

## ORIGINAL ARTICLE

## Development of the interval endurance capacity in elite and sub-elite youth field hockey players

M T Elferink-Gemser, C Visscher, M A J van Duijn, K A P M Lemmink

*Br J Sports Med* 2006;40:340–345. doi: 10.1136/bjsm.2005.023044

See end of article for authors' affiliations

Correspondence to: Dr Elferink-Gemser, Center for Human Movement Sciences, University of Groningen, Groningen, Netherlands; m.t.elferink-gemser@rug.nl

Accepted 6 December 2005

**Objectives:** To gain more insight into the mechanisms that underlie the development of interval endurance capacity in talented youth field hockey players in the 12–19 age band.**Methods:** A total of 377 measurements were taken over three years. A longitudinal model for interval endurance capacity was developed using the multilevel modelling program MLwiN. With the model, scores on the interval shuttle run test can be predicted for elite and sub-elite male and female field hockey players aged 12–19 years.**Results:** A polynomial model of order 2 adequately represents development of the test scores over time. The fixed part of the model contains a different intercept and linear age term for boys and girls, and a common quadratic term; the random part of the model has a common level 2 variance and sex specific level 1 variances. The model was significantly improved by including differential effects of performance level for age and sex. A negative effect was found for percentage body fat, and positive effects for additional training and motivation.**Conclusions:** During adolescence, both male and female elite hockey players show a more promising development pattern of interval endurance capacity than sub-elite youth players. Percentage body fat, additional training hours, and motivation influence this development. However, differences between the individual players are still considerable.

Match analyses make clear that field hockey is a high intensity non-continuous game in which the physiological demands are considerable.<sup>1–3</sup> Players carry out all sorts of explosive actions such as intermittent sprinting with many changes of direction, cruising, and dribbling the ball, placing it in the category of “heavy exercise”.<sup>4</sup> To perform at the highest level, players need a well developed interval endurance capacity. This is the ability to perform high intensity activities such as running and sprinting, as well as the ability to recover well during low intensity activities such as walking and jogging.<sup>5</sup> In terms of energy requirements, the aerobic capacity is most important during matches at the elite level. Although great anaerobic capacity is needed during the many brief bursts of high energy release, it is the aerobic capacity that is needed for efficient recovery during the short rest periods.<sup>6–8</sup>

In our longitudinal study on performance characteristics of talented youth field hockey players in the age band 12–18 years, a strong improvement in interval endurance capacity is apparent. Both male and female elite youth players improved more than sub-elite youth players with respect to interval endurance capacity over a period of two years.<sup>9–10</sup> So far, however, the interval endurance capacity of youth field hockey players who want to succeed is not known, or its relation to performance level. To unravel the relations between interval endurance capacity and performance level in talented field hockey players, it is essential to gain a deeper insight into the development of this performance characteristic.

As the interval endurance capacity is related to both aerobic and anaerobic capacity, one could look at the developmental pattern of these capacities in children and youngsters. In “normal” children, aerobic capacity—that is, maximum oxygen uptake—increases proportionally to body size and mass in both sexes.<sup>11–13</sup> Generally, anaerobic performance also increases with age. Girls improve from late childhood to 14–15 years of age, whereas in boys the increase

continues to 19 years. In late childhood and early adolescence, sex differences are evident and they are magnified later in adolescence.<sup>14</sup>

Factors that affect the development of aerobic and anaerobic capacity and therefore interval endurance capacity are multidimensional. The adolescent period is characterised by acceleration of somatic growth and rapid changes in body composition and hormonal status, including growth spurt and increase in fat-free mass.<sup>15</sup> Anthropometric characteristics such as body height, lean body mass, and percentage body fat influence the physiological aspects of a sports performance, such as interval endurance capacity. Increase in body height is related to an increase in lung volume and therefore with an increase in metabolism and endurance. A gain in lean body mass is related to an increase in muscle mass and therefore positively influences endurance, in contrast with a gain in body fat, which negatively influences endurance.<sup>16</sup>

It is generally known that, with training, players can improve their performance by increasing aerobic and anaerobic energy output during a particular movement. This is also the case in youth players.<sup>17</sup> However, it is not self evident that all players make use of their interval endurance capacity to the full during training or competition. A player has to be motivated to do so because intense activity can cause uncomfortable side effects such as fatigue and muscle soreness. Motivation affects the intensity and persistence of a player's behaviour, which in sport can obviously have a big impact on performance.<sup>18</sup>

The above characteristics of the players—that is, age, performance level, sex, anthropometric factors, training, and motivation—can potentially explain the development of interval endurance capacity in talented youth field hockey players. The goal of this study was to gain more insight into the mechanisms that underlie the development of interval endurance capacity.

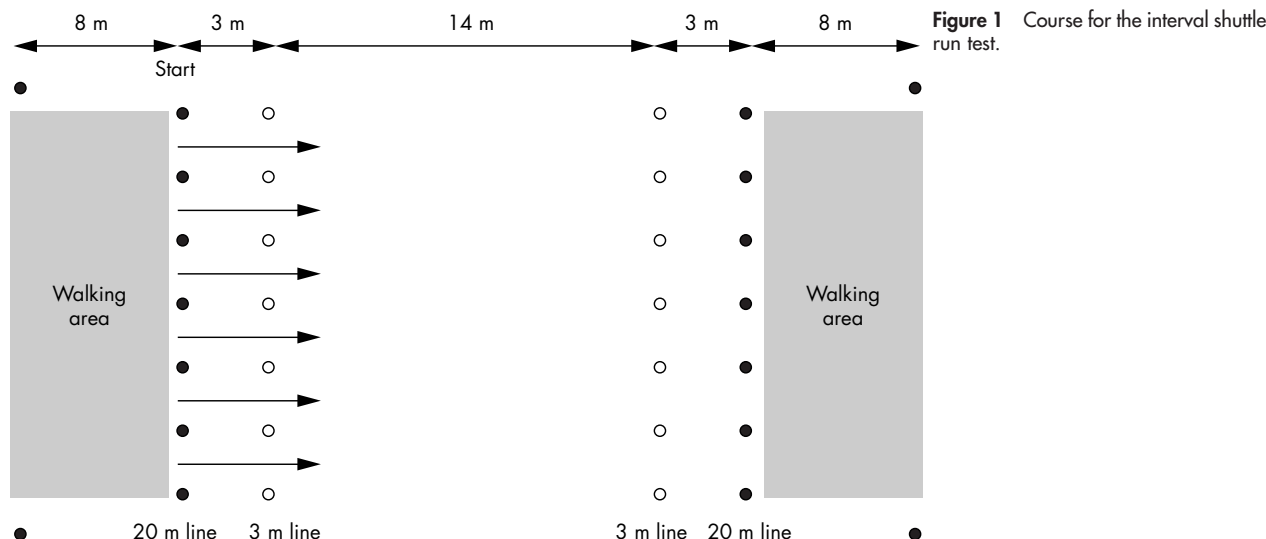


Figure 1 Course for the interval shuttle run test.

## METHODS

### Participants

During 2000–2003, 217 talented field hockey players aged 12–19 participated in a semilongitudinal study on the relation between multidimensional performance characteristics and performance level. This group consisted of 110 male and 107 female players. All participants were part of a talent development programme for a field hockey club of national prestige, and were playing at the highest level for their age category. Measurements were taken at the end of the competitive field hockey seasons 2000–2001 ( $t_1$ ), 2001–2002 ( $t_2$ ), and 2002–2003 ( $t_3$ ). In total, 404 measurements were taken, as 77 players were tested on all three occasions (231 measurements), 33 players were tested on two occasions (66 measurements), and 107 players were tested on one occasion only (107 measurements). Of these measurements, 392 contained scores for interval endurance capacity, and 377 measurements were complete in that there were scores for all variables.

As part of a talent development programme, young Dutch field hockey players considered to be elite are invited to train and play in a youth selection team for the Dutch Field Hockey Association. Talented players considered to be the current sub-elite youth players participate in the talent development programme at their field hockey club only. According to this distinction, players were divided into elite and sub-elite players on each occasion ( $t_1$ ,  $t_2$ ,  $t_3$ ).

### Procedure

Participants were informed about the procedure of the study before they gave their verbal consent. The field hockey clubs and trainers gave permission for the study. This study was submitted to the local medical ethics committee of the University of Groningen (METc). They decided that, because all tests are sports specific and resemble exercises often performed during regular training, permission was not required. The players completed the interval shuttle run test (ISRT) on a synthetic field hockey playing surface (water based pitch). Ambient temperature, humidity, and wind conditions were documented. Anthropometric measurements were taken, and the players filled in questionnaires about training and motivation.

### Anthropometric characteristics

Anthropometric measurements were height (m), lean body mass (kg), and percentage of body fat. The last of these was

estimated by leg to leg bioelectrical impedance analysis (Valhalla BIA; Valhalla Inc, San Diego, California, USA). This method proved to be reliable for estimating body fat percentage, and results correlated highly with values as obtained by underwater weighing and dual energy  $x$  ray absorptiometry.<sup>19</sup>

### Interval shuttle run test

Interval endurance capacity was measured with the ISRT (fig 1).<sup>5, 20</sup> The ISRT is a field test with intervals at a work to rest ratio of 2:1 and turns at 20 m. The frequency of the sound signals on a pre-recorded CD increases in such a way that running speed is increased by 1 km/h every 90 seconds from a starting speed of 10 km/h and by 0.5 km/h every 90 seconds from a starting speed of 13 km/h. Each 90 second period is divided into two 45 second periods in which players run for 30 seconds and walk for 15 seconds. The number of completed 20 m runs is recorded as the test score. During the ISRT, players were carrying their hockey stick. The reliability and validity of the ISRT as a maximal field test for intermittent sport players has been confirmed.<sup>20–22</sup>

### Training

Outcome variables of the questionnaire were field hockey training (hours/week) and additional training (hours/week). Time spent in matches, on average one hour a week, and time spent in physical education at school, on average 2.5 hours a week, were excluded.

### Motivation

Motivation was measured using the Dutch youth version of the psychological skills inventory for sports, a sports specific questionnaire with five point Likert-type questions, which has proved to be reliable in previous research.<sup>23–25</sup>

### Data analysis

Longitudinal changes in interval endurance capacity were investigated using the multilevel modelling program MLwiN.<sup>26</sup> Multilevel modelling is a relatively new extension of multiple regression, which is appropriate for analysing hierarchically structured data. In the present longitudinal data set, a simple two level hierarchy was defined, with the repeated measurements (defined as level 1 units) grouped within the individual players, who form the level 2 units. An advantage of using a multilevel regression modelling approach is that both the number of measurements and the

**Table 1** Scores for talented youth field hockey players presented by sex, performance level, and age (217 players; 377 complete measurements)

Cohort	n	Age (years)	Height (m)	Lean body mass (kg)	% Body fat	Field hockey training (h/week)	Additional training (h/week)	Motivation (1–5 points)	ISRT (runs of 20 m)
Male elite youth players									
12–13 years	11	12.88 (0.55)	1.62 (0.06)	43.3 (5.1)	10.75 (2.82)	3.4 (0.7)	6.2 (2.7)	4.51 (0.35)	58.82 (18.64)
14 years	20	13.95 (0.29)	1.67 (0.07)	49.6 (7.0)	9.23 (2.48)	3.9 (1.2)	5.0 (4.5)	4.56 (0.30)	77.10 (23.03)
15 years	21	15.04 (0.30)	1.73 (0.07)	52.8 (6.7)	7.94 (2.48)	4.8 (2.2)	3.0 (2.4)	4.24 (0.50)	88.76 (22.53)
16 years	13	16.06 (0.27)	1.78 (0.04)	59.7 (4.3)	7.97 (2.70)	5.0 (1.7)*	2.4 (2.5)*	4.27 (0.51)*	91.46 (21.55)
17 years	7	16.98 (0.31)	1.79 (0.06)	64.1 (2.9)	7.46 (3.03)	5.5 (1.4)	2.0 (2.0)	4.18 (0.58)	88.86 (29.13)
18–19 years	2	17.94 (0.24)	1.81 (0.05)	70.0 (0.3)	8.90 (1.12)	5.3 (1.1)	3.0 (2.8)	3.56 (0.80)	100.50 (0.71)
Male sub-elite youth players									
12–13 years	9	13.04 (0.40)	1.63 (0.09)	44.4 (7.3)	9.96 (4.72)	3.4 (0.7)	2.8 (2.7)	4.22 (0.44)	54.67 (23.77)
14 years	26	13.96 (0.32)	1.67 (0.08)	47.4 (6.8)	10.54 (5.90)	3.5 (0.6)	3.6 (4.4)	4.27 (0.44)	56.58 (18.64)
15 years	16	14.83 (0.32)	1.68 (0.10)	48.0 (8.8)	8.47 (4.49)	3.5 (0.9)*	4.7 (4.0)*	4.35 (0.38)*	81.19 (26.16)
16 years	29	15.97 (0.31)	1.77 (0.06)	57.0 (6.5)	8.89 (3.93)	3.5 (0.7)†	3.7 (3.5)†	4.17 (0.50)†	84.59 (20.48)
17 years	25	16.83 (0.34)	1.79 (0.06)	60.6 (6.3)	9.16 (4.45)	4.1 (1.4)*	3.4 (3.0)*	4.17 (0.63)*	74.16 (27.16)
18–19 years	21	17.91 (0.45)	1.81 (0.05)	67.7 (4.4)	7.31 (4.33)	4.3 (0.9)	1.8 (2.5)	4.06 (0.64)	74.90 (21.49)
Female elite youth players									
12–13 years	12	12.95 (0.32)	1.56 (0.08)	38.3 (5.1)	15.64 (5.17)	3.5 (1.1)†	5.3 (1.9)†	4.54 (0.29)†	48.50 (12.56)
14 years	17	14.01 (0.32)	1.62 (0.08)	41.9 (4.6)	19.05 (6.58)	3.7 (1.3)	3.3 (2.5)	4.55 (0.34)*	58.35 (12.92)
15 years	18	14.98 (0.29)	1.66 (0.06)	43.9 (3.5)	21.57 (4.76)	4.4 (1.1)*	2.3 (2.4)*	4.57 (0.47)†	65.67 (19.42)
16 years	15	16.07 (0.30)	1.67 (0.06)	44.5 (3.3)	22.65 (5.03)	5.5 (1.6)	1.5 (1.9)	4.36 (0.52)	59.80 (18.16)
17 years	9	17.00 (0.31)	1.69 (0.07)	48.5 (5.9)	18.88 (5.95)	6.0 (2.2)	2.5 (4.5)	4.68 (0.20)	61.00 (24.12)
18–19 years	0								
Female sub-elite youth players									
12–13 years	14	12.89 (0.45)	1.61 (0.05)	39.8 (3.5)	17.94 (7.32)	3.1 (0.4)†	2.1 (1.8)†	3.91 (0.47)†	47.79 (16.70)
14 years	25	13.88 (0.33)	1.64 (0.07)	42.3 (4.2)	18.20 (5.30)	3.1 (0.4)	2.7 (2.2)	4.19 (0.58)	57.08 (16.29)
15 years	18	14.92 (0.38)	1.66 (0.05)	41.8 (3.2)	21.18 (5.46)	3.3 (0.9)	1.5 (2.5)	4.06 (0.66)	51.44 (10.00)
16 years	27	15.88 (0.27)	1.69 (0.04)	44.5 (2.8)	24.02 (4.67)	3.4 (0.8)	1.4 (1.5)	3.93 (0.57)	48.88 (15.92)
17 years	21	16.79 (0.25)	1.69 (0.04)	45.7 (3.8)	25.23 (4.38)	4.5 (1.5)	2.2 (2.5)	4.23 (0.56)	51.29 (13.14)
18–19 years	16	17.84 (0.38)	1.71 (0.05)*	51.1 (3.9)*	21.95 (3.56)*	4.7 (1.0)*	1.8 (2.2)*	4.31 (0.38)*	46.35 (15.03)

Values are mean (SD). Field hockey training (hours a week) is exclusive of field hockey matches. Additional training (hours a week) is exclusive of physical education at school.

\*One missing value.

†Two missing values.

temporal spacing of the measurements may vary between players.<sup>27</sup> A multilevel model describes not only underlying population trends in a response (the fixed part of the model), but also models the variation around this mean response due to the time of measurement and due to individual differences (the random part).<sup>28</sup>

The first step in the multilevel modelling of interval endurance capacity data was to establish a satisfactory variance structure for these longitudinal data, using age (measured as months/12–15 years).<sup>28</sup> Then the difference between elite and sub-elite groups was modelled, taking into

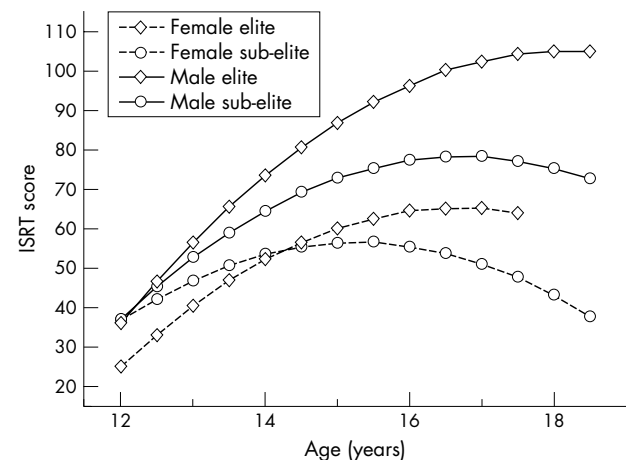
account interactions with age and sex. In the next step, the effects of the anthropometric variables height (m), lean body mass (kg), and percentage body fat were investigated. Subsequently, the effect of the total number of training hours a week, as well as the effect of different types of training (distinguishing field hockey training and additional training) were investigated. Finally, the effect of motivation was tested.

## RESULTS

Table 1 presents anthropometric variables, training, motivation, and interval endurance capacity scores by sex, performance level, and age.

**Table 2** Final multilevel model for interval endurance capacity data (377 measurements)

Fixed effects	Coefficient	SE	p Value
Constant	52.6	9.10	<0.001
Age (months/12–15 years)	6.21	1.20	<0.001
Age <sup>2</sup>	-1.83	0.363	<0.001
Boy	16.5	4.30	<0.001
Sub-elite	0.786	2.90	0.393
Age × boy	5.27	1.33	<0.001
Age × sub-elite	-5.11	1.39	<0.001
Boy × sub-elite	-13.0	4.55	0.002
Percentage body fat	-0.889	0.201	<0.001
Additional training	1.092	0.324	<0.001
Motivation	4.86	1.87	0.003
Random effects	Variance	SE	
Between individuals	136.0	25.43	
Within boy	292.8	39.20	
Within girl	105.9	16.31	
Deviance	3205.6		



**Figure 2** Predicted development of the interval endurance capacity, assessed as interval shuttle run test (ISRT) score, of talented youth field hockey players in the age band 12–19 years.

A polynomial model of order 2 adequately represents the development of the test scores over time (deviance 3394.0, difference from a fully saturated model of 43.9 on 36 degrees of freedom,  $p = 0.17$ ). The fixed part of the model contains a different intercept and linear age term for boys and girls, and a common quadratic term; the random part of the model has a common level 2 (between individual) variance and sex specific level 1 (measurement) variances. The model was significantly improved by including differential effects of performance level for age and sex (deviance 3367.8, difference from previous model 26.2 on 3 degrees of freedom,  $p < 0.01$ ). No effect was found for height and lean body mass, but a significant negative effect was found for percentage body fat ( $t = 4.423$ ,  $p < 0.01$ ). A positive significant effect was found for additional training ( $t = 3.374$ ,  $p < 0.01$ ), whereas no effect was found for field hockey training as such. Finally, a positive significant effect of motivation was found ( $t = 2.726$ ,  $p = 0.003$ ). Table 2 gives the model variables. The coefficients of the variables percentage body fat, additional training hours, and motivation are unstandardised. Their effects, however, can be interpreted such that an additional training hour could compensate for 1.23% body fat (1.093/0.889), or, likewise, is equivalent to 0.225 points on the motivation scale (1.093/4.86).

In fig 2, predicted mean scores of the ISRT derived from the multilevel model are plotted against age for elite and sub-elite boys and elite and sub-elite girls. The general trend is that interval endurance capacity increases with age in male youth players. However, elite youth players improve more across time than sub-elite youth players. In female players, the interval endurance capacity increases with age in elite youth players only. Sub-elite youth players improve until the age of about 15 and thereafter their interval endurance capacity decreases.

In fig 3, the data are presented for the four different sex and performance groups. The lines connect two or three individual yearly observations; the points are single individual observations. The bold solid lines depict the estimated mean ISRT score for "average" representatives of each group—that is, with mean scores on percentage body fat, additional training hours, and motivation (8.65, 3.82, and 4.35 for elite boys; 9.15, 3.36, and 4.2 for sub-elite boys; 20.0, 2.84, and 4.53 for elite girls, and 21.6, 1.94, and 4.11 for sub-elite girls respectively).

The dotted lines around the bold line indicate the 95% confidence region, taking into account between individual (level 2) variation. This variation is estimated by the level 2 variance of 136 (table 2), which is equivalent to a standard deviation of about 12 runs, indicating rather large differences between individuals, as is also apparent from fig 3.

The curvature of the lines represents the fitted second order polynomial (quadratic) model. It can be observed that the linear effect of the model is strongest for elite boys and least strong for sub-elite girls, and about equal for sub-elite boys and elite girls (because of the interaction effects with age and sub-elite). Also evident from the figure is the rather large within individual (level 1) variance, which is much larger for boys than for girls, estimated as 292.8 (equivalent to a standard deviation of about 17 runs) and 105.9 (standard deviation about 10 runs) respectively.

With the multilevel model for interval endurance capacity, if the age of a player, his or her percentage body fat, additional training hours, and motivation are known, scores on the ISRT for elite and sub-elite boys and girls can be predicted. Equations for the four subgroups can be derived from the model in table 2. The numbers in parentheses correspond to the coefficients of the fixed part of the model.

Elite boys:

$$\text{ISRT} = 52.6 + 16.5 + (6.21 + 5.27) \times \text{age} - 1.83 \times \text{age}^2 - 0.889 \times \text{percentage body fat} + 1.092 \times \text{additional training hours} + 4.86 \times \text{motivation}$$

Sub-elite boys:

$$\text{ISRT} = 52.6 + 16.5 + (0.786 - 13.0 + 6.21 + 5.27 - 5.11) \times \text{age} - 1.83 \times \text{age}^2 - 0.889 \times \text{percentage body fat} + 1.092 \times \text{additional training hours} + 4.86 \times \text{motivation}$$

Elite girls:

$$\text{ISRT} = 52.6 + 6.21 \times \text{age} - 1.83 \times \text{age}^2 - 0.889 \times \text{percentage body fat} + 1.092 \times \text{additional training hours} + 4.86 \times \text{motivation}$$

Sub-elite girls:

$$\text{ISRT} = 52.6 + 0.786 + (6.21 - 5.11) \times \text{age} - 1.83 \times \text{age}^2 - 0.889 \times \text{percentage body fat} + 1.092 \times \text{additional training hours} + 4.86 \times \text{motivation}$$

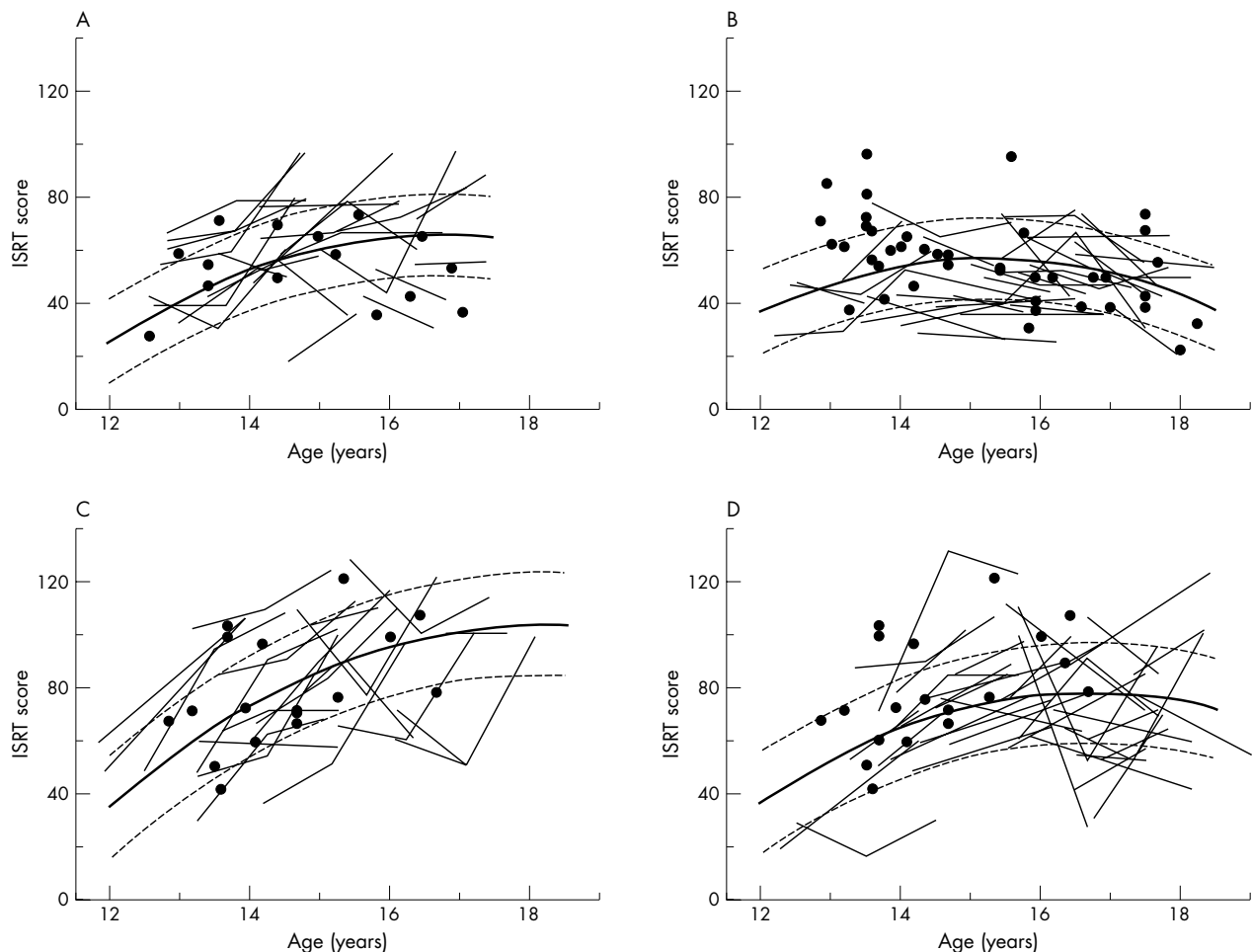
Thus the development of interval endurance capacity in the age band 12–19 years can be predicted with the multilevel model. For instance, it is predicted that an elite 15 year old male player will increase his performance on the ISRT in one year by  $(6.21 - 1.83 + 5.27) = 9.65$  runs. In contrast, in the age band 15–16 years, a sub-elite male player will increase "only" by  $(6.21 - 1.83 + 5.27 - 5.11) = 4.54$  runs. An elite girl is predicted to achieve an extra  $(6.21 - 1.83) = 4.38$  runs, whereas a sub-elite girl will run  $(6.21 - 1.83 - 5.11) = 0.73$  runs less according to the model.

## DISCUSSION

We used the multilevel modelling program MLwiN to analyse our data.<sup>26</sup> Multilevel modelling is a relatively new approach for examining longitudinal trends, with the advantage that both the number of measurements and the temporal spacing can vary between players. This makes it very suitable for our longitudinal study design in which some players participated once, and others in two or three measurements. Another advantage is that the multilevel model makes it possible to estimate a consecutive seven year development pattern with measurements taken for only three consecutive years. Therefore this statistical technique is very promising, and we recommend its application not only in talent research but in sports research in general.

The model predicts that interval endurance capacity develops differently in boys and girls, and elite and sub-elite players. During adolescence, differences between boys and girls become apparent. Boys show much more rapid development of their interval endurance capacity than girls, but differences are also notable within the male and female groups. During the ISRT, both aerobic and anaerobic energy production contribute to the total energy requirement.<sup>5</sup> In a "normal" population of adolescents, boys increase their aerobic and anaerobic performance with age, whereas girls improve to 14–15 years with a gradual decrease thereafter.<sup>13–14</sup> However, the development of interval endurance capacity in talented youth field hockey players is not quite the same as in "normal" adolescents. Instead of decreasing their performance after the age of 15, elite girls are able to sustain the improvement in their interval endurance capacity. Although boys and sub-elite girls seem to follow the "normal" pattern, elite boys improve their interval endurance capacity more than sub-elite boys.

Motivation was found to have a significant effect in improving the model. Motivation can be defined as the direction and intensity of one's effort.<sup>18</sup> As the road to the top is long, motivation is not only essential for current performance in a match or test, but also in talent development. Talented players have to devote long hours of training for many consecutive years to improve their performance level.<sup>29–30</sup> In addition, we found significant effects of additional training and percentage body fat. The effect of the



**Figure 3** Predicted curves for interval endurance capacity, as assessed by interval shuttle run test (ISRT) score, for (A) elite girls, (B) sub-elite girls, (C) elite boys, and (D) sub-elite boys. See the main text for further explanation.

latter was negative, which is in line with a study on young male gymnasts, swimmers, soccer, and tennis players.<sup>31</sup>

There is a large variation in interval endurance capacity within and between players. The within person variation—that is, the variance between measurements—is noticeable especially in boys and elite girls. This variation was based on the players tested repeatedly, which is about half of the population. As previous research underscored the reliability of the ISRT, we do not doubt the reliability of the test.<sup>21</sup> The between person variation is based on the total population and is clear-cut in the whole 12–19 year age band. It is evident that field hockey performance can be broken down into many multidimensional characteristics, of which interval endurance capacity is only one.<sup>32</sup> The combination of anthropometric, physiological, technical, tactical, and psychological characteristics results in a player's performance level.<sup>10</sup> Therefore it is possible for sub-elite players to possess great

interval endurance capacity—because they spend a lot of time on additional training—but, if they lack a high level of the other performance characteristics, they will not make it to the elite team of the Dutch Field Hockey Association. In their young adolescent years, it seems that players can still compensate for less well developed performance characteristics, such as interval endurance capacity. However, towards expertise, performance demands increase, and all players need to score highly for all performance characteristics, including interval endurance capacity.

It is apparent that the development of interval endurance capacity differs in male and female, elite and sub-elite youth

#### What is already known on this topic

- With training, young players can improve their aerobic and anaerobic capacity
- Motivation affects the intensity and persistence of a player's behaviour, which has a strong effect on performance

#### What this study adds

- The interval endurance capacity of elite youth field hockey players increases more, on average, than that of sub-elite youth players. From the age of 14, the gap between elite and sub-elite youth players becomes progressively larger
- Multilevel modelling is a promising statistical technique for analysing the development of sport capacity, not only for research purposes but trainers and coaches can also use the results for evaluating the development of their players

field hockey players. Percentage body fat, additional training hours, and motivation all influence this development. With the presented model, scores on the ISRT can be predicted for elite and sub-elite boys and girls. The results show that, during adolescence, the development pattern of interval endurance capacity of both male and female elite youth players is, on average, more promising than that of sub-elite youth players. However, the differences between individual players are considerable.

## ACKNOWLEDGEMENTS

This study was supported by a grant from the Dutch National Olympic Committee NOC\*NSF. We thank all players, trainers, and staff of the field hockey clubs Hertogenbosch and Rotterdam for their cooperation.

## Authors' affiliations

**M T Elferink-Gemser, C Visscher, K A P M Lemmink**, Center for Human Movement Sciences, University of Groningen, Groningen, the Netherlands

**M A J van Duijn**, Interuniversity Center for Social Science Theory and Methodology, University of Groningen

Competing interests: none declared

## REFERENCES

- Ghosh AK, Goswami A, Mazumdar P, et al. Heart rate & blood lactate response in field hockey players. *Indian J Med Res* 1991;**94**:351–6.
- Reilly T, Borrie A. Physiology applied to field hockey. *Sports Med* 1992;**14**:10–26.
- Aziz AR, Chia M, Teh KC. The relationship between maximal oxygen uptake and repeated sprint performance indices in field hockey and soccer players. *J Sports Med Phys Fitness* 2000;**40**:195–200.
- Patel DR, Stier B, Luckstead EF. Major international sport profiles. *Pediatr Clin North Am* 2002;**49**:769–92.
- Lemmink KAPM, Visscher C. The relationship between the Interval Shuttle Run Test and maximal oxygen uptake in soccer players. *Journal of Human Movement Studies* 2003;**45**:219–32.
- Bhanot JL, Sidhu LS. Maximal anaerobic power in Indian national hockey players. *Br J Sports Med* 1983;**17**:34–9.
- Boyle PM, Mahoney CA, Wallace WF. The competitive demands of elite male field hockey players. *J Sports Med Phys Fitness* 1994;**34**:235–41.
- Lothian F, Farrally M. A time-motion analysis of women's hockey. *Journal of Human Movement Studies* 1994;**26**:255–65.
- Elferink-Gemser MT. *Today's talented youth field hockey players, the stars of tomorrow? A study on talent development in field hockey*. Wageningen: Ponsen & Looijen, 2005.
- Elferink-Gemser MT, Visscher C, Lemmink KAPM, et al. Relation between multidimensional performance characteristics and level of performance in talented youth field hockey players. *J Sports Sci* 2004;**22**:1053–63.
- Krahenbuhl GS, Skinner JS, Kohrt WM. Developmental aspects of maximal aerobic power in children. *Exerc Sport Sci Rev* 1985;**13**:503–538.
- Kemper HCG (ed). *Amsterdam growth and health longitudinal study: medicine and sports science*. Basel: Karger, 2004;**47**.
- Kemper HCG, Koppes LL. Is physical activity important for aerobic power in young males and females? In: Kemper HCG, ed. *Amsterdam growth and health longitudinal study. medicine and sports science*. Basel: Karger, 2004;**47**:153–66.
- Martin JC, Malina RM. Developmental variations in anaerobic performance associated with age and sex. In: Van Praagh E, ed. *Pediatric anaerobic performance*. Champaign, IL: Human Kinetics, 1998:45–64.
- Bitar A, Vernet J, Coudert J, et al. Longitudinal changes in body composition, physical capacities and energy expenditure in boys and girls during the onset of puberty. *Eur J Nutr* 2000;**39**:157–63.
- Astrand PO, Rodahl K, Dahl HA, et al. *Textbook of work physiology: physiological bases of exercise*, 4th ed. New York: McGraw-Hill, 2003.
- Powers SK, Howley ET. *Exercise physiology: theory and application to fitness and performance*, 4th ed. New York: McGraw-Hill, 2001.
- Silva JM III, Weinberg RS. *Psychological foundations of sport*. Champaign, IL: Human Kinetics, 1984.
- Nunez C, Callagher D, Visser M, et al. Bioimpedance analysis: evaluation of leg-to-leg system based on pressure contact footpad electrodes. *Med Sci Sports Exerc* 1997;**29**:524–31.
- Lemmink KAPM, Dolleman G, Verheijen R, et al. Interval Sprint Test en Interval Shuttle Run Test: betrouwbaarheid en discriminerend vermogen van twee nieuwe voetbaltests. [English abstract]. *Geneesk Sport* 2000;**33**:39–48.
- Lemmink KAPM, Visscher C, Lambert M, et al. The Interval Shuttle Run Test for intermittent sport players: evaluation of reliability. *J Strength Cond Res* 2004a;**18**:821–7.
- Lemmink KAPM, Verheijen R, Visscher C. The discriminative power of the Interval Shuttle Run Test and the Maximal Multistage Shuttle Run Test for playing level of soccer. *J Sports Med Phys Fitness* 2004b;**44**:233–9.
- Mahoney MJ, Gabriel TJ, Perkins TS. Psychological skills and exceptional athletic performance. *The Sport Psychologist* 1987;**1**:181–99.
- Bakker F. Ontwikkeling van tests op het terrein van de sportpsychologie in Nederland en Vlaanderen. [Development of tests for the field of sport psychology in the Netherlands and Belgium]. *Sportpsychologie Bulletin* 1995;**6**:3–15.
- Companjen T, Bakker F. Overzicht van sportpsychologische vragenlijsten in Nederland en Vlaanderen. [Outline of questionnaires for the field of sport psychology in the Netherlands and Belgium]. *Sportpsychologie Bulletin* 2003;**14**:34–41.
- Goldstein H, Rasbash J, Plewis I, et al. *A user's guide to MLwiN*. London: Multilevel Models Project, Institute of Education, University of London, 1998.
- Maas CJM, Snijders TAB. The multilevel approach to repeated measures for complete and incomplete data. *Qual Quant* 2003;**37**:71–89.
- Snijders TAB, Bosker RJ. *Multilevel analysis. An introduction to basic and advanced multilevel modelling*. London: Sage Publications, 2000:166–99.
- Ericsson KA, Krampe RT, Tesch-Römer C. The role of deliberate practice in the acquisition of expert performance. *Psychol Rev* 1993;**100**:363–406.
- Ericsson KA. The acquisition of expert performance: an introduction to some of the issues. In: *The road to excellence: the acquisition of expert performance in the arts and sciences, sports and games*. Mahwah, NJ: Lawrence Erlbaum Associates, 1996:1–50.
- Baxter-Jones ADG, Helms P, Maffulli N, et al. Growth and development of male gymnasts, swimmers, soccer and tennis players: a longitudinal study. *Ann Hum Biol* 1995;**22**:381–94.
- Nieuwenhuis CF, Spamer EJ, Van Rossum JHA. Prediction function for identifying talent in 14- to 15-year-old female field hockey players. *High Ability Studies* 2002;**13**:21–33.