Abstract

Background: A player’s fitness can be a key factor that may make the difference between victory and failure. Because technical and tactical skills are predominant factors in tennis it is of great importance to organize the fitness training as efficient and time saving as possible. The German Tennis Federation (DTB) has established a biannual nationwide physical testing including ~ 400 squad players. The results obtained are used for basic talent identification as well as the development of training guidelines, including individualized training programs. The present article shows the concept for fitness testing and training design of the DTB. Two sample player profiles are presented to show the usefulness of the testing protocols and the individual conclusions obtained in order to design individualized training programs.

Material and Methods: Between the years 2009 and 2013, the sample of the 1052 best male and female junior players in Germany was evaluated using a battery of standard anthropometric and physical performance tests. Players were recruited from their respective regional federations and all the athletes were tested twice a year in a three week period.

Results: The individualized training programs are based on established percentiles considering sex, chronological age and the stage of maturation. Results show individual profiles of two players, including the percentile rank relative to their peers and related to both, their chronological and biological age.

Conclusions: The results enable the identification of weaknesses in different parameters and allow to design efficient physical training programs. Regarding the limited training time and the great amount of time needed to improve tennis specific skills this approach enables a more efficient way to design physical training programs.

Keywords
Talent identification – testing – physical fitness – tennis

A. Ulbricht et al.

ORIGINALARBEIT/ORIGINAL PAPER

Conception for Fitness Testing and Individualized Training Programs in the German Tennis Federation

Alexander Ulbricht, Jaime Fernandez-Fernandez, Alexander Ferrauti
Department of Training and Exercise Science, Faculty of Sports Science, Ruhr-University Bochum, Germany

Eingegangen/Submitted: 14.05.2013; akzeptiert/Accepted: 12.07.2013

Introduction

In tennis, the sport-specific technical skills are predominant factors (e.g., racket and ball handling skills and stroke techniques) [28]. However, the player’s fitness can be a key factor that may make a difference between victory and failure. It is widely accepted that to execute advanced shots and to compete effectively against progressively more elite opponents, players require higher levels of physical fitness [8]. It has been suggested that tennis players require a mixture of speed, agility, and power combined with medium to high aerobic and anaerobic capacity. Thus, successful performance cannot be defined by one predominant physical attribute; tennis requires on a complex interaction of several physical components and metabolic pathways [8,12,18].

It is important that the player and coach obtain objective information about the players’ physical performances to clarify the objectives of training, plan short- and long-term training programs, provide objective feedback and motivate the player to train harder [29]. Competition naturally provides the best test for an athlete, but in an athletic activity as complex as tennis it is difficult to isolate the various components within the sport and get objective measures of performance. Thus, fitness testing can provide relevant information about specific parts of the sport [23]. Moreover, specific training programs can then be designed based on the players’ fitness testing results. From a practical point of view, the goals of testing are to enhance a player’s performance (i.e., providing individual profiles of their respective strengths and weaknesses), reduce the risk of injury and design an appropriate training program so that the athlete’s playing career can be as long as possible [18,27].

During the last few years, tennis players have been observed to devote a great amount of time to improve their tennis skills throughout technical and tactical training, with an average of 15–20 h of technical training per week even at a young age [6]. Because technical and tactical skills are predominant factors in tennis [10], coaches tend to place their training priorities on technical/tactical contents, and therefore, only just a minimum of specific physical training sessions
Zusammenfassung

Hintergrund: Im modernen Leistungs- 
tennis gewinnt die Athletik zunehmend an Bedeutung, obwohl Technik und Tak- 
tik nach wie vor primär leistungslimitie- 
rend sind. Folglich sollte das Konditions- 
training möglichst individualisiert und 
dadurch ressourcensparend sein. Der 
Deutsche Tennis Bund betreibt seit vier 
Jahren eine konditionelle Leistungsdiag-

nositik mit allen Kaderspielern auf des-

ten Grundlage individuell angepasste 
Trainingsempfehlungen gegeben wer-

den. Der vorliegende Beitrag beschreibt 
die Durchführung der Testbatterie und 
verdeutlicht anhand von zwei Fallbe-

dielen den Wert von differenzierten 
leistungsdiagnostischen Befunden fü-

r eine individuelle zielgerichtete Ausrich-
tung des Konditionstrainings.

Methoden: Im Zeitraum von 
2009-2013 nahmen 1052 männliche 
und weibliche C-/D-Kaderspieler im 
Alter von 10 bis 18 Jahren am „DTB-

Konditionstest“ teil. Dieser beinhaltet 
standardisierte anthropometrische und 
 konditionelle Untersuchungen.

Resultate: Grundlage der individuellen 
Leistungssteuerung ist der Vergleich 
der Individualbefunde mit alters-, ge-

schlechts- und entwicklungsrelatier-

nen Normprofilen, deren Anwendung 
anhand von zwei Beispielen verdeut-
lucht wird. Die entwickelten Normpro-

file basieren auf Halbjahresgruppierun-

gen und berücksichtigen sowohl das 
chronologische als auch das biologi-

sche Alter.

Schlussfolgerungen: Die Fallbeispiele 
verdeutlichen die Notwendigkeit ent-

wicklungsrerlativer Normprofile für 
eine individuelle, zielgerichtete Aus-

richtung des Konditionstrainings. Auf 
der Grundlage der Ergebnisse werden 
eindeutige Stärken und Schwächen in 
den unterschiedlichen motorischen 
Hauptfaktoren deutlich gemacht, so 
kann eine klare Schwerpunktsetzung 
für das Training empfohlen werden.

Schlüsselwörter
Talentforschung – Leistungsdiagnostik – DTB-Kon-
ditionstest – Tennis

per week can be programmed. As a 
consequence, training strategies 
aiming for fitness improvements (i. 
e., based on the individual profiles 
of strengths and weaknesses) are 
warranted.

Norm values and percentile tables 
for junior tennis players which have 
been generated and used to assess a 
given performance are commonly 
based on chronological age 
[3,17,26]. However, since there is 
a large variation in physical, 
emotional and cognitive develop-

ment of athletes in adolescence 
(i.e., fundamental changes in bi-

ological characteristics at the age of 
12-15 years) [19], it seems that 
chronological age is not a good 
indicator on which to base athletes 
training programs. A practical 
approach to design optimal individ-

ual training programs which are 
related to certain periods of train-

ability during the process of matu-
ration is the use of an athlete's peak 
height velocity (PHV) as a reference 
point [13]. The PHV is the fastest 
rate of growth during the adolescent 
growth spurt, and can be a useful 
reference point providing valuable 
information about an individual's 
stage of maturation, enhancing the 
efficiency of development train-

ing, competition and recovery pro-

grams [1]. Established profiles just 
based on the chronological age do 
not consider the individual stage of 
maturaiton, thus obviously repres-

enting a weakness in the testing 
procedures.

Thus, the aim of this study is to 
establish percentiles based on nor-

mative data of physical fitness test-
ing for tennis players based on 
chronological and biological age 
and to present the concept for fit-

ness testing and training design of 
the German tennis federation 
including player profiles which in 
addition to chronological age con-

side the stage of maturation and 
which can be used as a reference 
to design individualized training 
programs.

Methods

Participants

Between the years 2009 and 2013, 
the sample of the 1052 best male 
and female junior players in 
\[...\] Germany was evaluated using a bat-
tery of standard anthropometric and 
physical performance tests (i.e., The 
German Physical Condition Tennis 
Test). Players were recruited from 
their respective regional federations 
and all the athletes were tested 
twice a year in a three week period 
(March and September). Players 
were tested at their respective fed-
eration base and passed four 
stations of different testing pro-
dcedures in a group of three, spend-
ing 30 minutes for each station; 
accordingly an overall time of 
approximately two hours was 
required for a players testing. To 
ensure standardization of test 
administration across the entire 
study period, all tests were carried 
out in the same order and using the 
same testing devices and 
supervisors.

Measurements

All fitness tests were performed in an 
indoor facility (i.e., tennis court 
(Rebound Ace surface) and physio-
therapy room) (\ref{tab:1}). Testing 
began after a 15 min individual 
warm-up, which consisted of low-

intensity forward, sideways, and 
backwards running, multi-direction-
al acceleration runs, skipping 
and hopping exercises, and jumps 
of increasing intensity.

Anthropometrics

Sessions started with the measure-
ments of players’ body dimensions 
which included; body height, body
mass and sitting height. Body height was measured with a fixed stadiometer (±0.1 cm, Holtain Ltd., Crosswell, UK), sitting height with a purpose-built table (±0.1 cm, Holtain Ltd., Crosswell, UK), body mass with a digital balance (±0.1 kg, ADE Electronic Column Scales, Hamburg, Germany).

**Grip strength**
Handgrip strength was measured using a hydraulic hand dynamometer (Baseline®; Irvington, NY). The subject was asked to perform a maximal voluntary contraction, standing with the dynamometer at one side (i.e., dominant hand) and gripping the dynamometer as hard as they could, for 3 s. 2 trials were performed for each hand (i.e., dominant and non-dominant hand). The average of the 2 trials for each hand was considered to be the maximum voluntary handgrip strength [16]. Dominant and non-dominant hand was tested.

**Push-up Test**
Subjects were asked to perform as many push-ups as possible [7]. Subjects were asked to do the following: place hands approximately 0.10–0.20 m wider than shoulder width, and maintain a horizontal spinal position (i.e., maintaining a straight-leg position, with their knees off of the mat). All subjects were required to bend their elbows to lower their body until the chest was approximately 12 cm from the mat while maintaining the prescribed position with their backs. The subjects extended the elbows, returning to the start position. The speed of movement was controlled with an audio pacer set to 3 s for each repetition. The maximum number of repetitions performed with an appropriate technique (a maximum was set to 50) was retained.

**Sit-up Test**
Subjects were asked to lie on a mat in a face up position with the knees bent at right angles [7]. The feet were placed flat on the mat and the subjects’ arms were extended down to the sides (i.e., hands toward sides of heels during the movement), the position was supervised by the co-examiner. When the examiner signaled “go”, a timer was started and the subjects performed as many repetitions as possible. The speed of movement was controlled with an audio pacer set to 3 s for each repetition. The maximum number of repetitions performed with an appropriate technique (a maximum was set to 50) was retained.

**Vertical Jumping**
Countermovement jumps (CMJ) without arm swing were performed on a contact platform (Haynl Elektronik, Germany) according to Bosco et al [4]. Each player performed 2 maximal CMJs interspersed with 45 seconds of passive recovery, and the best jump (i.e., highest height attained) was retained for further analysis [4].

**Repetition Jumps**
Repetition Jumps were performed with hands kept to the hips. Subjects were asked to keep their knees as stiff as possible and to have as brief a contact time as possible [14]. From the flight and contact time jump efficiency (flight time²/contact time) was calculated [20].

**Twenty-meter Sprint Run**
Time during a 20-m dash in a straight line (with 5 and 10 m split times) was measured by means of single beam photocell gates placed 1.0 m above the ground level (Sportronic TS01-R04, Leutenbach-Nellmersbach, Germany). Each sprint was initiated from an individually chosen standing position, 50 cm behind the photocell gate, which started a digital timer. Each player performed 2 maximal 20-m sprints interspersed with 3 minutes of passive recovery, and the fastest time achieved was retained.

**Tennis specific sprint test**
Players performed a tennis specific sprint test (TSS) to the forehand and backhand side. For the TSS, a special testing device was used, which
consisted of a twofold signal panel with two light-emitting diodes (LEDs) (right-left). By activating one LED of the signal panel (i.e., and remaining on during the whole repetition), the time was initiated. The player stood with his racket in a frontal position (i.e., looking to the net) in the middle of the baseline. Upon seeing a signal, players turned sideward and ran to the prescribed backhand or forehand corner. The players were instructed to run forward in a straight line, perform a stroke simulation against a ball pendulum (PracticeHit®, WA, USA) and turn 180° when their feet were in line with the hitting-turning point marked with the ball pendulum. After performing the stroke, they returned to the initial position. Each sprint time was measured using a photocell system (Sportronic TS01-R04, Leutenbach-Nellmersbach, Germany). Each player performed 2 maximal repetitions to each side, interspersed with 90 s rest of passive recovery, and the fastest time achieved was recorded.

Serve velocity
A radar gun (Stalker Professional Sports Radar, Radar Sales, Plymouth, MN) was used to measure first-serve. The radar was positioned on the center of the baseline, 4 m behind the server, aligned with the approximate height of ball contact and pointing down the center of the court. The serves for subjects who were right-handed served to the left serve box (from the right) and the ones who were left-handed served at the right serve box (from the left).

Medicine Ball Throws (MBT): overhead, forehand and backhand
For the overhead MBT the players stand at a line with the feet side by side and slightly apart, and facing the direction to which the ball is to be thrown, holding a 2 kg medicine ball. The ball is brought back behind the head, and then thrown vigorously forward as far as possible, without crossing the line. Additionally, players performed a forehand and backhand MBT according to previous methods [27]. Players stood sideways to the starting line and simulated a forehand/backhand stroke tossing the ball as far as possible, without crossing the line. For all MBT, the distance from the line to the point where the ball lands was measured and the best performance, among two efforts, was recorded to the nearest 5 cm.

Hit & Turn Tennis test
The Hit and Turn Test was developed as an acoustically controlled progressive on-court fitness test for tennis players, which can be performed simultaneously by one or more players [11]. The test involves specific movements along the baseline (i.e., side steps and running), combined with forehand and backhand stroke simulations at the doubles court corner (distance 11.0 m) (Figure 1). At the beginning of each test level, the players stand with their racket in a frontal position in the middle of the baseline. Upon hearing a signal, the player turns sideways and runs to the prescribed (i.e., by a CD player) backhand or forehand corner. After making their shot, they return to the middle of the court using side steps or crossover steps (while looking at the net). When passing the middle of the baseline again, they turn sideways and continue to run to the opponent’s opposite corner. The end of the test was considered when players fail to reach the cones in time or was no longer able to fulfill the specific movement pattern. Maximal completed level was used for the determination of the tennis-specific aerobic fitness. Figure 1.

Maturity status
Pubertal timing was estimated according to the biological age of maturity of each individual as described by Mirwald et al. [22]. The age of peak linear growth (age at peak height velocity) is an indicator of somatic maturity representing the time of maximum
growth in stature during adolescence [22]. Biological age of maturity (years) was calculated by subtracting the chronological age at the time of measurement from the chronological peak-velocity age [2,22]. Thus, a maturity age of -1.0 indicates that the player was measured 1 year before this peak velocity; a maturity of 0 indicates that the player was measured at the time of this peak velocity; and a maturity age of +1.0 indicates that the participant was measured 1 year after this peak velocity [21].

Calculations and statistics

In a first step participants were grouped by gender and chronological age. Half year categories were used to create 12 age groups (from younger than 11 to older than 16 years of age) (Table 2). The means and standard deviations for each test were calculated according to the age and gender groups.

In a second step the Age of Peak Height Velocity was calculated for all participants. Half year categories were used to create 12 biological age groups (more than 2.5 years before APHV to more than 2.5 years away from APHV) (Table 3). The means and standard deviations for each test were calculated according to the created biological age and gender groups.

After the means and standard deviations were calculated, percentile tables were established for each of the groupings (by age (biological and chronological) and gender). A percentile is defined as the point on the distribution below which a given percentage of the scores is found and it can be used to give a norm-referenced interpretation of an individual fitness score within a distribution that often consist of scores from a comparable group of individuals [24]. In the present case using the German Physical Condition Tennis Test protocol, all regional squad players in Germany can be compared using the normative data and the percentile tables. Additionally, individual player profiles were established (Figures 2 and 3). In order to provide a better interpretation of the results for coaches and athletes, as well as an easy way to detect weaknesses, four major performance categories were created (strength (including grip strength, push-ups and sit ups), power (medicine ball throws and serve velocity), speed and jumping (counter movement jump, repetition jumps, linear and tennis specific sprints) and endurance (Hit & Turn Tennis Test)). Results are presented in a “spider” diagram.

Results

Table 4 shows an example of the percentiles obtained for male players from 15.0 to 15.5 years old. Table 5 shows an example of (all percentiles can be downloaded from www.spowiss.rub.de/trawi/) the percentiles obtained for male players -0.5 to 0.0 years before PHV.

| Table 2. Overview of the participants according to gender and chronological age (HJ = half year, (1HJ players are aged i.e. 11.0 to 11.49, 2HJ players are aged from 11.5 to 11.99 years old). |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Years of Chronological Age | sex | n | < 11 | 11.1 HJ | 11.2 HJ | 11.2 HJ | 12.1 HJ | 12.2 HJ | 12.2 HJ | 13.2 HJ | 13.2 HJ | 14.2 HJ | 14.2 HJ | 15.2 HJ | 15.2 HJ | >= 16 |
| Female | 418 | 21 | 36 | 40 | 35 | 71 | 43 | 31 | 29 | 42 | 27 | 22 | 21 |
| Male | 634 | 22 | 47 | 57 | 57 | 94 | 58 | 59 | 56 | 64 | 54 | 34 | 32 |
| Total | 1052 | 43 | 83 | 97 | 92 | 165 | 101 | 90 | 85 | 106 | 81 | 56 | 53 |

| Table 3. Overview of the participants according to gender and biological age (ranging from more than 2.5 years before PHV to more than 2.5 years away from PHV). |
| Years to/from Peak Height Velocity | sex | n | < -2.5 | -2.5 to -2.0 | -2.0 to -1.5 | -1.5 to -1.05 | -1.0 to -0.5 | -0.5 to 0 | 0 to 0.5 | 0.5 to 1 | 1 to 1.5 | 1.5 to 2.0 | 2.0 to 2.5 | 2.5 to 3.0 |
| Female | 418 | 0 | 4 | 18 | 27 | 37 | 39 | 48 | 53 | 51 | 51 | 52 | 52 | 38 |
| Male | 634 | 38 | 64 | 87 | 84 | 59 | 49 | 50 | 42 | 44 | 39 | 40 | 38 |
| Total | 1052 | 38 | 68 | 105 | 111 | 96 | 88 | 98 | 95 | 95 | 90 | 92 | 76 |
Table 4. Percentile table for male athletes aged 15.0 to 15.5 years old (n=54). Average values and standard deviation (±SD) are presented (dh=dominant hand, ndh=non-dominant hand; BM=body mass, BMI=body mass index, CMJ=counter movement jump; RJ=repetition jumps, FH=forehand, BH=backhand).

<table>
<thead>
<tr>
<th>Chronological Age 15.0 to 15.5</th>
<th>Anthropometry</th>
<th>Strength</th>
<th>Speed &amp; Jumping</th>
<th>Upper Body Power</th>
<th>Endurance</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean ± SD</td>
<td>177.4 ± 6.5</td>
<td>65.5 ± 7.3</td>
<td>20.8 ± 1.7</td>
<td>42.8 ± 8.3</td>
<td>37.6 ± 7.8</td>
</tr>
<tr>
<td>Percentiles</td>
<td>10 168.4</td>
<td>53.9 18.6</td>
<td>31 27 14 13</td>
<td>33.5 1.12</td>
<td>1.94 3.35</td>
</tr>
<tr>
<td></td>
<td>20 171.3</td>
<td>61.0 19.0</td>
<td>35 29 16 19</td>
<td>34.6 1.22</td>
<td>1.90 3.31</td>
</tr>
<tr>
<td></td>
<td>30 172.9</td>
<td>63.2 19.8</td>
<td>38 33 18 23</td>
<td>35.0 1.31</td>
<td>1.88 3.28</td>
</tr>
<tr>
<td></td>
<td>40 175.6</td>
<td>63.9 20.4</td>
<td>40 36 21 26</td>
<td>35.7 1.39</td>
<td>1.86 3.24</td>
</tr>
<tr>
<td></td>
<td>50 177.5</td>
<td>65.5 21.0</td>
<td>42 38 22 31</td>
<td>36.9 1.43</td>
<td>1.85 3.22</td>
</tr>
<tr>
<td></td>
<td>60 179.0</td>
<td>67.0 21.3</td>
<td>45 39 24 36</td>
<td>38.6 1.47</td>
<td>1.84 3.15</td>
</tr>
<tr>
<td></td>
<td>70 181.1</td>
<td>68.9 21.6</td>
<td>47 41 25 41</td>
<td>39.1 1.52</td>
<td>1.79 3.12</td>
</tr>
<tr>
<td></td>
<td>80 184.0</td>
<td>70.9 21.9</td>
<td>52 45 28 48</td>
<td>40.0 1.68</td>
<td>1.76 3.09</td>
</tr>
<tr>
<td></td>
<td>90 185.4</td>
<td>74.7 23.2</td>
<td>54 49 30 50</td>
<td>43.3 1.85</td>
<td>1.72 3.01</td>
</tr>
</tbody>
</table>
Table 5. Percentile table for male athletes -0.5 to 0.0 years before PHV (n=49). Average values and standard deviation (±SD) are presented (dh=dominant hand, ndh=non-dominant hand; BM=body mass, BMI= body mass index, CMJ= counter movement jump; RJ= repetition jumps, FH=forehand, BH=backhand).

<table>
<thead>
<tr>
<th>Years to PHV -0.5 to 0.0</th>
<th>Anthropometry</th>
<th>Strength</th>
<th>Speed &amp; Jumping</th>
<th>Upper Body Power</th>
<th>Endurance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Height [cm]</td>
<td>BM [kg]</td>
<td>BMI [kg/m²]</td>
<td>Grip strength [cm]</td>
<td>Push ups [cm]</td>
</tr>
<tr>
<td>mean</td>
<td>167.3</td>
<td>52.1</td>
<td>18.6</td>
<td>31.1</td>
<td>26.7</td>
</tr>
<tr>
<td>± SD</td>
<td>± 4.5</td>
<td>± 4.6</td>
<td>± 1.3</td>
<td>± 5.0</td>
<td>± 4.6</td>
</tr>
<tr>
<td>Percentiles</td>
<td>10</td>
<td>162.0</td>
<td>47.0</td>
<td>16.8</td>
<td>25</td>
</tr>
<tr>
<td>20</td>
<td>162.5</td>
<td>48.0</td>
<td>17.6</td>
<td>18.2</td>
<td>28</td>
</tr>
<tr>
<td>30</td>
<td>163.7</td>
<td>49.2</td>
<td>18.2</td>
<td>18.3</td>
<td>30</td>
</tr>
<tr>
<td>40</td>
<td>165.5</td>
<td>50.6</td>
<td>18.3</td>
<td>18.3</td>
<td>30</td>
</tr>
<tr>
<td>50</td>
<td>167.0</td>
<td>51.4</td>
<td>18.6</td>
<td>18.6</td>
<td>30</td>
</tr>
<tr>
<td>60</td>
<td>169.1</td>
<td>53.0</td>
<td>18.8</td>
<td>18.8</td>
<td>31</td>
</tr>
<tr>
<td>70</td>
<td>169.8</td>
<td>54.1</td>
<td>19.1</td>
<td>19.1</td>
<td>32</td>
</tr>
<tr>
<td>80</td>
<td>170.8</td>
<td>56.0</td>
<td>19.5</td>
<td>19.5</td>
<td>34</td>
</tr>
<tr>
<td>90</td>
<td>175.1</td>
<td>60.2</td>
<td>20.8</td>
<td>20.8</td>
<td>38</td>
</tr>
</tbody>
</table>
**Testing March 2013**

**Antropometrics**

<table>
<thead>
<tr>
<th>Date of birth</th>
<th>01.12.1997</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age of Peak Height Velocity (PHV)</td>
<td>13,5</td>
</tr>
<tr>
<td>Years to PHV</td>
<td>1,8</td>
</tr>
<tr>
<td>Sex</td>
<td>male</td>
</tr>
<tr>
<td>Handedness</td>
<td>right</td>
</tr>
<tr>
<td>Chronological age</td>
<td>[years]</td>
</tr>
<tr>
<td></td>
<td>13,3</td>
</tr>
<tr>
<td>Height</td>
<td>[cm]</td>
</tr>
<tr>
<td>Body Mass</td>
<td>[kg]</td>
</tr>
<tr>
<td>BMI</td>
<td>[kg/m²]</td>
</tr>
</tbody>
</table>

**Power**

| Grip strength D           | [kg]  | 31 | 39 | 39 | 48 | 53 | 80-90 | >90 |
| Grip strength ND          | [kg]  | 28 | 30 | 34 | 40 | 44 | 70-80 | 80-90 |
| Peak up test              | [s]   | 15 | 21 | 23 | 25 | 25 | 70-80 | 60-70 |
| Sit up test               | [s]   | 25 | 26 | 23 | 23 | 21 | 20-30 | 20-30 |

**Upper body power**

| Serve velocity            | [km/h] | 139,6 | 150,8 | 150,9 | 167,3 | 175,6 | 70-80 | 60-70 |
| Serve accuracy            | [P]    | 2     | 4     | 4     | 5     | 3     |
| Medicine ball throw over head | [cm]  | 810 | 913 | 950 | 1090 | 1090 | 80-90 | 70-80 |
| Medicine ball throw forehand | [cm]  | 800 | 885 | 1120 | 1140 | 1220 | 50-60 | 40-50 |
| Medicine ball throw backhand | [cm]  | 850 | 990 | 1090 | 1120 | 1210 | 60-70 | 60-70 |
| Jumping ability           | [cm]   | 40,7 | 43,3 | 41,1 | 45,8 | 48,7 | >90   | >90 |

**Repetition jumps**

| Contact time              | [ns]   | 156,0 | 151,7 | 158,3 | 166,7 | 161,7 |
| Jump height               | [cm]   | 38,7 | 38,0 | 33,8 | 40,5 | 41,6 |
| Efficiency                | [index] | 2,02 | 2,65 | 1,74 | 2,01 | 2,10 | >90   | >90 |

**Complex Speed**

| Linear sprint             | [s]    | 1,84 | 1,79 | 1,79 | 1,71 | 1,69 | >90   | >90 |
|                          | [s]    | 3,18 | 3,12 | 3,10 | 3,05 | 2,93 | >90   | >90 |

**Tennis specific sprint**

| Forehand                  | [s]    | 2,73 | 2,69 | 2,73 | 2,65 | 2,69 | 60-70 | 50-60 |
| Backhand                  | [s]    | 2,76 | 2,82 | 2,86 | 2,62 | 2,77 | 80-90 | 80-90 |

**Tennis specific endurance**

| H1k and T1m Test          | [Level] | 14,0 | 14,7 | 15,1 | 16,0 | 15,6 | 20-30 | 20-30 |
| H1max                     | [h/min] | 195 | 192 | 198 | 190 | 199 |
| Vo2max est                | [ml/min/kg] | 56,2 | 57,3 | 59,3 | 59,6 | 59,7 |

**Note:**
- Values are shown in years, cm, kg, km/h, P, cm, and s.
- All values are based on biological maturation (PHV).

**Figure 2**

Individual profile of player A.
Testing March 2013

![Image: Figure 3: Individual profile of player B.

<table>
<thead>
<tr>
<th>Anthropometrics</th>
<th>07.02.1998</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date of birth</td>
<td></td>
</tr>
<tr>
<td>Age of Peak Height Velocity (PHV)</td>
<td>15.3</td>
</tr>
<tr>
<td>Years to/from PHV</td>
<td>-0.1</td>
</tr>
<tr>
<td>Sex</td>
<td>male</td>
</tr>
<tr>
<td>Handiness</td>
<td>right</td>
</tr>
<tr>
<td>Chronological age</td>
<td>[yrs]</td>
</tr>
<tr>
<td>Height</td>
<td>[cm]</td>
</tr>
<tr>
<td>Body mass</td>
<td>[kg]</td>
</tr>
<tr>
<td>BMI</td>
<td>[kg/m²]</td>
</tr>
<tr>
<td>Power</td>
<td></td>
</tr>
<tr>
<td>Grip strength D</td>
<td>[kg]</td>
</tr>
<tr>
<td>Grip strength ND</td>
<td>[kg]</td>
</tr>
<tr>
<td>Push-up test</td>
<td>[s]</td>
</tr>
<tr>
<td>Sit up test</td>
<td>[s]</td>
</tr>
</tbody>
</table>

Upper body power

Serve velocity [km/h] 125.6, 126.6, 135.8, 141.9, 148.7, < 10, 70-80
Serve accuracy [°] 4, 5, 3, 5, 4
Medicine ball throw over head [cm] 550, 580, 620, 690, 785, 10-20, 80-90
Medicine ball throw forehand [cm] 760, 870, 900, 940, 1040, < 10, 80-90
Medicine ball throw backhand [cm] 710, 780, 820, 840, 1005, 10-20, 80-90

Jumping ability

Countermovement jump [cm] 31.5, 34.1, 36.2, 37.5, 38.7, 60-70, 80-90
Repetition jumps

Contact time [ms] 180.7, 186.7, 166.3, 160.7, 164.7
Jump height [cm] 23.1, 25.8, 24.1, 25.5, 26.0

Efficiency [index] 1.04, 1.13, 1.19, 1.27, 1.33, 30-40, 70-80

Complex Speed

Linear sprint

10m [s] 1.91, 1.92, 1.99, 1.86, 1.84, 50-60, 70-80
20m [s] 3.42, 3.41, 3.39, 3.25, 3.22, 50-60, 80-90

Tennis specific sprint

Forehand [s] 2.83, 2.71, 2.74, 2.75, 2.71, 50-60, > 90
Backhand [s] 2.85, 3.00, 2.04, 2.82, 2.86, 50-60, 70-80

Tennis specific endurance

Tie and Turn Test [Level] 15.0, 15.0, 16.0, 18.0, 18.4, 80-90, > 90
Hemex [km/min] 203, 206, 204, 204, 203

Vo2 max ext [ml/min/kg] 57.9, 57.9, 59.6, 63.9, 63.1

BMI: Body Mass Index
Vo2 max ext: estimated maximum oxygen uptake
**Percentiles based on chronological age

Figure 3: Individual profile of player B.
Figure 4
Development of height (5.a), CMJ (5.b) and Hit & Turn performance (5.c) from 11.8 to 15.2 years old. Mean values (±SD) for each age are presented, and individual development of two players (A and B) is included.
An example of individual player profiles are presented in Figures 2 and 3. Figure 4 shows an example of the development of height (5.a), CMJ (5.b) and Hit & Turn performance (5.c) from 11.8 to 15.2 years old. Mean values (±SD) for each age are presented, and individual development of two players (A and B) is included.

Discussion

The concept of fitness testing of the German Tennis Federation provides a useful frame for the development of an individualized database and a more efficient program of the physical fitness training in junior tennis players. Results obtained from the testing protocols and the age-group percentiles developed, coaches and physical trainers can have individual profiles of the players, with their respective strengths and weaknesses. Moreover, the established testing schedule (i.e., 2 times per year), allows an individual follow-up and the possibility to observe the development of physical qualities, analyzing improvement ratings related to age and gender, which can be used as a reference. An individual report (including the percentile rank relative to their peers and related to both, their chronological and biological age) is provided every six months for each player as well as their coaching staff and parents. In addition to this information specific individualized training program recommendations are designed and discussed with coaches and players. The following two individual cases are used to illustrate our common procedure and recommendations.

Player A (Figure 2), is a right handed male player at age 15.2 years old, he passed his APHV at 13.5 years, with the average of APHV for all other tested male players found at 13.8 years. Body height and body mass as well as the body mass index clearly show that this player belongs to the heavier and taller boys and thus, to the higher percentiles compared to the biological and chronological norm values. Interestingly, there is a significant body mass increase in the last two years, from 48.5 to 72.4 kg, which leads to an increase of the body mass index (BMI) from 18.0 to 22.0. Regarding the physical performance, it should be mentioned that performance percentiles based on chronological and biological age show only minor differences because no accelerated or retarded development was found for this player. The results clearly show very high scores in most of the power as well as the speed & jumping categories. We assume that the increase in body mass is mainly induced by an increase in muscle mass, which is illustrated by a continuous increase in the strength and power qualities analyzed (i.e., grip strength and medicine ball throws) and finally, in the transfer of dynamic power into tennis specific skill performance, with an increase in the serve velocity from 140 to 180 km/h in the last two years. Upper and lower body strength has great importance in tennis, not only in the enhancement of athletic performance but also in the prevention and rehabilitation of injuries [27].

For example, due to the importance of the tennis serve, as the most powerful and potentially dominant shot in tennis, strength-focused training interventions, especially in developmental players, can be helpful to increase performance levels [25]. In this regard, players should perform supervised strength training programs, two to three times per week (i.e., combination of core stabilization, elastic resistance exercises, and upper body plyometric exercises (i.e., medicine ball throws)), focusing on the primary muscle groups and stabilizers involved in tennis specific movement patterns.

Analyzing speed and jumping performance, results show that player A has a really good base for tennis, reaching the highest percentile in all jumping tests as well as in the linear sprint test (20 m). However, the transfer of speed qualities into tennis specific movements seems to be not perfectly adjusted, with the player showing average percentiles (e.g., 50-60), especially when running to the forehead corner (i.e., to the right). Attention should be given to the change of direction to the forehead corner. This part of the tennis footwork was found to be of predominant importance, as in general, players are used to cover their backhand side and therefore, running more distance towards their forehead [12]. It is reasonable to assume that specific running velocity (i.e., short runs with changes of direction) is one of the determining factors in tennis performance [12,14].

Finally, in the endurance performance, player A shows a major weakness compared with his peers in Germany, with his individually results categorized in the lower third of his reference group, reaching a maximum test level of 15.6. It can be speculated that the player’s body composition (relatively high body weight and muscle mass) and muscle fiber profile (perhaps a huge amount of fast twitch fibers) has a negative impact on endurance capacity. In this regard, as a training recommendation the focus will be on endurance training, especially during the pre-season cycle, with 3-4 weeks training blocks. These training blocks might include a combination of high-intensity (i.e., 4 x [6 x 45 seconds on level 16, with 30-second rest between repetitions,
2 minutes between sets) and repeated sprint based training (i.e., 3 x [10 x 5-second] shuttle sprints, with 20-second rest between repetitions, 3 minutes between sets), as it has been shown that this might be an appropriate tool to optimize the development of cardiovascular fitness in competitive tennis players [9]. A positive effect on the change of direction would be also expected, as during acceleration and deceleration movements, the involvement of specific muscles (e.g., biceps femoris, rectus femoris, hip adductors, iliopsoas) could lead players to positive changes in specific coordination and agility [5,9].

The extracted sample of player B shows a male player aged 15.2 years (Figure 3), similar to player A. However, the age of peak height velocity for player B was estimated to be at an age of 15.3 years. This means that, from a biological point view, player B is almost 2 years behind his peer (player A). The anthropometric data show that player B belongs to the smallest and lightest percentile of his chronological age group, that means, he is a "late" mature compared with his peers (i.e., APHV for all males was at the age of 13.5 years). There are substantial differences between percentiles based on chronological or biological age. For example, while player B shows poor upper body power performance when he's analyzed from a chronological point of view (i.e., percentile 10-20), he seems to be good (i.e., percentile 80-90) when he's analyzed from a biological point of view. Thus, if we just use results based on the chronological age percentiles would probably lead to an inaccurate interpretation of the results. Moreover, the setup for an optimal training program could be disturbed [1]. Therefore we highly recommend the additional use of normative data and percentiles which consider an individual's stage of maturation. Since tournament play is commonly organized in age groups based on chronological age, these percentiles could also provide valuable information for players and coaches, and the best way appears to be a combination of percentiles based on chronological (i.e., to compare individual players with their peers) and biological age (i.e., to prescribe individualized training programs).

**Conclusion**

To the best of our knowledge, this is a unique approach analyzing an entire youth system in tennis. The German Physical Condition Tennis Test allows to compare the physical fitness of the players nationwide and helps to minimize the training volume focused on fitness training. As shown in the present manuscript, and following the individuality training principle [15], the response of one athlete to a training program might vary considerably from that of another athlete. Therefore, coaches must assess the physical status of each individual and apply training techniques consistent with their specific requirements and limitations. This would lead to a more efficient design of physical training programs, saving time for the tennis specific training. In this regard, a challenging task for the future is the implementing of high quality athletic training, and the German Tennis Federation (DTB) is currently installing a specific education program related to this issue.

**Conflict of interest**

The authors declare no conflict of interest.

**References**

[1] Balyi I, Hamilton A. Long-term athlete development, trainability and physical preparation of tennis players. ITF Strength and Conditioning for Tennis (49-57) London, ITF Ltd 2003, DOI:


Corresponding address:
Alexander Ulbricht
Ruhr-Universität Bochum
Lehrstuhl für Trainingswissenschaft
Fakultät für Sportwissenschaft
Gesundheitscampus Nord, Haus-Nr.10
Raum 1.079
44801 Bochum
Tel.: +49 (0)234 32-25969
Fax: +49 (0)234 32-14775
E-Mail: alexander.ulbricht@rub.de
http://www.spowiss.rub.de/traiwi/

Available online at www.sciencedirect.com

SciVerse ScienceDirect