0.488.

Table 2.
Outcome variables for both intensity situations of the PTTF-test divided by age category and gender

	N	PTTFlevel	Heart rate (beats.min-1)	Stroke velocity (kph)	Stroke accuracy (points)	VA-index	PE(%)
			'BASELINE'- SITUATION				
♂ U14	7	n/a	181.8 ± 10.2	95.8 ± 6.5	2.7 ± 0.3	27.8 ± 5.4	12.4 ± 7.9
♀ U14	7	n/a	176.5 ± 10.6	95.4 ± 5.8	2.2 ± 0.4	22.2 ± 4.0	21.5 ± 11.9
Total U14	14	n/a	179.1 ± 10.4	95.6 ± 5.9	2.5 ± 0.5	25.0 ± 5.4	17.0 ± 10.8
♂ U16	7	n/a	179.6 ± 4.9	105.3 ± 5.5	2.6 ± 0.6	31.3 ± 5.6	21.0 ± 5.0
♀ U16	7	n/a	173.1 ± 11.4	101.5 ± 6.8	2.8 ± 0.4	31.8 ± 5.7	18.8 ± 8.9
Total U16	14	n/a	176.3 ± 9.1	103.4 ± 6.2*	2.7 ± 0.5	31.6 ± 5.5**	19.9 ± 7.0
♂ 16+	7	n/a	161.8 ± 12.6	107.7 ± 10.7	3.1 ± 0.6	39.3 ± 7.3	20.5 ± 11.8
♀ 16+	5	n/a	171.2 ± 7.7	104.8 ± 4.0	2.5 ± 0.1	30.2 ± 3.1	22.1 ± 7.6
Total 16+	12	n/a	165.7 ± 11.5** #	106.5 ± 8.4***	2.8 ± 0.5	35.5 ± 7.4***	21.2 ± 9.9
			'FINAL'-SITUATION				
♂ U14	7	7.8 ± 0.7	197.6 ± 9.9	90.3 ± 7.9	2.1 ± 0.8	19.7 ± 8.2	18.1 ± 8.5
♀ U14	7	8.4 ± 1.3	192.7 ± 5.9	87.6 ± 7.5	1.2 ± 0.3	10.3 ± 3.2	28.8 ± 3.1
Total U14	14	8.1 ± 1.0	195.1 ± 8.2	89.0 ± 7.5	1.7 ± 0.8	15.0 ± 7.7	23.5 ± 8.3
♂ U16	7	8.6 ± 1.2	191.4 ± 8.0	98.6 ± 3.6	1.4 ± 0.5	14.5 ± 5.6	31.9 ± 10.3
♀ U16	7	8.4 ± 0.8	190.2 ± 8.2	92.4 ± 6.7	1.7 ± 0.6	16.0 ± 6.4	26.0 ± 10.3
Total U16	14	8.5 ± 1.0	190.8 ± 7.8	95.5 ± 6.1*	1.6 ± 0.5	15.3 ± 5.9	28.9 ± 10.4
♂ 16+	7	10.0 ± 1.0	185.5 ± 4.0	98.9 ± 8.6	1.8 ± 0.4	19.7 ± 6.2	35.2 ± 6.3
♀ 16+	5	8.6 ± 1.5	183.7 ± 3.7	99.3 ± 4.4	1.5 ± 0.2	16.5 ± 1.8	35.5 ± 2.1
Total 16+	12	9.4 ± 1.4**	184.8 ± 3.8**	99.0 ± 6.9**	1.7 ± 0.4	18.3 ± 5.0	35.3 ± 4.8***

n/a. non applicable variable in the 'BASELINE'-situation;
In comparison with the Total U14 group: *. effect significant at the α=0.050 level; **. effect significant at the α=0.010 level; ***. effect significant at the α=0.001 level. In comparison with the Total U16 group: #. effect significant at the α=0.050 level.

Table 3.
Repeated Measures ANOVA Test of Within-Subjects Effects for Heart Rate in the PTTF-test.

Effect	MS**	df***	F	p	Partial Eta squared
IS*	5168.306	1	140.269	0.000#	0.805
IS* x Age category	20.744	2	0.563	0.575	0.032
IS* x Gender	16.543	1	0.449	0.507	0.013
IS* x Age category x Gender	112.236	2	3.046	0.061	0.152
Error	36.846	34			

*. Intensity Situation; **. mean square; ***. degrees of freedom; #. effect significant at the α=0.001 level.

With regard to the Intensity situation x Age category interaction, a significant effect was found on VA-index; ($F(2,34) = 6.432$, p=.004; partial $\eta^2 = 0.274$). However, the effect was not apparent for the remaining technical outcome variables. Table 2 shows the mean stroke velocity, mean stroke accuracy, VA-index and PE in both the intensity situations for all age categories and per gender.

DISCUSSION

The current study successfully introduced the new Physical Technical Tennis-specific Field test (PTTF-test) protocol which captures the fluctuations in technical skills under increasing physical intensity in adolescent talented tennis players. This study first compared performance in the PTTF-test between age categories and gender. Hereafter, we captured decreasing technical performance under increasing physical intensity.

At first, the mean heart rates, PTTFlevel and technical skills were compared in both the 'BASELINE' and 'FINAL' intensity situation between age categories and gender. Results from this analysis revealed that the 16+ group reached a higher PTTFlevel in the PTTF-test protocol and exhibited lower mean heart rates in both intensity situations than the U14 group. These results were not surprising, given the rapid development of physical fitness during this period of youth hood (Faff et al., 2000; Kramer et al., 2016). Faff and colleagues demonstrated that body mass, maximal oxygen uptake, maximal running speed, blood lactate concentration, and, to a lesser extent, speed of running at anaerobic threshold, increase with age in male and female tennis players from 12 to 24 years old (Faff et al., 2000). In addition, Kramer and colleagues showed that male as well as female junior elite tennis players improved on upper and lower body-power, speed and agility during U14-U16 (Kramer et al., 2016). Furthermore, we found that the U16 and 16+ groups performed higher mean stroke velocity values in the 'BASELINE'-situation and in the 'FINAL'-situation than the U14 group, which is in accordance with earlier research demonstrating that forehand stroke velocity and backhand stroke velocity are positively correlated with age for male youth tennis players (González-González et al., 2018).

Table 4.
Repeated Measures MANOVA Test of Within-Subjects Effects for technical performance in the PTTF-test.

Effect	Variable	MS**	df***	F	p	Partial Eta squared
IS*	Velocity	1037.817	1	100.310	0.000#	0.747
	Accuracy	19.923	1	144.388	0.000#	0.809
	VA-index	4042.995	1	278.325	0.000#	0.891
	Percentage Errors	1919.228	1	32.353	0.000#	0.488
IS* x Age category	Velocity	2.716	2	0.263	0.771	0.015
	Accuracy	0.255	2	1.849	0.173	0.098
	VA-index	93.430	2	6.432	0.004##	0.274
	Percentage Errors	92.122	2	1.553	0.226	0.084
IS* x Gender	Velocity	0.953	1	0.092	0.763	0.003
	Accuracy	0.003	1	0.023	0.881	0.001
	VA-index	5.543	1	0.382	0.541	0.011
	Percentage Errors	6.796	1	0.115	0.737	0.003
IS* x Age category x Gender	Velocity	16.736	2	1.618	0.213	0.087
	Accuracy	0.227	2	1.646	0.208	0.088
	VA-index	37.434	2	2.577	0.091	0.132
	Percentage Errors	11.626	2	0.196	0.823	0.011
Error	Velocity	10.346	34			
	Accuracy	0.138	34			
	VA-index	14.526	34			
	Percentage Errors	59.321	34			

* . Intensity Situation; ** . mean square; ***. degrees of freedom;
#. effect significant at the α=0.001 level; ##. effect significant at the α=0.010 level.

Second, the increase in physical intensity between the 'BASELINE'-situation and the 'FINAL'-situation of the PTTF-test protocol was assessed. The results showed that participants' mean heart rate was significantly higher in the 'FINAL'-situation than in the 'BASELINE'-situation. This confirms our hypothesis that the PTTF-test is able to analyse technical skills under increasing physical intensity, contributing to the criterion validity of the PTTF-test. The absence of interaction effects (intensity situation x gender, intensity situation x age category and intensity situation x age category x gender) confirms that this result is apparent for both male and female tennis players, as well as for the U14, U16 and 16+ age groups.

Third, the technical skill variables between the 'BASELINE'-situation and the 'FINAL'-situation were compared to analyse the effect of increasing physical intensity. The results revealed that intensity level influenced all technical skill variables. Scores for stroke velocity, stroke accuracy and VA-index were lower and PE were higher at the 'FINAL'-situation compared with the 'BASELINE'-situation, indicating that all technical skills decreased as physical intensity increased. Only an Intensity situation x Age category interaction effect for VA-index was found, the decrease of VA-index was more severe in the older age groups. The U16 and 16+ groups performed significantly better than the U14 group in the 'BASELINE'-situation; however, a difference in performance that was not apparent in the 'FINAL'-situation anymore. The absence of any further interaction effects suggests that the decrease of the technical skills stroke velocity, stroke accuracy and PE by increased physical intensity holds for all age categories and gender. These results contribute to confirmation of the criterion validity of the PTTF-test for capturing decreasing technical performance under increasing physical intensity.

The current study has established a test protocol which captures the decrease in technical skills under increasing physical intensity in adolescent talented tennis players. The technical skills stroke velocity, stroke accuracy, VA-index and PE are yet well studied. Regarding their discriminative value for performance level, stroke velocity (Kolman et al., 2017; Landlinger et al., 2012; Vergauwen et al., 1998; Vergauwen et al., 2004), stroke accuracy (Baiget et al., 2014; Baiget et al., 2016; Del Villar et al., 2007; Kolman et al., 2017; Lyons et al., 2013; Vergauwen et al., 1998; Vergauwen et al., 2004), VA-index (Kolman et al., 2017; Vergauwen et al., 1998) and PE (Kolman et al., 2017; Vergauwen et al, 1998) have all been able to discriminate between tennis players of different performance levels. However, the discriminative value of their decrease under increased physical intensity has yet to be determined. In the current study, only elite performers per age category have been included. As such, it remains interesting to investigate how technical skills fluctuate under increasing physical intensity for sub-elite and novice tennis players to be able to monitor their performance as well. Therefore, future research is needed in tennis players of different performance levels. Even more to further support the criterion validity of the PTTF-test.

Regarding the method, no measures for test-retest reliability were part of this study, which can be considered a limitation. However, from multiple cited on-court tennis tests we know that test-retest reliability is often very good (Baiget, et al., 2014; Kolman et al., 2017; Smekal et al., 2000). Still, we recommend test-retest reliability measures for future research with the PTTF-test. The results for inter-rater reliability showed an excellent consensus between two observers for accuracy score determination based on ball bounce location. The use of Playsight Smartcourt for video review of ball bounce location has contributed to this result and is an advantage of the PTTF-test protocol. Additionally, the sample size in this study might be considered as a limitation. In terms of feasibility, one has to realize that the test takes quite some time to administer. In addition, not all tennis courts are equipped with high-tech video review systems and ball machines with adjustable programs which can be considered as limitations of the PTTF-test, which challenge reproducibility of this study.

The PTTF-test provides a new method for capturing decreasing technical skills under increasing physical intensity for well-trained boys and girls of different age categories. Future research should investigate whether the PTTF-test is applicable for coaches to discriminate between players' performance levels even further. Implications for coaches and tennis players so far might be to implement the PTTF-test at the beginning and the end of a determined time period in order to monitor tennis players' progress. The PTTF-test might be used for the monitoring of baseline technical skills, the decrease of technical skills under physical intensity or physical fitness in a tennis-specific setting by monitoring the reached final intensity level of the PTTF-test.

CONCLUSIONS

In this study the PTTF-test protocol was successfully introduced as a new method for capturing decreasing technical performance under increasing physical intensity. At first, results showed that the older age group (16+) reached a higher PTTFlevel in the PTTF-test protocol and exhibited lower mean heart rates in both intensity situations (BASELINE versus FINAL) than the youngest age group (U14). The results showed an increase in physical intensity (heart rate) between the 'BASELINE'-situation and the 'FINAL'-situation of the PTTF-test protocol for all age categories and both genders. The results revealed that all technical skills decreased when comparing the FINAL intensity level to the BASELINE intensity level. The current test PTTF protocol is a promising test for coaches and players to analyse and monitor the performance of technical skills under increasing physical intensity.

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