Soccer Endurance Development in Professionals

C. R. Roescher, M. T. Elferink-Gemser, B. C. H. Huijgen, C. Visscher

University Medical Center Groningen, University of Groningen, Center for Human Movement Sciences, Groningen, The Netherlands

Abstract

The development of intermittent endurance capacity, its underlying mechanisms and role in reaching professional level in soccer was investigated. The sample included 130 talented youth soccer players aged 14–18, who became professional (n=53) or non-professional (n=77) players in adulthood. In total 229 Interval Shuttle Run Test (ISRT) scores were taken over five years. Players who became professionals improved from age 14 to 18 on average from 68 to 109 runs in contrast to players who remained amateurs (from 73 to 93 runs). A longitudinal model was developed using linear mixed models procedures. Intermittent endurance capacity can be predicted adequately with a two-level hierarchical model (p < 0.05). Anthropometric characteristics and playing position did not improve model fit (p > 0.05). The estimated ISRT score necessary to reach professional level is: ISRT = -375.77 + 62.89*(51.20 + 4.20) * age -1.50 * age^2 + 3.54 * hours of soccer training + 1.18 * additional training hours. In conclusion, intermittent endurance capacity improves with age in talented youth soccer players. From age 15 players who reached the professional level show a faster development than their non-professional counterparts. This development is positively influenced by both soccer specific and additional training.

Introduction

Soccer can be characterized as a high-intensity, intermittent game in which both the aerobic and anaerobic energy systems play an important role [5, 14, 22, 23, 30]. During a 90 min game, elite level players run 8–12 km at an average intensity close to the lactate threshold and aerobic metabolism provides about 90% of the energy cost of soccer match play [20]. Within this endurance context, a soccer player has to perform numerous bouts of explosive activities, such as jumping, kicking, tackling, turning, and sprinting which are mainly covered by anaerobic metabolism [22]. However, a high degree of aerobic capacity is needed to recover from these high activity efforts [1, 11, 33].

To compete at professional level, talented youth soccer players need to develop their intermittent endurance capacity in order to meet the demands of the game. They have to be able to perform high-intensity work repeatedly and recover rapidly during periods of low-intensity exercise [22]. Intermittent endurance capacity has been successful in discriminating soccer players of different performance level and there seems to be a threshold below which an individual player is unlikely to perform successfully in top-class soccer [22, 31]. Also the importance of developing intermittent endurance capacity to be successful in soccer has been acknowledged [36]. In field hockey – which can also be classified as a high intensity, intermittent game – elite youth players show a faster development pattern of intermittent endurance capacity than sub-elite youth players [7].

As far as the authors are aware, no existing research has examined the development of intermittent endurance capacity in a group of talented youth soccer players over several consecutive years and linked this directly to its role in reaching professional level, despite the fact that some well appreciated researchers recommended such a design [31, 37]. The cross-sectional nature of research on talented athletes restricts performance prediction and there have been only few attempts to validate predictive models in longitudinal approaches [31]. Consequently, until now, information about the development of intermittent endurance capacity of talented...
process of talent identification in the development of intermittent endurance capacity during their youth soccer period. A difference in the development of intermittent endurance capacity for talented youth soccer players who will ultimately reach professional level and who will not can be a useful indicator in the process of talent identification and selection. Furthermore, there is probably a critical age from which the development of intermittent endurance capacity in talented youth soccer players must continue in order to become a professional player later on in their career. In talented youth field hockey players, there is a faster development of intermittent endurance capacity in elite compared to sub-elite players from 14 years of age [7].

Considering the general population of adolescent males, aerobic and anaerobic capacity – and therefore intermittent endurance capacity – improves with age, partly as a result of growth and maturation [3]. Peak improvement in aerobic and anaerobic capacity is influenced by peak height and weight velocities [2,29]. Both were found to occur at 13.8±0.8 years of age in a group of Flemish male youth soccer players [29]. Earlier studies indicated that increases in aerobic and anaerobic capacity are related to numerous factors such as height, (lean) body mass, and percentage of body fat [9,19,21,26,27,31]. Furthermore, physiological development can be influenced by training. Several studies showed that training is a major contributor to the development of soccer expertise in both professional and talented youth soccer players [8,13,14,18,37]. There is some evidence that the physiological capacity of talented youth soccer players is related to their positional role in the team. Despite some contrasting results, the finding that midfield players cover the greatest distances and possess the highest intermittent endurance capacity is rather stable [3,6,22,31]. Therefore, these characteristics (i.e., age, height, lean body mass, percentage of body fat, soccer- and additional training per week, and playing position) potentially explain the development of intermittent endurance capacity in talented youth soccer players.

The main goal of this study is to investigate the relationship between the development of intermittent endurance capacity in talented youth soccer players aged 14–18 and adulthood playing level (i.e., professional or non-professional) and gain more insight into the underlying mechanisms (i.e., age, height, lean body mass, percentage of body fat, soccer- and additional training per week, and playing position) affecting this development.

Methods

Participants

During 2001–2006, 130 talented youth soccer players aged 14–18 participated in a longitudinal study. All participants were part of a talent development program of two Dutch professional soccer clubs and were playing at the highest level, which consists of the best 0.5% of the total soccer players in their age category. Measurements were taken annually, with the exception of 2004, resulting in 5 measurement occasions. As a result of drop out (poor performance), injuries, no follow up, and joining the talent development program after age 14, not all of the players were tested on every measurement occasion. The first reason could bias the results, but as the proportion of this sort of incomplete data is rather low (<15%), the impact will be small. As can be seen in Table 1, 58 players were tested on one and 48 players on two measurement occasions. There are 21 players who were tested three times and three players were tested on four measurement occasions. A total of 229 measurements (ISRT scores) were obtained. Because there are substantial differences between the physiological demands of goalkeepers and field players, the former were excluded from analysis. Despite the fact that all of these talented youth soccer players were involved in a talent development program for at least one year, just a minority of them reached professional level later on in their career (i.e., above age 20). Professional players (n=53) are considered as those who play in the selection (first or second team) of a Premier league club or in the first team of a first division club. Non-professional players (n=77) are considered as those who play in the second team of a first division club or at amateur level.

Procedures

All participants were informed about the procedures of the study before they gave their verbal consent and permission was given by the parents, soccer clubs, and trainers. This study was conducted in accordance with the ethical standards of the University Medical Center Groningen. The study has been performed in accordance with the ethical standards of the IJSM [12]. Ambient temperature, humidity and wind conditions were documented. The Interval Shuttle Run Test (ISRT) was performed on an artificial grass playing surface. Anthropometric measurements (height, weight, and percentage of body fat) were taken. The latter was estimated by means of leg-to-leg bioelectrical impedance (BIA) analysis (Valhallia BIA, Valhallia, Inc., San Diego, CA). Furthermore, the players completed questionnaires about training characteristics and playing position.

Interval Shuttle Run Test

Intermittent endurance capacity was measured with the ISRT [17,35]. During the ISRT players are required to run back and forth on a 20 m course with pylons set 3 m before the turning lines (▶ Fig. 1). The frequency of the sound signals on a pre-recorded compact disc increased in such a way that running speed was increased by 1 km/h every 90 s from a starting point of 10 km/h and by 0.5 km/h every 90 s from 13 km/h. Each 90 s period was divided into two 45 s periods in which players run for

Table 1 Number of measurements and number of players per adulthood playing level.

<table>
<thead>
<tr>
<th>Number of measurements</th>
<th>Number of professional players</th>
<th>Number of non-professional players</th>
<th>Total number of players</th>
<th>Total number of measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>21</td>
<td>37</td>
<td>58</td>
<td>58</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>33</td>
<td>48</td>
<td>96</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>6</td>
<td>21</td>
<td>63</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>total</td>
<td>53</td>
<td>77</td>
<td>130</td>
<td>229</td>
</tr>
</tbody>
</table>
percentage of body fat, hours of soccer- and additional training
attacker; level 2). Both age and age 2 were entered in the model to
possible explanatory variables were added in order to improve
playing level as independent factors. In the following steps other
approach was to create a model that explains changes in inter-
players, assuming that the missing data are random [17, 28, 34].
that the temporal spacing of measurements may vary between
individual players (level 2). In multilevel structures, balanced data
are not required to obtain efficient estimates. This means that it
is not necessary to have the same number of lower level units
(repeated measurements) within each higher level unit (the
individual players). Another advantage of multilevel models is
that the hierarchical structure of this present data set can be
described as repeated measures (level 1) grouped within indi-
individual players (level 2). In multilevel structures, balanced data
are not required to obtain efficient estimates. This means that it
is not necessary to have the same number of lower level units
(repeated measurements) within each higher level unit (the
individual players). Another advantage of multilevel models is
that the temporal spacing of measurements may vary between
players, assuming that the missing data are random [17,28,34].
The first step in this linear mixed-models statistical analysis
approach was to create a model that explains changes in inter-
mittent endurance performance, including age and adulthood
playing level as independent factors. In the following steps other
possible explanatory variables were added in order to improve
the fit of the model. These were: age, height, lean body mass,
percentage of body fat, hours of soccer- and additional training
per week (level 1), and playing position (defender, midfielder, or
attacker; level 2). Both age and age 2 were entered in the model to
find the best model fit. The hypothesis is that intermittent
endurance performance increases most rapidly around the
growth spurt period, which occurs approximately at 14 years of
age in adolescent male youth soccer players [29]. At an older age,
the improvement per year is expected to be smaller, therefore
age 2 is also entered in the model, to indicate if the best model
fit is linear or a quadratic curve. Random intercepts and random
slopes were considered, allowing a unique intercept for each
individual player and properly accounting for correlations
amongst repeated measures within individual players [28]. The
model fit was evaluated by comparing Akaike’s Information Crite-
rieron (deviance) of the empty model, the model without pre-
dicting variables, with the final model. An alpha of 0.05 was
adopted for all tests of significance.

Results

Descriptive data for anthropometric characteristics, training, and intermittent endurance capacity scores by age and performance
level are illustrated in Table 2. Fig. 2 shows the predicted mean scores of the ISRT derived from the multilevel model, plotted against age for talented youth soccer players who made it to the top (professional) and who did not (non-professional). In general, intermittent endurance capacity improves with age in talented youth soccer players aged 14–18. However, from 15 years of age players who have ultimately reached professional level improve more across time than non-professional players. From this age there is only a very small improvement of intermittent endurance capacity in non-
professional players, while the development of professional players continues almost linearly. This difference becomes signi-

ificant from 17 years of age (p<0.05).

The estimated models of the ISRT scores for professionals com-
pared to non-professional players that included age as inde-
pendent factor are presented in Table 3. The table shows that
age (as a continuous variable), age 2 , soccer training, additional training (level 1) and adulthood playing level (level 2) as well as
the interaction between age and adulthood playing level signifi-
cantly improve the model fit (p<0.05). The random slopes did
not improve model fit. The model shows a different intercept and linear age term for professional and non-professional play-
ers, but a common quadratic age term. Both soccer and addi-
tional training are positively related to intermittent endurance capacity. Anthropometric characteristics (level 1) and playing
position (level 2) did not improve model fit significantly.

For a talented youth soccer player, the ISRT score necessary to
reach professional level can be estimated with the following
equation: ISRT = −375.77–62.89+(51.20+4.20)*age–1.50*age 2 +
3.54*hours of soccer training +1.18*additional training hours.
For a non-professional soccer player the equation is: ISRT=
−375.77+51.20*age–1.50*age 2 +3.54*hours of soccer training+
1.18*additional training hours. For example, to reach the
top a 16 year old soccer player is predicted to develop his inter-
mittent endurance capacity by 5.9 runs in one year. In this age
band a talented youth soccer player who is not likely to reach
professional level is predicted to improve only by 1.7 runs. This
difference in development is the coefficient of the interaction
effect between age and adulthood playing level; i.e., 4.2
(5.9–1.7).

Discussion

This study investigated the development of intermittent endur-
ance capacity of current professional and non-professional soc-
cer players during the years they were involved in a Dutch talent
development program between 14–18 years of age. In most pre-
vious research on physiological development a cross-sectional
design has been applied. This study is unique in that it followed
talented youth soccer players over several consecutive years to
monitor the development of intermittent endurance capacity, the underlying mechanisms affecting this development and its role in reaching professional level in soccer. The relationship between the development of intermittent endurance capacity during the youth soccer period of talented players and ultimate performance level later on in their career has been examined in order to create a developmental profile to which talented youth soccer players can be compared. Since adulthood playing level was determined afterwards, this study is not truly predictive itself. The model needs to be cross validated on other samples before it could prove a useful tool to predict future performance level of current talented youth soccer players.

Using multilevel analyses, a prediction model was created to estimate the development of intermittent endurance capacity for talented youth soccer players who will ultimately reach the top (professional) and who will not (non-professional). The model predicts that, although the initial development is similar for both groups, from 15 years of age players who ultimately reached professional level show a faster development pattern than their non-professional counterparts. However at age 15 the ISRT score between both adulthood playing levels does significantly differ. From age 17, the ISRT score between both adulthood playing levels does significantly differ. This is in accordance with another longitudinal study on the development of intermittent endurance capacity in talented youth field hockey players in which the gap between elite and sub-elite players becomes larger from 14 years of age [7]. In a study of Jankovic et al. [16], youth soccer players aged 15–17 who were considered successful later on in their career possessed better physiological fitness than their less successful peers.

Both soccer specific and additional training were positively related to the development of intermittent endurance capacity and were found to have a significant effect in improving the model. However, the effect of soccer specific training is three times that of additional training. One extra hour of soccer specific training leads to an improvement of 3.54 runs on the ISRT, while one hour of additional training improves the ISRT score with only 1.18 runs. This positive relation between intermittent endurance performance and soccer specific training is in line with the expectations, since expert performance is determined by the amount of time a person engages in a practice activity with the primary goal of improving some aspect of performance, i.e., deliberate practice [8].

Anthropometric characteristics (height, lean body mass, and percentage of body fat) did not improve model fit significantly.

### Table 2
Mean scores (SD) for talented youth soccer players presented by age and performance level.

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>n</th>
<th>Height (m)</th>
<th>n</th>
<th>Lean body mass (kg)</th>
<th>n</th>
<th>Body fat (%)</th>
<th>n</th>
<th>Soccer Training (hours/wk)</th>
<th>n</th>
<th>Additional training (hours/wk)</th>
<th>n</th>
<th>Interval Shuttle Run score (runs of 20 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>professional</td>
<td>14</td>
<td>11</td>
<td>1.69 (0.08)</td>
<td>11</td>
<td>51.76 (6.13)</td>
<td>11</td>
<td>9.18 (2.53)</td>
<td>11</td>
<td>6.68 (0.90)</td>
<td>11</td>
<td>4.18 (2.63)</td>
<td>11</td>
</tr>
<tr>
<td>15</td>
<td>22</td>
<td>1.73 (0.07)</td>
<td>20</td>
<td>56.07 (7.65)</td>
<td>20</td>
<td>8.68 (2.97)</td>
<td>20</td>
<td>6.64 (0.90)</td>
<td>21</td>
<td>2.33 (2.56)</td>
<td>21</td>
<td>81.64 (15.76)</td>
</tr>
<tr>
<td>16</td>
<td>17</td>
<td>1.75 (0.08)</td>
<td>17</td>
<td>58.27 (9.01)</td>
<td>17</td>
<td>10.99 (4.63)</td>
<td>17</td>
<td>7.71 (1.70)</td>
<td>17</td>
<td>2.74 (2.61)</td>
<td>17</td>
<td>90.47 (23.35)</td>
</tr>
<tr>
<td>17</td>
<td>27</td>
<td>1.76 (0.07)</td>
<td>27</td>
<td>62.32 (6.47)</td>
<td>27</td>
<td>8.90 (3.32)</td>
<td>27</td>
<td>7.34 (0.94)</td>
<td>24</td>
<td>2.28 (1.65)</td>
<td>24</td>
<td>99.26 (21.12)</td>
</tr>
<tr>
<td>18</td>
<td>27</td>
<td>1.80 (0.08)</td>
<td>25</td>
<td>68.01 (7.66)</td>
<td>25</td>
<td>7.40 (2.48)</td>
<td>25</td>
<td>9.08 (2.39)</td>
<td>24</td>
<td>2.08 (2.54)</td>
<td>24</td>
<td>108.63 (18.76)</td>
</tr>
</tbody>
</table>

### Table 3
Multilevel model for intermittent endurance capacity.

<table>
<thead>
<tr>
<th>Fixed effects</th>
<th>Coefficient</th>
<th>Standard Error</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>constant (intercept)</td>
<td>-375.77</td>
<td>175.50</td>
<td>0.034</td>
</tr>
<tr>
<td>age</td>
<td>-51.20</td>
<td>21.84</td>
<td>0.020</td>
</tr>
<tr>
<td>age²</td>
<td>-1.50</td>
<td>0.68</td>
<td>0.028</td>
</tr>
<tr>
<td>professional</td>
<td>-62.89</td>
<td>29.76</td>
<td>0.036</td>
</tr>
<tr>
<td>age² professional</td>
<td>4.20</td>
<td>1.83</td>
<td>0.023</td>
</tr>
<tr>
<td>soccer training</td>
<td>3.54</td>
<td>0.92</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>additional training</td>
<td>1.18</td>
<td>0.53</td>
<td>0.029</td>
</tr>
<tr>
<td>deviance</td>
<td>1821.47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>deviance empty model</td>
<td>2051.76</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Several studies concluded that physical performance is related to anthropometric characteristics, partly as a result of growth and maturation [3,19,25,29]. However, anthropometric characteristics are also related to chronological age, and lean body mass and percentage of body fat can be influenced by training [9,21,31]. Since chronological age and training already made a significant contribution to the improvement of the model this may account for the non-significant influence of anthropometric characteristics on the development of intermittent endurance capacity in this study. Furthermore, the influence of anthropometric characteristics may be less obvious in a group of talented youth soccer players already highly selected (i.e., best 0.5% of their age group) and exposed to systemized training [37].

Playing position did not significantly improve the model for intermittent endurance capacity. Although, a trend was found for midfielders to obtain the highest scores on the ISRT, followed by defenders and attackers. This trend is in accordance with previous research, it was found that midfielders and full backs have the highest maximal oxygen uptakes (VO₂ max > 60 ml/kg/min) and perform best in intermittent exercise tests [31]. Another study showed that midfield players have significantly higher VO₂ max than defenders using the expression ml/kg/min, whereas no significant differences were found among players grouped by position expressing VO₂ max absolutely or using appropriate scaling procedures [38].

The current study suggests that the age of 15 seems to be crucial with respect to reaching professional level in soccer or not. From this age there is only a very small improvement of intermittent endurance capacity in talented youth soccer players who became non-professionals, while the development of players who reached the professional level continues almost linearly. Until age 15, the development of intermittent endurance capacity of non-professional players parallels that of the professionals, indicating that until then no distinction can be made on the basis of this physiological performance characteristic. When a player becomes older, his intermittent endurance capacity must develop to a certain minimum in order to meet the increasing demands of the game. From this age, intermittent endurance performance might be one of the indicators in the identification and selection of potential top players.

Although intermittent endurance capacity plays a very important role in top-class soccer, it is only one of the multidimensional performance characteristics that accounts for on-field performance. To reach professional level in soccer, at least four multidimensional qualities are needed; i.e., physiological, technical, tactical, and psychological [5,14,24,32,37]. Therefore, it is difficult to predict ultimate performance potential in talented youth soccer players with a high degree of probability on the basis of just one performance characteristic. A recent study indicated that the technical quality of dribbling in soccer can assist in identifying the best players for the future during adolescence in a large group of all talented youth soccer players [15]. The longitudinal results showed that during adolescence the talented players who ultimately became professionals were faster than the talented players who ultimately remained non-professional. Although Williams and Reilly [37] noted that physiological measurements cannot be used reliably on their own for talent identification and selection purposes, they also argued that physiological characteristics (such as intermittent endurance capacity) may be more influential in successful performance in the future, since contemporary professional soccer will be played at a higher tempo. Furthermore, technical and tactical skills are highly dependent on the player's physiological capacity [4]. Therefore, superior technical and tactical ability in soccer can only be consistently demonstrated throughout the course of a 90 min game by soccer players with high intermittent endurance capacity [35].

The current study does not indicate how intermittent endurance capacity develops after age 18. The model presented in Fig. 2 may suggest that this development proceeds linearly after age 18, however a curvilinear relationship would be more realistic. Future research could examine the development of intermittent endurance capacity of talented soccer players after age 18 to clarify this issue. Furthermore, it could be investigated if the development of intermittent endurance capacity would be successful in distinguishing between players of a national team and non-international professional players. Intermittent endurance capacity may not be sensitive enough to discriminate between these even more highly selected players, since this population becomes smaller and more homogenous, particularly with respect to physical and physiological characteristics [37].

In conclusion, intermittent endurance capacity improves with age in talented youth soccer players. This improvement, which is positively influenced by both soccer specific and additional training, is larger in players who reached the professional level than in their non-professional counterparts. The gap between players from both levels of performance becomes progressively larger from the age of 15. The model created in this study can assist in hypothesizing successful soccer players for the future by estimating the ISRT score necessary to reach professional soccer.

References
9 Ericsson KA, Krampe RT, Teschromer C. The role of deliberate practice in the acquisition of expert performance. Psychol Rev 1993; 100: 363–406

17 Landau S, Everitt BS. Analysis of repeated measures II: Linear mixed model. Boca Raton, FL: Chapman & Hall; 2004