STUDIES IN SPORT, PHYSICAL EDUCATION AND HEALTH

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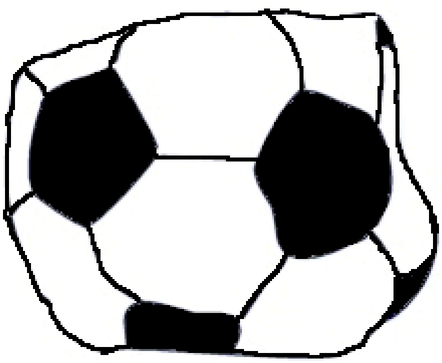
A Two-Year Follow-Up Study in the U11, U13 and U15 Age Groups



JYVÄSKYLÄN YLIOPISTO

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ABSTRACT

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This study monitored the U11 (10.8 ± 0.3 y, n = 14), U13 (12.7 ± 0.2 y, n = 14) and U15 (14.7 ± 0.3 y, n = 12) year-old soccer teams over a period of two years in terms of anthropometrics, body composition, hormonal status, physical performance, soccer skills, general perceptual-motor skills and soccer-specific perceptual-motor skills. Additional cross-sectional datasets measured from Finnish young soccer players were utilized in technical soccer skill and general perceptual-motor skill analyses. The results suggested that the young soccer players' height and weight fitted well into the standard deviation of Finnish growth charts in all age groups. The soccer players' percentage of body fat was lower than that of controls in all age groups. During the two-year monitoring period soccer players' muscle mass increased more than the controls between ages U15 to U17. There was no difference in serum testosterone concentration between the soccer players and age-matched controls but large differences were observed between individuals within the same age group, particularly in the U13 - U15 groups. Physical fitness of soccer players was better than their age-matched counterparts not engaged in soccer but a tendency was observed that the difference decreased with age in speed-related tasks, remained the same in endurance performance and increased in strength. The analysis of soccer skill tests revealed that skills in soccer players have improved between the years of 2000 and 2011. Actual ball-handling skills in boys were better than in girls and the performance in skill tests improved with age. It seemed that general and soccer-specific perceptual-motor skills improved with age but soccer-specific skills became increasingly important with age. Thus, these skills can be expected to discriminate post-pubertal players better than pre-pubertal players. Based on the present study, it can be concluded that: 1) equal opportunities for late maturating children to experience competence in soccer is warranted; 2) substantial functional (and health) benefits can be achieved through soccer engagement; 3) the windows of accelerated adaptation of different functional abilities should be utilized in a better way in target age groups; 4) A proper periodization for strength, speed and endurance training is needed in order to optimize the young soccer players development during growth.

Keywords: football, growth, maturation, puberty, reaction time, hormones

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I owe you a favor,

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LIST OF ORIGINAL PUBLICATIONS

The present thesis is based on the following original articles which are referred to in the text by their Roman numerals.

I Vänttinen T, Blomqvist M, Häkkinen K. Development of body composition, hormone profile, physical fitness, general perceptual motor skills, soccer skills and on-the-ball performance in soccer-specific laboratory test among adolescent soccer players. *Journal of Sports Science and Medicine 2010 9: 547 - 556.*

II Vänttinen T, Blomqvist M, Luhtanen P, Häkkinen K. Effects of age and soccer expertise on general tests of perceptual and motor performance among adolescent soccer players. *Perceptual and Motor Skills 2010 110: 675-92.*

III Vänttinen T, Blomqvist M, Nyman K, Häkkinen K. Changes in body composition, hormonal status and physical fitness in 11, 13 and 15 year old Finnish regional youth soccer players during a two year follow-up. *Journal of Strength and Conditioning Research 2011 25(12): 3342-51.*

IV Vänttinen T, Blomqvist M, Häkkinen K. Dribbling and passing skill development of male and female soccer players aged 9 to 17 years in Finland. *Submitted for publication*.

V Vänttinen T, Blomqvist M, Häkkinen K. Development of general and soccer-specific perceptual-motor skills during a two-year follow up in three different age groups in a regional soccer club. *Submitted for publication*.

ABBREVIATIONS

Accuracy	passing accuracy in the soccer-specific laboratory test
Anticipation time	anticipation phase in the soccer-specific laboratory test
CMJ	countermovement jump
EHF	eye-hand-foot coordination
Fat%	percentage of body fat
Feint-target	feint-target phase in the soccer-specific laboratory test
Muscle	muscle mass
Leg	maximal bilateral isometric leg strength
Pass	passing skill test
PAT	peripheral awareness
RFD	rate of force development
Selection	selection phase in the soccer-specific laboratory test
Soc-Lab	soccer-specific laboratory test
Testo	serum testosterone concentration
U11	under 11 years
U12	under 12 years
U13	under 13 years
U14	under 14 years
U15	under 15 years
U16	under 16 years
U17	under 17 years
VO_2max	maximal oxygen uptake
Yo-Yo	Yo-Yo endurance test level 1

CONTENTS

1 INTRODUCTION

Soccer practitioners are constantly seeking the most effective ways to develop young players (le Gall et al. 2010). This is a challenging task because the requirements of soccer play are multifactorial (Reilly et al. 2000). The complexity of the game can be realized by observing the number of review articles published in the research literature from different specific aspects required in soccer. Such reviews have dealt with e.g. physiology (Bangsbo 1994, Reilly et al. 2000, Impellizzeri et al. 2005, Stolen et al. 2005), biomechanics (Lees & Nolan 1998), testing (Hoff 2005, Svensson & Drust 2005), skills (Ali 2011, Russell & Kingsley 2011, O'Reilly & Wong 2012), training (Hoff & Helgerud 2004, Reilly 2005), small-sided games (Hill-Haas et al. 2011), talent identification (Unnithan et al. 2012), fatigue (Mohr et al. 2003, Bangsbo et al. 2006), recovery (Nedelec et al. 2012, Nedelec et al. 2013), injuries (Junge & Dvorak 2004, Olsen et al. 2004), psychology (Morris 2000) and nutrition (Maughan 2007). Therefore, identifying the most important qualities to be monitored during the growth is rather difficult because it is impossible to completely explain the interactions behind successful soccer performance. Nevertheless, it is important to generate scientific observations that might complement intuitive judgments about young players' development on their way to soccer expertise (Reilly et al. 2000).

Based on previous research literature, three major objectives for monitoring soccer players during childhood and adolescence can be classified. First, the talent identification among soccer clubs and academies has become popular across the world because early recruitment into high-quality coaching is considered to be crucial in the long-term development of soccer expertise (le Gall et al. 2010, Meylan et al. 2010). Second, testing provides objective feedback about players' strengths and weaknesses to be used for planning appropriate short- and long-term training programmes for each individual (Svensson & Drust 2005). Third, the efficiency of the training programmes can be evaluated based on players' responsiveness to them (Huijgen et al. 2009, Meylan et al. 2010).

The most important factors for measuring performance in soccer are physical condition, technical skills and tactical performance (Rosch et al. 2000, Hoff 2005). Physical condition of soccer players is usually tested in terms of endurance, speed, agility, strength and power (Reilly et al. 2000, Hoff & Helgerud 2004, Haugen et al. 2013). Technical skills have been determined using various skill tests (Rosch et al. 2000, Malina et al. 2005, Huijgen et al. 2010) and game analysis (Rampinini et al. 2009a, Dellal et al. 2011, Russell et al. 2013). Players' tactical skills have been studied through questionnaires (Elferink-Gemser et al. 2004, Kannekens et al. 2011) and qualitative game analysis (Blomqvist et al. 2005). All these abilities improve during the growing years but the timing of the greatest improvement takes place at different times (Beunen & Malina 1988, Philippaerts et al. 2006) and in most of the cases is linked more to players' biological age than to their chronological age (Malina et al. 2004, Malina et al. 2005).

Soccer in Finland is mainly seen as a recreational activity, and since 1999 the entire competition system in children soccer has been based on the ''All Sports'' philosophy. This philosophy emphasizes that every child has the right to participate and the rules of "All Sports" guarantees equal opportunities for each player regardless of their abilities in age groups less than 12 years. As soccer culture in Finland is different than in many "big soccer countries", national research is needed in order to find out how the Finnish players are characterized compared to age-matched counterparts in other countries (Malina et al. 2004, Da Silva et al. 2008, Wong del & Wong 2009, le Gall et al. 2010, Buchheit et al. 2012). From non-competitive perspective, previous research has shown that aerobic exercise provides substantial functional and health benefits in all age groups (Mersy 1991, Janssen & Leblanc 2010). This has also been proven in soccer context (Randers et al. 2012, Krustrup et al. 2013). However, it is uncertain to what extent children and youths participating in soccer in Finland differ from non-playing counterparts in their functionality and what kind of changes occurs during the growth.

Soccer is the most popular sport in the world that is why the number of soccer studies is growing rapidly in the research literature. However, there are still a rather limited number of studies in which a longitudinal and/or multidisciplinary approach has been utilized to examine how young soccer players develop during childhood and adolescence. In addition, there is very limited academic soccer research done in youth soccer specifically in Finland. Therefore, the aim of this study was examine how Finnish regional soccer players develop in terms of anthropometrics, body composition, hormonal profile, physical performance characteristics, general perceptual-motor skills, soccer skills and soccer-specific perceptual-motor skills in U11, U13 and U15 age groups during a two-year monitoring period. The hypotheses of the present study were that between U11 to U17 age groups Finnish young soccer players improve more than their age-matched controls in physical performance variables but overall less than their international elite counterparts who are training in more professional environment.

2 REVIEW OF THE LITERATURE

2.1 General overview of the postnatal growth

Scammon's curves of systematic growth provide an excellent overview of postnatal growth (Scammon 1930). The curves presented in Figure 1 demonstrate how the growth of different tissues is attained by age as a percentage of the total increment between birth and 20 years of age. The general curve describes the growth as a whole (stature, weight, dimensions). This curve usually has four phases. At first, there is a rapid growth during early childhood followed by a constant growth during middle childhood. The third phase is characterized by rapid growth during the adolescent growth spurt. The fourth phase consists of a slow increase and cessation of growth at early adulthood.

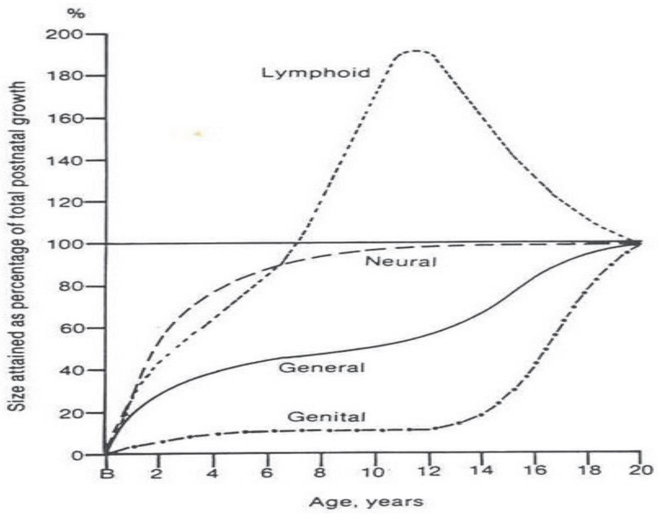

FIGURE 1 Scammon's curves of systematic growth (Scammon 1930), with permission from the University of Minnesota press.

The neural curve describes the growth of the central nervous system (brain and nerves). The neural growth is rapid during early and middle childhood as approximately 95 % of size is already attained by about 7 years of age. After that, neural tissues demonstrate steady growth with a small growth spurt during puberty. The genital curve describes the growth of the primary (e.g. testes and penis) and secondary sex (e.g. pubic and facial hair) characteristics. The lymphoid curve includes tissues which are mainly involved with the person's immunological capacities and the resistance to infectious diseases.

2.2 The development of young soccer players

2.2.1 Anthropometrics and body composition

Elite soccer players are characterized by heterogeneity in body size (Reilly et al. 2000). Usually goalkeepers and defenders are the tallest and heaviest whereas midfielders tend to be the shortest and lightest due to various demands in different playing positions (Bloomfield et al. 2005). As presented in Table 1, elite male players are generally around 1.80 m tall and their weight is about 75 kg (Bloomfield et al. 2005, Besson et al. 2012). Male soccer players' percentage of body fat is typically between 8 – 12 % (Mujika et al. 2000, Rienzi et al. 2000, Casajus 2001, Strudwick et al. 2002). It has been shown that the somatotype distribution demonstrates higher than normal average mesomorphy and a power and strength oriented genotype at elite standard soccer players (Rienzi et al. 1998, Santiago et al. 2008, Juffer et al. 2009).

The preadolescent rate of growth in males is around 5 cm/year in height and 2-3 kg/year in weight. During the growth spurts at the age of around 14 years the rate increases to around 10 cm/year in height and 10 kg/year in weight (Tanner et al. 1966). Between ages 10 to 17 years muscle mass is more than doubled from 15 kg to over 30 kg. At the same time muscle mass relative to total body weight increases from 46 % to around 53 % (Malina et al. 2004). During the adolescent growth spurt relative fatness gradually declines to reach the lowest value at about 16 to 17 years (Malina et al. 2004). The height and weight of young soccer players during growth is shown to be similar to the normal population (Malina 2003) but young soccer players are generally leaner than average persons (Baxter-Jones & Helms 1996, Hansen et al. 1999a, Hammami et al. 2013). There are not many studies that have examined young soccer players' body composition. In a study by Valente-dos-Santos et al. (2012) fat free mass of Spanish young soccer players increased 76 % from 32.2 kg to 56.8 kg between 11 to 17 years. Hoshikawa et al. (2013) found that young soccer players have higher relative distribution of muscle mass within thigh compared to general youths.

Anthropometrical and body composition development reflects children's maturity status that is why these factors have been related to players physical performance and skill characteristics as well as having an impact on the selection process in youth soccer (Malina et al. 2004, Gil et al. 2007a, Nedeljkovic et al. 2007, Gravina et al. 2008, le Gall et al. 2010, Meylan et al. 2010, Valente-Dos-Santos et al. 2012, Vandendriessche et al. 2012). This means that more matured children have an increasing and persistent advantage over less matured children in sport (Helsen et al. 2012). Players further ahead in physical and cognitive development are likely to be nominated as talented, that is, likely to lead to a vicious circle in which intrinsic and extrinsic motivation enhances children's perceived competence which in turn stimulates children to practice more.

To summarize, anthropometrical and body composition features are rarely limiting factors in soccer but may predict the playing position. During a rapid period of growth the maturity related differences in body size may predict players' performance characteristics but these differences in biological age should be regarded as a temporal advantage of more matured players and this should be taking into account when interpreting young players' future potential.

TABLE 1 Height and weight of elite soccer players in different age groups.

Age Group	n	Int. code	Season	Height (m)	Weight (kg)	Reference
U11	40	ESP	2012	1.43±0.06	36.4±5.3	Valente-dos-Santos et al. 2012
U12	40	ENG	2011	1.47±0.06	39.9±5.7	Williams et al. 2011
U13	47	ENG	2011	1.53±0.07	46.1±8.2	Williams et al. 2011
U14	16	FRA	2010	1.65±0.11	52.5±9.9	le Gall et al. 2010
U15	16	FRA	2010	1.72±0.10	59.3±10.3	le Gall et al. 2010
U16	16	FRA	2010	1.76±0.08	65.3±8.8	le Gall et al. 2010
U17	16	ESP	2011	1.79±0.07	70.8±8.4	Spencer et al. 2011
Adults						
Premier	578	ENG	2001/02	1.81±0.06	75.3±7.3	Bloomfield et al. 2005
La Liga	528	ESP	2001/02	1.80±0.06	75.0±5.6	Bloomfield et al. 2005
Serie A	499	ITA	2001/02	1.81±0.05	74.3±5.4	Bloomfield et al. 2005
Bundesliga+	-	GER	2011/12	1.84	77.5	Besson et al. 2012
Super league*	-	ISR	2011/12	1.80	74.0	Besson et al. 2012
Volyn Lutsk+	-	UKR	2011/12	1.87	79.5	Besson et al. 2012
FC Barcelona*	-	ESP	2011/12	1.78	73.0	Besson et al. 2012

* = smallest average value in the national league and club team in season 2011/12; + = highest average value in the national league and club team in season 2011/12; U = under

2.2.2 Hormones

2.2.2.1 Overview of the hormonal regulation during growth

The regulation system formed by growth hormone and insulin-like growth factors is the most important all the way from early childhood to the end of growth. The thyroid and steroid hormones also affect growth through this system. Growth hormone, insulin-like growth factor 1 and thyroid hormones have growth-stimulating properties which are primarily involved in the maintenance of normal growth during pre-pubertal years. The events of puberty and the adolescent growth spurt in males are closely related to elevated production of steroid hormones by the testes. Testosterone itself has rather a limited role in the regulation of the growth spurt. The growth spurt is mediated by increased aromatase activity in the testes around mid-puberty. This increased aromatase activity enables the production of estrogen hormones from androgens, and estrogen hormones are, at least partly, responsible for triggering the growth spurt. However, testosterone promotes bone growth and skeletal maturation. The effects of testosterone specifically underline the dramatic increase in muscle mass and fat-free mass in males (Malina et al. 2004, Välimäki et al. 2009).

2.2.2.2 Testosterone

Testosterone is a steroid hormone from the androgen group which in males is synthesized mainly in the testes from cholesterol precursors (Malina et al. 2004). Serum testosterone concentration in males remains very low up to the age of 10 years followed by a mild increase between 10 - 12 years and a drastic rise during the actual puberty. The peak concentration of 24 ± 5 nmol/l can be obtained at the age of around 25 years. Testosterone is known to promote skeletal growth, increase muscle mass, reduce fat tissue, promote nerve conduction velocity, increase hematopoiesis, organize neural circuits and structural anatomy of the brain during puberty, promote aggressiveness and competitive behavior (Tan 1996, Carre & McCormick 2008, Välimäki et al. 2009, Blakemore et al. 2010, Paus et al. 2010). Compared to athletes in other sports, soccer players' baseline testosterone level has been found to be lower than in wrestlers and sprinters (aggressive sports) but higher than in swimmers and cross-country skiers (endurance sport) although the variation in players' testosterone concentration was large (Bosco & Viru 1998, Pillay 2006). In general, research evidence that testosterone levels differ between athletes in different sports is weak. The strongest evidence seems to be that a high amount of endurance training reduces plasma testosterone (Hackney 1989).

There are few studies that have examined the relationships between testosterone concentration and performance characteristics in soccer. Bosco et al. (1996) found that the players with better explosive leg strength and sprint running performance had a higher basal level of testosterone. Hansen et al. (1999b) demonstrated that the development of strength was related to changes in serum testosterone concentrations among young soccer players during puberty. According to Baldari et al. (2009) a weak androgen steroid salivary dehydroepiandrosterone but not salivary testosterone was related to standing long jump performance in 10 - 14 year-old soccer players. Acute increases of 15 - 30 % in testosterone levels have been obtained after a soccer game (Edwards et al. 2006, Trumble et al. 2012).

2.2.2.3 Cortisol

Cortisol is a steroid hormone produced by the adrenal glands. It is a catabolic hormone inhibiting protein synthesis and in severe case can cause growth failure of a child. Sport related functions of cortisol are increased carbohydrate and fat metabolism through gluconeogenesis and lipolysis. Cortisol also activates the immune system and reduces inflammatory reactions (Malina et al. 2004, Välimäki et al. 2009). Normal resting cortisol values of 500 nmol/l has been measured in elite players in Italian league (Jonetz-Mentzel & Wiedemann 1993, Lippi et al. 2009). No effects of age have been found in cortisol levels between pre-pubertal and pubertal players or between pubertal and adult players (Cacciari et al. 1990, Lippi et al. 2009). Acute increases between 78 % to more than 200 % in cortisol levels have been reported due to a soccer game (Edwards et al. 2006, Thorpe & Sunderland 2012).

2.2.3 Strength

2.2.3.1 Maximal strength

Soccer players at an elite level tend to have a power and strength oriented genotype (Santiago et al. 2008, Juffer et al. 2009) which indicates that strength and power are important physiological co-determinants of soccer performance (Hoff 2005, Helgerud et al. 2011). A game induced fatigue in strength and explosive power is shown to be around 10-15 % which is likely to have a negative impact on players' performance (Greig 2008, Thorlund et al. 2009, Ali & Williams 2012). Therefore, a number of studies have proposed that by increasing strength in the appropriate muscle groups, acceleration and speed skills such as jumping, turning and sprinting, may be improved and higher resistance to fatigue achieved (Reilly & Doran 2003, Wisloff et al. 2004, Hoff 2005, Billot et al. 2010, Chelly et al. 2010, Bogdanis et al. 2011, Helgerud et al. 2011). Other benefits gained through specified strength training are the ability to maintain balance and reductions of the risk of injury (Reilly & Doran 2003). However, it is worth to acknowledge that the level of maximal strength in top level soccer is not exceptional as world class players have been shown to increase their half squat one repetition maximum over 50 % with a strength training program executed twice a week only for 8 weeks (Helgerud et al. 2011). Improvements of this magnitude gained in such a short period of time are to be expected from a previously untrained individual, but not from well-trained athletes familiar to strength training (Häkkinen et al. 1985, Ahtiainen et al. 2003). Soccer players relatively low leg strength is a little surprising when taking into account that more than 85 % of the soccer coaches reported using parallel squat and, to a lesser extent, other resisted leg exercises as a part of conditioning program in the Spanish league (Reverter-Masia et al. 2009).

Strength development with age in males is rather linear until puberty when a clear acceleration can be observed due to increased muscle mass mediated by increased hormonal activity, mainly increased testosterone secretion

(Malina et al. 2004). Studies among the general population suggest that strength attains maximal growth after the maximal height spurt, which occurs at the age of around 14 years in males in western societies (Malina et al. 2004, Välimäki et al. 2009). Young soccer players' strength development is similarly tied to general growth and hormonal maturity (Hansen et al. 1999b, Philippaerts et al. 2006, Nedeljkovic et al. 2007, Degache et al. 2010, Hoshikawa et al. 2013). Young soccer players are suggested to have higher leg strength than general age-matched counterparts (Christou et al. 2006, Gissis et al. 2006, Hoshikawa et al. 2013) but controversial results have been reported whether or not soccer training alone improves muscularity or strength more than normal growth during the stage of rapid growth (Christou et al. 2006, Hoshikawa et al. 2013).

Resistance training with high loads has been suggested for soccer players as it increases strength and power without noticeable change in muscle mass (Hoff 2005, Bogdanis et al. 2011, Helgerud et al. 2011). Specific strength training leads to substantial strength gains also among young soccer players (Christou et al. 2006, Chelly et al. 2009, Keiner et al. 2013). This is why dynamic strength training has been recommended to be added as a part of an annual training program for young soccer players (Kotzamanidis et al. 2005, Christou et al. 2006, Chelly et al. 2009). According to Keiner et al. (2013) one repetition maximum related to body weight in parallel squat for elite young players with long-term training experience should be a minimum of 2.0 for 16- to 19-year-old players, 1.5 for 13- to 15-year-old players and 0.7 for the 11- to 12-year-old players. Other particularly important muscles to be trained, beside the lower extremities, are trunk muscles as it has been shown that the muscularity of the erector spinae and quadratus lumborum contributes to a fast performance in sprint distance less than 20 m in young soccer players (Kubo et al. 2010).

2.2.3.2 Explosive strength of lower extremities

The ability to produce a powerful single action as well as the capacity to repeat explosive bouts are important determinants of players' performance in soccer (Reilly et al. 2000, Stroyer et al. 2004). Explosive strength is required in many match-winning actions such as sprinting, change of speed direction and jumping (Meylan & Malatesta 2009). In the extreme case, players' explosive strength has even been shown to be directly related to a competitive success in soccer (Arnason et al. 2004). A countermovement jump (Table 2) has been the most popular method to determine soccer players' explosive leg strength as it has been shown to be related to players sprinting speed during adolescence as well as in adulthood (Wisloff et al. 2004, Buchheit et al. 2010a). Male soccer player's typical value in the countermovement jump settles around 40 cm (Haugen et al. 2013). The highest value, although not comparable with the values measured with a contact mat, reported in research literature for soccer player is 71.6 cm performed by an unspecified UEFA champions' league player (Helgerud et al. 2011).

TABLE 2 Development of soccer players' explosive strength of the lower extremities by age determined with a countermovement jump.

Age	Nat	n	Level	CMJ (cm)	Reference
U10	ESP	15	Regional	26.5±6.2	Fernandez-Gonzalo et al. 2010
U10	FIN	54	Best 15%	26.4	Vilkki 2012
U11	POR	40	Regional	25.6±4.2	Valente-Dos-Santos et al. 2012
U11	FIN	748	Best 15%	27.3	Vilkki 2012
U12	SAM	82	Regional	25.5±3.4	Nedeljkovic et al. 2007
U12	POR	57	Regional	27.8±5.0	Valente-Dos-Santos et al. 2012
U13	FRA	10	Regional	32.5	Diallo et al. 2001
U13	POR	83	Regional	30.6±5.3	Valente-Dos-Santos et al. 2012
U13	FIN	2221	Best 15%	31.9	Vilkki 2012
U14	FRA	16	Internationals	43.7±7.3	le Gall et al. 2010
U14	POR	80	Regional	32.9±5.0	Valente-Dos-Santos et al. 2012
U14	QAT	17	Academy	32.0±3.1	Buchheit et al. 2010b
U15	FRA	16	Internationals	47.9±6.1	le Gall et al. 2010
U15	QAT	10	Academy	39.2±4.1	Buchheit et al. 2010b
U15	FIN	4312	Best 15%	38.5	Vilkki 2012
U16	FRA	16	Internationals	50.6±6.4	le Gall et al. 2010
U16	QAT	12	Academy	37.9±3.7	Buchheit et al. 2010b
U17	ITA	21	Internationals	40.9±5.1	Castagna & Castellini 2013
U17	QAT	17	Academy	42.6±4.0	Buchheit et al. 2010b
U17	FIN	1677	Best 15%	41.7	Vilkki 2012
U18	ENG	20	Elite	47.0	Needham et al. 2009
U18	ESP	8	Regional	42.5	Gorostiaga et al. 2004
U18	QAT	14	Academy	44.5±5.2	Buchheit et al. 2010b
U19	ESP	10	Club team	46.6±3.3	Mujika et al. 2009
U19	POR	20	Elite	45*	Ascensao et al. 2011
U20	ITA	17	Internationals	40.2±4.7	Castagna & Castellini 2013
U21	ITA	18	Internationals	40.3±4.3	Castagna & Castellini 2013
Adult	FRA	29	Elite	41.6±4.2	Cometti et al. 2001
Adult	NOR	17	Elite	56.4±4.0	Wisloff et al. 2004
Adult	FIN	1665	Best 15%	44.5	Vilkki 2012

U = under, Best 15 % = the best 15 % of the total number of cases reported in column "n"= category "Excellent" in a Finnish reference table

A general development of explosive strength during growth is similar in nature as found in maximal strength. Explosive jump performance increases rather linearly with age until 12 years followed by an adolescent spurt between ages 12 - 15 years (Ostyn et al. 1980, Haubenstricker & Seefeld 1986, Beunen et al. 1989, Focke et al. 2013). General pediatric literature suggests that the fastest development in explosive strength occurs after the maximal height spurt at the same time with the maximal growth of muscle mass (Beunen & Malina 1988, Malina et al. 2004). Philippaerts et al. (2006) suggested that young soccer players' fastest development in explosive leg strength occurred at the same time with the maximal height spurt, although players' development continued almost at the same level for at least a further 18 months. These authors reported that the peak improvement among young Flemish soccer players in the vertical jump was around 5 cm in a year which is in agreement with the development observed in studies presented in Table 2.

Young players' explosive leg strength is shown to be higher than that of an average young person but can be further improved with specific training implemented in parallel with conventional soccer training (Gorostiaga et al. 2004, Cortis et al. 2009, Thomas et al. 2009, Buchheit et al. 2010a, Bonnette et al. 2011, Hammami et al. 2013). Maximal strength training has been considered to play an important role in improving explosive actions due to maximal mobilization of working muscles through this type of training (Wisloff et al. 2004). However, explosive high velocity training is crucial as greater improvements in the rate of force development and explosiveness has been demonstrated with lower training loads and higher contraction velocities (Häkkinen et al. 1985, Wilson et al. 1993). Training protocols including explosive type resistance training and plyometric training have been recommended specifically for young soccer players as these methods has been shown to improve players explosive leg strength (Sedano et al. 2011, Loturco et al. 2013).

2.2.4 Sprinting speed

In a soccer game, elite player covers from 2 km to more than 3 km with high-intensity running from which the total distance covered by sprinting is 250 - 350 meters (Bradley et al. 2009, Dellal et al. 2011, Di Salvo et al. 2013). On average, the number of sprints varies from 30 - 55 depending on the playing position so that central defenders have the least number of sprints and wide midfielders the most (Di Salvo et al. 2013). The mean recovery time between sprints varies from 51 to 101 seconds in different playing positions (Bradley et al. 2009). In more than 95 % of the cases, the sprint distances are less than 20 meters, which means that sprint duration is usually less than 3 seconds (Mohr et al. 2003, Di Salvo et al. 2010). Speed and the ability to repeat high-intensity running are important characteristics in top level soccer proven by the facts that top-level players are faster and they do more high-intensity running than lower level players (Bangsbo & Franks 2000, Cometti et al. 2001, Reilly et al. 2003, Kaplan et al. 2009, Rampinini et al. 2009b, Di Salvo et al. 2013, Rebelo et al. 2013). Sprinting has also been shown to be directly related to the most important determinant of the game result as Faude et al. (2012) found that straight sprints (47 %) are the most common actions preceding the goals followed by jumps (16 %), rotations (6 %) and change-in-direction sprints (6 %). The best performance times for elite adult players found in research literature are less than 1.50 s in 10 meters and less than 3.70 s in 30 meters (Wisloff et al. 2004).

Sprinting speed improves rather linearly from childhood to late adolescence without indication of a clear adolescent spurt (Haubenstricker & Seefeld 1986). During childhood speed improvement is gained by increasing both stride frequency and stride length whereas during adolescence the improvement is achieved almost entirely by increasing the stride length (Mero et al. 1990). Young players' fastest development in sprinting speed is suggested to occur at the same time with the maximal height spurt (Philippaerts et al. 2006). As this occurs at the same time when a young soccer player's future potential is often

TABLE 3 Development of soccer players' sprinting time by age.

Age	Nat	n	Level	10m (s)	20m (s)	30m (s)	40m (s)	Reference
U11	GRE	24	Regional	2.11	3.83	5.62		Michailidis et al. 2013
U11	FIN	1197	Best 15%	1.95		4.92		Vilkki 2012
U12	ENG	40	Academy	1.98±0.09		5.04±0.20		Williams et al. 2011
U12	QAT	59	Academy	2.02				Buchheit et al. 2012
U13	ENG	47	Academy	1.97±0.14		4.97±0.20		Williams et al. 2011
U13	QAT	7	Academy	1.96±0.07				Buchheit et al. 2010b
U13	FIN	2799	Best 15%	1.84		4.58		Vilkki 2012
U14	ENG	40	Academy	1.89±0.08		5.71±0.25		Williams et al. 2011
U14	FRA	16	International	1.96±0.10	3.34±0.14	4.61	5.88±0.29	le Gall et al. 2010
U14	QAT	17	Academy	1.89±0.06				Buchheit et al. 2010b
U15	ENG	41	Academy	1.79±0.09		4.46±0.23		Williams et al. 2011
U15	QAT	10	Academy	1.79±0.08		4.57±0.23		Buchheit et al. 2010b
U15	FRA	16	Internationals	1.87±0.08	3.17±0.13	4.35	5.52±0.40	le Gall et al. 2010
U15	FIN	5380	Best 15%	1.70		4.16		Vilkki 2012
U16	ENG	32	Academy	1.77±0.06		4.29±0.15		Williams et al. 2011
U16	BEL	18	International	1.82±0.06	3.13±0.10	4.38±0.16		Vandendriessche et al. 2012
U16	QAT	12	Academy	1.77±0.05				Buchheit et al. 2010b
U16	FRA	16	Internationals	1.82±0.10	3.06±0.16	4.23	5.40±0.29	le Gall et al. 2010
U17	BEL	21	Internationals	1.82±0.08	3.12±0.12	4.33±0.16		Vandendriessche et al. 2012
U17	QAT	17	Academy	1.74 ±0.04				Buchheit et al. 2010b
U17	FIN	1519	Best 15%	1.67		4.07		Vilkki 2012
U18	ENG	20	Elite	1.78	3.04			Gorostiaga et al. 2004
U18	QAT	14	Academy	1.71±0.04				Mendez-Villanueva et al. 2010
U19	ESP	13	Elite	1.82±0.06	3.08±0.11	4.25±0.15		Lopez-Segovia et al. 2010
Adult	FRA	29	Elite	1.80±0.06	-	4.22±0.19	-	Cometti et al. 2001
Adult	NOR		Elite	1.82±0.03	3.00±0.03	4.00±0.20		Wisloff et al. 2004
Adult	ENG	106	Elite	1.83±0.08				Little & Williams 2005
Adult	FIN	1318	Best 15%	1.65		4.01		Vilkki 2012

U = under, Best 15% = the best 15 % of the total number of cases reported in column "n" = category "Excellent" in a Finnish reference table evaluated e.g. by soccer academies, sprinting speed has been one of the factors in which differences between the selected and unselected or elite and sub-elite players have been observed during puberty (Gissis et al. 2006, Gil et al. 2007a, Gravina et al. 2008, Figueiredo et al. 2009, le Gall et al. 2010, Lago-Penas et al. 2011, Vandendriessche et al. 2012). Sprinting time results around the world in different age groups are presented in Table 3.

Physical development offers two "windows of trainability" for speed. The first related to the nervous system maturation can be observed at the age of 7 - 8 years and the latter related to the increase in muscle mass between 14 to 15 years (Viru et al. 1998). Training interventions in which young soccer players sprinting speed has improved more than observed with normal growth have included strength training (Christou et al. 2006b), high-intensity interval training (Dupont et al. 2004), complex and contrast training (Mujika et al. 2009, Maio Alves et al. 2010), short and long sprint training (Meckel et al. 2012) and plyometric training (Meylan & Malatesta 2009). In adult players, maximal strength has been shown to be related to sprinting speed and with maximal strength training sprinting speed can be improved, and even to a greater extent if combined with speed training (Kotzamanidis et al. 2005, Wong et al. 2010, Helgerud et al. 2011).

2.2.5 Agility

Soccer player performs more than 700 turns and swerves and makes more than 1300 changes in running intensity in a soccer game (Mohr et al. 2003, Bloomfield et al. 2007). It has been shown that regardless of age the elite players are better than lower level players in agility tests which is not necessarily the case in the sprint tests (Gil et al. 2007a, Figueiredo et al. 2009, Kaplan et al. 2009, Chan et al. 2011, Rebelo et al. 2013). These findings indicate that straight sprint and agility are relatively independent qualities and therefore requires different task-specific training and testing procedures (Young et al. 2001, Little & Williams 2005, Chaouachi et al. 2012). The same seems to be the case also between repeated-sprint-ability and repeated-change-of-direction ability (Wong del et al. 2012). The difference between agility and straight sprint arises from different running techniques. The aim in straight sprint is to minimize vertical changes in the displacement of center of mass in order to minimize braking forces whereas decelerations and lowering the center of mass in turns play a key role in sprints with directional changes (Mero et al. 1987, Sayers 2000, Sheppard & Young 2006).

There are several factors that emphasize the importance of agility testing specifically during childhood and adolescence. First, Mirkov et al. (2010) demonstrated that soccer players were particularly good in agility and coordination tasks compared to physically active age-matched controls in the 11 to 14 year-old groups. Second, Gil et al. (2007) found that selected players were faster than non-selected players in the agility test in all age groups between 14 - 16 years, whereas selected players sprint time was better only in the youngest 14 year group. Third, it has been suggested that agility tests at adolescence can provide useful information in terms of preceding future career progression as agility test was able to discriminate players' future playing status irrespective of age (Gonaus & Muller 2012). Fourth, agility tests have been recommended because biological maturation affects motor coordination tests less than morphology or fitness tests (Vandendriessche et al. 2012).

According to pediatric literature, the development of agility is fastest during pre-puberty after which the improvement slows down during adolescence to reach the final level at the age of around 18 years (Malina et al. 2004). Research among young soccer players suggests that the fastest development during adolescence occurs at the same time with the maximal height spurt (Philippaerts et al. 2006, Nedeljkovic et al. 2007). The greatest improvement, around 5% per year, have been found in the fast-growing age groups (12 - 15 years) also in those datasets in which players were treated by their chronological age (Valente-Dos-Santos et al. 2012, Vilkki 2012). The current body of knowledge suggests that the agility can be improved, regardless of age, with exercises that mimic the demands of the change of direction speed such as horizontal jumps, loaded vertical jumps, sport-specific agility drills and general agility training, but not so much with traditional sprint, strength or power training (Bloomfield et al. 2007, Brughelli et al. 2008, Jullien et al. 2008, Thomas et al. 2009, Castillo-Rodriguez et al. 2012, Michailidis et al. 2013).

2.2.6 Endurance

2.2.6.1 Aerobic capacity

Aerobic fitness can be defined physiologically as maximal oxygen uptake (VO_2max) which is the highest rate for skeletal muscles to utilize oxygen in the provision of energy for locomotion (Rowland 2005). Traditionally high VO_2max has been considered an important quality in soccer as a significant relationship between VO_2max and distance covered during a soccer game has been observed and in some cases even teams success in league has been related to players VO_2max (Reilly & Thomas 1976, Apor 1988, Bangbo 1994, Wisloff et al. 1998). A player with a high VO_2max is suggested to perform more sprints and technical actions, to maintain technical and tactical skill level and to recover faster throughout a whole game (Ekblom 1986, Bangbo & Mizuno 1988, Helgerud et al. 2001, Tomlin & Wenger 2002, Rampinini et al. 2009b). However, the VO_2max is not a particularly sensitive measure of performance capability in soccer as recent studies have failed to show any meaningful difference in VO_2max between elite and sub-elite players in various age groups (Reilly et al. 2000, Gil et al. 2007a, le Gall et al. 2010, Lago-Penas et al. 2011, Tonnessen et al. 2013). Neither has young nor adult players VO_2max changed from the 1990`s even though the tempo in contemporary soccer has increased (Reilly 2005, Carling et al. 2012, Tonnessen et al. 2013). It is likely that a player needs a certain level of aerobic power, around 60 ml/kg/min (Table 4) in order to perform successfully in elite soccer (Reilly et al. 2000). This value has been proposed as elite players VO_2max values settle between 57-67 ml/kg/min around the world (Casajus

2001, Dawson et al. 2002, Hoff 2005, Da Silva et al. 2008, Manna et al. 2010, Boone et al. 2012, Tonnessen et al. 2013).

TABLE 4 Maximal oxygen uptake (VO_2max) values presented for soccer players in research literature.

Age	NAT	n	Group	VO_2max (ml/kg/min)	Reference
U10	ESP	15	Academy	59.7±9.2	Fernandez-Gonzalo et al. 2010
U12	ESP	15	Academy	60.5±8.6	Fernandez-Gonzalo et al. 2010
U13	DEN	21	Elite	58.2±6.7	Hansen & Klausen 2004
U14	FRA	158	Academy	58.0±3.2	Carling et al. 2012
U14	DEN	21	Elite	64.0±9.3	Hansen & Klausen 2004
U14	FRA	16	Internationals	59.2±9.3	le Gall et al. 2010
U15	DEN	21	Elite	62.6±6.5	Hansen & Klausen 2004
U15	FRA	16	Internationals	61.5±3.9	le Gall et al. 2010
U16	DEN	21	Elite	60.1±5.9	Hansen & Klausen 2004
U16	FRA	16	Internationals	62.4±2.7	le Gall et al. 2010
U17	CHN	16	Internationals	60.5±5.4	Wong del & Wong 2009
U18	ITA	15	Club	61.8±4.5	Impellizzeri et al. 2006
U18	POL	19	Club	63.6±4.2	Jastrzebski et al. 2013
Adult	NOR	14	Elite	67.6±4.0	Wisloff et al. 1998
Adult	ESP	15	Elite	66.4±7.6	Casajus 2001
Adult	BRA	162	Elite	63.3±6.2	Signorelli et al. 2012

U = under

The absolute VO_2 of an average male more than doubles from around 1.5 l/min to 3 - 4 l/min between 7 to 17 years of age due to the enlargement of the oxygen deliver organs such as the lungs, heart and skeletal muscles (Mirwald et al. 1986, Rowland 2005). However, when VO_2max is expressed relative to body weight, no marked changes are observed across different age groups in males. Young soccer players' VO_2max is higher than that of an average young person due to soccer training in which more than 25 % of the training time is spent at moderate or high intensity heart rate zones (Castagna et al. 2011, Jastrzebski et al. 2013). The effect of soccer training was demonstrated by Hammami et al. (2013) who showed that young soccer players VO_2max increased 8 ml/kg/min from 48 to 56 ml/kg/min during an 8 month soccer season, while VO_2max in the age-matched control group remained at the same around 47 ml/kg/min during the whole monitoring period. It can also be added that soccer is beneficial at every stage of life as it has been shown that by playing soccer for six months untrained middle-aged men improved their aerobic fitness and reduced their blood pressure and cardiovascular risk profile (Krustrup et al. 2013).

It is likely that puberty is the time period when VO_2max has the strongest influence on soccer performance because an accelerated improvement in aerobic endurance occurs between 11 - 15 years in males (Viru et al. 1998) and the aerobic system plays a significant role in the maintenance of intensity level in a soccer game during adolescence (Meckel et al. 2009). This suggestion receives further support from a study by Gil et al. (2007) who found a difference between selected and non-selected players' VO_2max during puberty but not anymore at early adulthood. Regardless of age, high-intensity interval training and small-sided games are suggested to be the best training methods for improving soccer players VO_2max (Dupont et al. 2004, Impellizzeri et al. 2006, Mujika et al. 2007, Rampinini et al. 2007b, Hill-Haas et al. 2009, Castagna et al. 2011, Helgerud et al. 2011, Brandes et al. 2012, Dellal et al. 2012). The former is easy to structure and the latter having a possibility to improve technical and tactical skills in conjunction with aerobic power (Hill-Haas et al. 2011). Based on the research literature around 8 % improvement in VO_2max can be achieved with specialized training executed twice a week for a normal pre-season conditioning period of 8 weeks (Impellizzeri et al. 2006, Helgerud et al. 2011).

2.2.6.1.1 Hemoglobin and hematocrit

Hemoglobin is the iron-containing oxygen-transport protein in the red blood cell. Karpovich & Millman (1942) were probably the first to demonstrate that the amount of hemoglobin is related to performance of athletes, and furthermore, to a greater extent in longer lasting than in brief sport performance. The concentration of the hemoglobin in the blood cells rises from 120-140 g/l to 140-160 g/l between 10 to 17 years of age. A clear acceleration in the number of red blood cells and the hemoglobin concentration can be detected in males at the puberty due to increased hormonal activity (Malina et al. 2004). Hemoglobin concentrations of soccer players are similar to that of an average person in all age groups (Malcovati et al. 2003, Nikolaidis et al. 2003, Hansen & Klausen 2004, Silva et al. 2008).

Hematocrit is the volume percentage of red blood cells in blood. It has potential explanatory power for endurance performance as red blood cells contain hemoglobin which deliver oxygen to be used for energy production in the muscles. A reference range for hematocrit for adult males is 42-52 %. The percentage of red blood cells rises from average of around 40 % at the age of 10 years to around 47 % at the age of 18 years (Estridge et al. 1999, Acosta et al. 2004). Hematocrit of soccer player does not differ from that of an average person at any age (Malcovati et al. 2003, Nikolaidis et al. 2003, Hansen & Klausen 2004).

2.2.6.2 Endurance performance

In a heterogeneous group of individuals, VO_2max serves as a good indicator of a person's endurance performance ability, but it is not a synonym for endurance performance (Figure 2) at any age (Rowland 2005, Vollaard et al. 2009). During the growing years this can be readily noticed by observing what happens in endurance related variables. As already mentioned, VO_2max per body weight does not improve during growth but endurance performance and running economy do (Krahenbuhl et al. 1989, Rowland 2005, Fernandez-Gonzalo et al. 2010). For example, Krahenbuhl et al. (1989) demonstrated that endurance performance improved 29 % and running economy 16 %, while VO_2max per body weight decreased 13 % in a group of boys who were initially tested at the age of 10 years and then again at the age of 17 years.

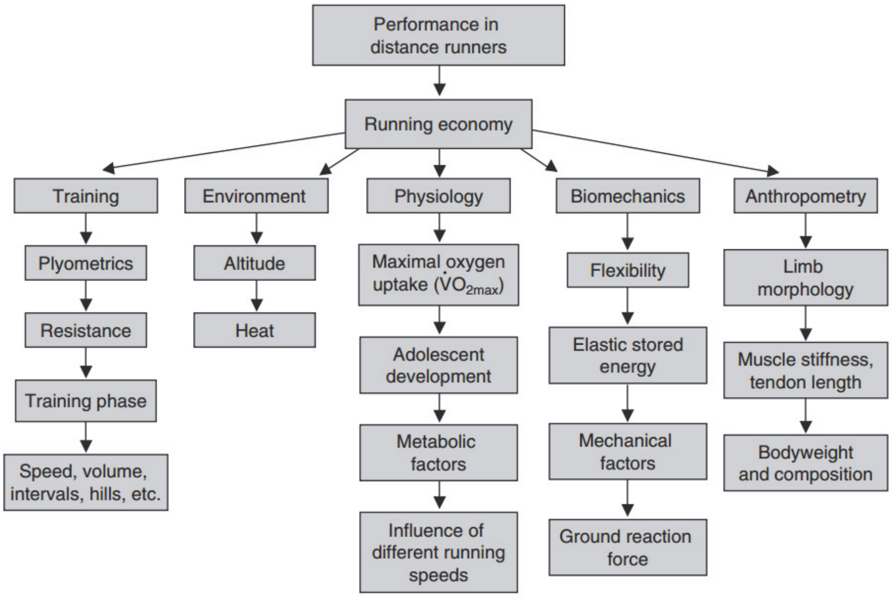

FIGURE 2 Factors affecting running economy (Saunders et al. 2004), with permission from the Springer Science + Business Media.

Soccer is played around the world and, therefore, a variety of different endurance tests are presented in soccer research literature. The rationality of different tests has been derived from players' actual movement patterns revealed by the time-motion analysis (Bangsbo 1994, Mohr et al. 2003). The time-motion analysis has shown that the total distance covered during a game in elite soccer is over 10 km, from which moderate or high intensity running is between 2 – 3.5 km (Bradley et al. 2009, Di Salvo et al. 2013). The amount of high intensity running is suggested to be more important than the total distance in discriminating elite and sub-elite players (Ekblom 1986, Bangsbo et al. 1991, Mohr et al. 2003, Di Salvo et al. 2013). This is why various intermittent endurance testing protocols have been used to mimic the demands of the game more closely (Krustrup et al. 2003, Lemmink et al. 2004, Spencer et al. 2006, Rampinini et al. 2007a, Gonaus & Muller 2012, Ingebrigtsen et al. 2012, Wong del et al. 2012). However, the differences between continuous and intermittent endurance tests are not necessarily particularly great as significant correlations between these tests have been found in several studies and both tests have been used to predict players VO_2max (Leger & Gadoury 1989, Castagna et al. 2006, Bangsbo et al. 2008, Castagna et al. 2010, Dupont et al. 2010, Wong et al. 2010).

The peak development in young soccer players' continuous endurance performance and repeated-sprint ability is shown to occur at the same time with the adolescent growth spurt (Philippaerts et al. 2006, Mujika et al. 2009b, Valente-Dos-Santos et al. 2012). Studies carried out among young soccer players have suggested that chronological age (Table 5), body size, maturity and training background are the main factors to explain endurance performance during growth (Malina et al. 2004, Wong et al. 2009, Figueiredo et al. 2011). The importance of endurance training can be justified by the facts that both total distance covered and high-intensity running usually decrease throughout the game in all age groups (Castagna et al. 2009, Buchheit et al. 2010c). According to Mujika et al. (2009a) endurance performance and agility were also the physical abilities which continue to develop after the age of 18 years to the age of adulthood in a group of highly trained players while this was not the case in the explosive leg strength and straight speed.

Players' endurance performance can be improved with small-sided games and high-intensity interval training which increases players' oxygen uptake and improves running economy (Dupont et al. 2004, Mujika et al. 2007, Rampinini et al. 2007b, Castagna et al. 2011, Helgerud et al. 2011, Brandes et al. 2012, Dellal et al. 2012, Gunnarsson et al. 2012). Strength and explosive training can be use to improve athletes' neuromuscular and anaerobic performance (Mikkola et al. 2007). All of these training methods including high-intensity interval training, high resistance and explosive strength training, plyometric training and combinations of these methods have been used successfully when soccer players endurance performance and fatigue resistance has been improved (Dupont et al. 2004, Mujika et al. 2007, Wong et al. 2010, Bogdanis et al. 2011, Helgerud et al. 2011). In addition, Elferink-Gemser et al. (2012) has shown that intermittent endurance performance has improved 36 – 61 % over a decade in the U13 to U19 age groups which indicates that soccer training, deliberately or not, has adapted to the growing demands of contemporary soccer.

TABLE 5 Soccer players' continuous and intermittent endurance performance development by age.

	Yo-Yo IRL1			Yo-Yo EL1		
U11	797±267m	n=50	Deprez et al. 2012	2100m*	n=5	Vilkki 2012
U13	1218±402m	n=26	Deprez et al. 2012	2180m*	n=137	Vilkki 2012
U15	1616±422m	n=48	Deprez et al. 2012	2460m*	n=1439	Vilkki 2012
U17	2340±401m	n=66	Deprez et al. 2012	2560m*	n=1184	Vilkki 2012
Adults	2414±456m	n=17	Mujika et al. 2009a	2640m*	n=1372	Vilkki 2012

U = under; IRL1 = intermittent recovery level 1; EL1 = endurance level 1; * = the best 15 %

2.2.7 Skill acquisition

2.2.7.1 A simple information processing model

Soccer has been classified as "open-skill" sport in which the environment is constantly changing and movements have to be continually adapted (Thelwell et al. 2006). Within open-skill sports the performance can be simplified to three stages which are stimulus identification (perception), decision making and motor execution (Welford 1968, Whiting 1969). It has been argued that "skill" in soccer is too difficult to determine but valuable information can be achieved through cognitive (perception, anticipation, decision-making) and motor skill ("technique") measurements (Ali 2011).

2.2.7.2 General perceptual-motor skills

Probably the first modern sport studies to demonstrate that a top athlete performs better than an ordinary person in general reaction time tasks were published by Abel (1924) and Fullerton (1925) who analyzed the famous baseball player Babe Ruth and concluded that one reason for his exceptional hitting ability was his superior vision. Since then several studies have shown that athletes possess better visual abilities than non-athletes (Stine et al. 1982, Christenson & Winkelstein 1988, Sillero Quintana et al. 2007, Stephenson 2007). Studies examining precisely soccer players have also suggested that soccer players have better eye-hand and eye-foot reaction time than ordinary people (Montes-Mico et al. 2000, Ando et al. 2001, Luhtanen et al. 2005).

The progression of performance in reaction time tasks during growth approximates the process of neural maturation so that the effect of age is more marked for complex reaction tasks (Fulton & Hubbard 1975, Thomas et al. 1981, Luchies et al. 2002, Der & Deary 2006). Around 95 % of the total size of the central nervous system is already attained by 7 years of age but the maturational processes in the nervous system are known to continue well through adolescence (Malina et al. 2004, Paus 2005, Steinberg 2005). Puberty is characterized by a temporal neural inefficiency which is believed to be caused by the phase shift between proliferation and pruning in the brain but at the end this process leads to more efficient synaptic configurations (McGivern et al. 2002). Increased testosterone secretion during puberty partly explains the changes of the nervous system in males as testosterone is known to promote the functional and anatomical development of the nerves and brain (Sakai & Woody 1988, Stocker et al. 1994, Tan 1996, Steinberg 2005, Cahill 2006). Beside general growth, learning and experience have an impact on many levels of the brain structure and function (Durston & Casey 2006).
Practically speaking, performance in reaction time tasks improve up to 20 years of age after which reaction time increases 0.5 msec per year in a simple reaction task and 1.6 msec in "go-no-go" reaction task (Fozard et al. 1994). Psychophysiologically the fastest simple reaction time at any age cannot be less than 100 ms due to time needed for stimulus recognition, conduction of action potential via efferent neuron to muscle and muscle contraction itself (Kauranen 2011).

Miyaguchi et al. (2013) showed that children who liked to play soccer had better reaction time compared to children who preferred statistic plays at the age of 4 - 6 years. Elite players have also been shown to perform slightly better in reaction time tasks than sub-elite players in all age groups between U9 to U17 (Ward & Williams 2003, Gonaus & Muller 2012). Loran and Griffiths (1998) suggested that visual skills might be even more important than is generally recognized, noting that there was a connection between visual performances and playing skill in a group of 14-year-old soccer players. However, in a study by Ward & Williams (2003), sub-elite players' peripheral reaction time improved 8 %

more than elite players between ages 9 to 17 years. A similar tendency was also observed in the results presented by Gonaus et al. (2012) who showed that elite players responded slightly quicker but improved less than age-matched sub-elite players in multi-choice reaction time test of the lower limbs between ages 14 to 17 years. Thus, it seems that differences between elite and sub-elite players in reaction time tasks can be expected to be found mainly in the younger age groups and the difference seems to diminish as players become older.

2.2.7.3 Skill assessments in youth soccer

The tempo of contemporary soccer has increased compared to previous decades, which means that players' performance abilities need to improve constantly in order to respond to the growing demands of the game (Huijgen et al. 2009). Based on the game analysis carried out in elite soccer, a player has an average of 30-60 ball actions during a game, although the range is large (Carling & Dupont 2011). The most frequent course of actions in the game is to take possession of the ball and pass, make a first touch pass or take the possession, dribble and pass (Rampinini et al. 2009a, Dellal et al. 2011). A logical consequence is that the fundamental technical skills required in soccer are ball control, dribbling, passing and shooting (Rosch et al. 2000, Ali 2011, O'Reilly & Wong 2012). The effects of game induced fatigue to technical performance do not seem to be particularly significant as it has been shown that players are able to maintain skill-related performance throughout the game and when competing in successive matches within a short period of time (Carling & Dupont 2011, Russell et al. 2013). Actually, short passing ability has been shown to improve after 45 min high-intensity intermittent exercise (Bullock et al. 2012).

Skill influenced by many physiological and psychological factors is more difficult to determine than physiological indicators (Malina et al. 2005). Nevertheless, compared to the fact that the successful skill execution is the most important aspect of soccer play, studies conducted on skill performance in the research literature are still rather few (Ali 2011). This is a surprising as it has been suggested that adolescence dribbling performance can predict the best players for the future, i.e. the players who are going to reach the professional level (Huijgen et al. 2009). Moreover, skill tests (especially those including speed-dribbling) have been shown to distinguish elite and sub-elite players in different age groups (Reilly et al. 2000, Malina et al. 2004, Vaeyens et al. 2006, Figueiredo et al. 2009, Huijgen et al. 2009, Rebelo et al. 2013). Taking into account that training is known to be the most important factor for the development of soccer skills (Helsen et al. 2000, Huijgen et al. 2010, Figueiredo et al. 2011, Valente-Dos-Santos et al. 2012), it is evident that young players' technique monitored over a prolonged period of time can provide valuable information for soccer coaches about the players' long-term development and responsiveness to training programmes (Huijgen et al. 2009, Meylan et al. 2010).

The results in technical skill tests improve with age in young soccer players, but the development is not straightforward. The fastest development occurs already in pre-pubertal years (Valente-Dos-Santos et al. 2012). During the puberty and late adolescence, development has been shown to fluctuate from minor regression to a few percentage improvements depending on the test but the overall tendency has been that players improve with small steps up until adulthood (Rosch et al. 2000, Vaeyens et al. 2006, Huijgen et al. 2010, Valente-Dos-Santos et al. 2012). Thus, the effect of age and maturity do have an impact but biological maturity affects less in skill tests than in fitness tests (Malina et al. 2005, Valente-Dos-Santos et al. 2012, Vandendriessche et al. 2012).

It has been shown that accumulated hours of practice differentiate elite and sub-elite players so that the time spent in individual practice under 12 years of age and especially the amount of deliberate team practice thereafter is greater among elite players compared to sub-elite players (Helsen et al. 1998, Ward et al. 2007). Developmental activities of young elite soccer players have also been shown to follow both the early specialization and early engagement pathways around the world (Ford et al. 2012). These findings emphasize unambiguously that a high amount of deliberate soccer training is needed in order to become a skilful player. As a final note, the importance of technical skills can be highlighted with the argument presented by Fernandez-Gonzalo et al. (2010):"…, it seems that when the technical level is similar in two different soccer teams, the physical capacity plays a key role".

2.2.7.4 Soccer-specific perceptual-motor skills

Although athletes with quicker general reaction time might have an advantage over slower ones in individual game situations, the current consensus in sport research is that general perceptual-motor skills may only set potential limits to performance, but once that limit is exceeded, it is sport-specific perceptual-motor skills that separate elite athletes from non-elites (Ferreira 2002). This also means that any meaningful differences between elite and non-elite athletes cannot be expected to occur in general measures of motor ability, such as general reaction time tasks (Henry 1958, Starkes & Deakin 1984, Ericsson & Lehmann 1996, Schmidt & Lee 2005). This suggestion is further supported by the fact that differences in reaction time tasks are usually conveyed as hundredths of a second, as compared to differences of tenths of a second that have been found in studies focused on game reading skills, such as anticipation time (Savelsbergh et al. 2002, Vaeyens et al. 2007a). This is why several authors have emphasized that it is sport-specific perceptual and decision-making factors which are particularly important in ball games (Blomqvist et al. 2000, Young et al. 2002, Ward & Williams 2003, Vaeyens et al. 2007a). It has even been argued that cognitive skills play a crucial role in the final outcome since the differences in physical performance characteristics at the elite level are very small (Roca et al. 2012).

Perceptual and decision-making skills are essential factors in soccer performance because players must respond to sensory stimulus around them before actual physical performance or technical skill can be executed (Sheppard & Young 2006, Vaeyens et al. 2007b). It is well documented that elite athletes are superior compared to less skilled athletes in their ability to anticipate the next movement based on other players' postural cues and to make appropriate decisions during a game (Helsen & Starkes 1999, Vaeyens et al. 2007a, Vaeyens et al. 2007b, Diaz del Campo et al. 2011, Roca et al. 2011, Diaz et al. 2012, Roca et al. 2012). This superiority in soccer has been detected already at the 9 year-old age groups (Ward & Williams 2003). According to Vayens et al. (2007) successful decision-makers at the age of 13-16 years are using more goal-oriented search strategies such as spending more time in fixating the player in possession of the ball and alternated gaze more frequently between the player with the ball and other areas in the game. The skilled decision makers have also been shown to employ a search strategy involving more fixations of shorter duration in a different sequential order and toward more disparate and informative locations compared to less skilled counterparts (Roca et al. 2011). It is also worth to note that efficient decision-making is an important part of tactical expertise which, in turn, is prerequisite for expert performance in soccer (Elferink-Gemser et al. 2004, Kannekens et al. 2009, Kannekens et al. 2011).

Expertise and domain-specific knowledge can only be achieved through years of deliberate practise (Ericsson & Lehmann 1996, Roca et al. 2012). Berry et al. (2008) has suggested that accumulated hours invested in invasion-type activities and not necessarily intent (skill development of fun) or specificity that facilitates the development of perceptual and decision-making expertise in team sports. In practice this means that soccer players are likely to gain particular benefit also from experience in invasion activities in other sports than soccer. This suggestion is consistent with previous research showing that transfer of perceptual and decision-making skills across sports is possible (Smeeton et al. 2004, Abernethy et al. 2005). Nevertheless, it has been hypothesized that soccer-specific play activity during the childhood and adolescence provides the best conditions for players to engage in anticipation and decision making leading to lasting adaptations and improvements in these abilities (Roca et al. 2012). Again, small-sided games have been recommended for young soccer players as these games allow players to develop their physical abilities, technical skills and decision-making abilities at the same time in a real soccer context (Reilly 2005). In small-sided games physiological, technical and cognitive goals can be easily manipulated by changing pitch area, rules, the number of players or more than one of these variables at the same time (Hill-Haas et al. 2011). In addition with traditional training, video based perceptual training is a promising method to improve athletes' game awareness and decision-making abilities (Gabbett et al. 2008). To summarize, sport-specific perceptual and cognitive performance improves with domain-specific practice rather than with age and the development is not necessarily a straightforward process, not even among elite performers (Abernethy 1988, Tenenbaum et al. 2000, Ward & Williams 2003, Vaeyens et al. 2007a).

3 PURPOSE OF THE STUDY

This work contains data from three different age groups of a regional soccer team monitored for two years. This data was further extended with a dataset from the nationwide soccer skill database and with general perceptual-motor skill measures in U16 and U19 groups that possessed different levels of soccer expertise. The overall purpose of this thesis was to examine how Finnish regional soccer players develop in terms of anthropometrics, body composition, hormonal profile, physical performance characteristics, general perceptual-motor skills, soccer skills and soccer-specific perceptual-motor skills between U11 to U17 age groups. The specific aims of the present study were as follows:

1. To monitor how young soccer players development in anthropometrics, body composition, hormonal profile and physical performance characteristics differs from age-matched controls not engaged to soccer (I, III).

2. To investigate what are the connections between soccer expertise and general perceptual-motor skills (I, II, V).

3. To investigate how technical soccer skills develop over time, across sex and by age (I, IV, V).

4. To investigate how soccer-specific perceptual-motor skills develop with age (I, V).

5. To examine what are the relationships between anthropometrical, body composition, hormonal and performance variables in different age groups (I, II, IV, V).

6. To compare the performance characteristics of young Finnish soccer players to age-matched counterparts in other countries (comparison based on research literature; I-V).

4 METHODS

4.1 Subjects

The subjects of the present study were young soccer players 9 to 17 years of age. These main subjects, who were followed for two years, included three age groups from a regional club team of the area of 160.000 inhabitants. On a global scale these players could be defined as sub-elite or recreational players although according to the Finnish standards the club was classified as one of the top youth soccer organization in Finland. In addition to the main subjects, the data from youth national teams and from nation-wide soccer skill database was utilized in order to broaden the perspective of the present research. When players' physical performance characteristics were measured, two control groups not participating in soccer, consisting of age-matched school boys were measured at the start and end of the follow-up period, with the same tests used in the soccer players (III).

On average, the U11 players had started playing soccer at the age of 5.9 ± 0.9 year (played ~5 years) and participated 4.3 ± 0.8 times/wk in organized sports. The same values for the U13 group were 5.8 ± 1.1 year (played ~7 years) and 4.8 ± 0.9 times/wk and for the U15 group 5.6 ± 0.9 year (played ~9 years) and 5.1 ± 0.9 times/wk, respectively. The control groups participated in organized sports 1.2 ± 1.1 times/wk in the younger age group (10.7 ± 0.3 y, n = 14) and 0.4 ± 0.8 times/wk in the older age group (14.7 ± 0.3 y, n = 10).

4.2 Study design

This study followed the U11 (10.8 ± 0.3 y, n = 14), U13 (12.7 ± 0.2 y, n = 14) and U15 (14.7 ± 0.3 y, n = 12) year-old soccer team over period of two years in terms of body composition, hormonal status, physical performance, technical soccer skills, general perceptual-motor skills and soccer-specific perceptual-motor skills (Table 6). All tests related to follow-up were performed annually at the same time of the calendar year during preparation season and testing took place at the same time of the day. The subjects were instructed to avoid vigorous exercise the day preceding the tests. Testing protocol included six separate measurement sessions in a time frame of two weeks: 1) Body composition and serum hormones; 2) Countermovement jump, sprinting time, agility, and endurance performance; 3) Strength tests; 4) Maximal oxygen uptake test; 5) Soccer skill tests; 6) General perceptual-motor skill and soccer-specific laboratory test. In addition, the data measured from the U19 national team (n = 16), U-16 national team candidates (n = 40), regional club teams (n = 123) and school boys (n = 122) is presented in the general perceptual-motor skills section (II). In the section presenting technical soccer skills (IV), an analysis based on the nationwide soccer skill database (n = 28 993) is included.

TABLE 6 Overview of the study design.

	Anthropometrics and Body Composition	Hormones	Physical Fitness	Technical Skills	General Perceptual-motor Skills	Soccer-Specific Perceptual-motor skills
Baseline	x	x	x	x	x	x
1st year	x	x	x	x		
2nd year	x	x	x	x	x	x
Datasets				1	2	

1 = cross-sectional data from the nationwide soccer skill database; 2 = cross-sectional data from the U16 and U19 groups with different levels of soccer expertise

4.3 Anthropometrics, body composition and serum hormones

All body composition measurements were performed by the same experienced health care professional between 7.30 – 8.30 a.m. after 12 h of fasting. The height of the subjects was measured using the standard stadiometer technique with a precision of 0.5 cm. Body composition was recorded in terms of weight, total muscle mass, percentage of body fat and lean weight of trunk, arms and legs with an eight-polar bioimpedance body composition analyzer (Inbody 720, Biospace Co., Seoul, Korea). According to validity report produced by the manufacture the intraclass correlation coefficient in fat free mass between Inbody 720 and dual-energy X-ray absorptiometry among 731 subjects was 0.98 (Biospace 2002). Serum testosterone and cortisol concentration were taken from a venous blood sample after a 12 h fast between 7.30 – 8.30 a.m. (Immulite 1000, DPC Diagnostics Corporation, Los Angles, USA). The intraassay coefficient of variation in determining the concentration of testosterone in males varies typically between 3.3 - 5.5 % with the use of commercial kits (Boots et al. 1998).

4.4 Physical fitness tests

4.4.1 Maximal and explosive strength

Subjects' strength was recorded using measures of maximal bilateral isometric leg press, maximal isometric strength of trunk extension (back muscles) and flexion (abdominal muscles) and grip strength. Maximal bilateral isometric strength of leg extensor muscles was measured on an electromechanical leg press dynamometer in a sitting position, with a knee angle of 107° (Häkkinen et al. 1998). The force signal was recorded and analyzed with a Codas™ computer system (Codas v 1.0, Dataq Instruments Inc., Akron, USA). Maximal isometric strength of trunk extension (back muscles) and flexion (abdominal muscles) was measured in a dynamometer in which the participant stood in an upright position, fixed at the height of their pelvis and chest, and pushed as much as possible either backwards or forwards against the plate with the force transducer. Grip strength of the dominant hand was measured with a dynamometer which was adjusted so that the base rested on the first metacarpal and the handle on the middle of four fingers. In all strength tests, the subject was instructed to give a maximum isometric effort for about 5 seconds. Maximal peak force was defined as the highest value of force (N) recorded during the test. Strong verbal encouragement was given to the subjects in order to motivate them to give their best in the strength tests (III). The intraclass correlation coefficient is shown to be more than 0.90 for grip, trunk and leg strength measurements in electromechanical dynamometers (Bohannon 1986, Wessel et al. 1999, Essendrop et al. 2001).

Maximal rate of force development in the leg press, countermovement jump and 5-jump was measured in order to analyze the subjects' explosive strength of lower extremities. The maximal rate of force development in the 107° leg press was analyzed from the same trials as maximal strength was analyzed. The subjects were instructed to produce maximal strength in the leg press as fast as possible. The maximal rate of force development (RFD) was analyzed with a Codas™ computer system and defined as the greatest increase in force in a given 50 ms time period (Häkkinen et al. 1998). Countermovement jump (hands placed on the hips) was measured on an Ergo jump™ contact mat (Boscosystem srl, Cittaducale, Italy). Based on the flight time the system automatically displayed the result of measured jump in centimetres at the accuracy of a tenth of centimetre. The coefficient of variation in countermovement jump test is shown to be 2.4% (Moir et al. 2004). 5-stride jump into a long jump pit was measured with a measuring tape (Chamari et al. 2008). The results were recorded at the accuracy of one centimetre. The best out of three trials was selected for further analysis in all strength and power tests (III).

4.4.2 Sprinting time and agility

Sprinting time was measured with an all-out sprint from a stationary start on a track. In the sprint test, the subjects started 0.70 m behind (heel on the line) the photocells which triggered the start of the time signal. The time-stopping photocells were placed at the distance of 10 m and 30 m from the starting line. Performance time was recorded by the photo cell timer with a precision of one hundredth of a second. The best out of three trials was selected for further analysis (I, III). The coefficient of variation in sprinting time tests is shown to be approximately 2 % (Moir et al. 2004). An 8-figure test track, recommended by the Football Association of Finland, was used as an agility test (Figure 3). Mirkov et al. (2008) have reported 0.84 intraclass correlation coefficient and 2.5 % error of measurement for similar type of agility test. In the agility test, the subject ran back and forth to touch a pole placed 11m from a starting line. On the way to the pole as well as on the way back to the finish line the subject performed a slalom run in a 2 m x 2 m rectangle placed 4.5m apart from the starting line and from the pole. That is, a figure-eight-shaped run was performed when the test is considered as a whole. The test starts 0.70 m behind (heel on the line) the photocell which triggered the start of the time signal and finished when the subject ran through the photocell gate placed in line with the starting gate. A photocell timer recorded the result with a precision of one hundredth of a second. The best out of three trials was selected for further analysis (I, III).

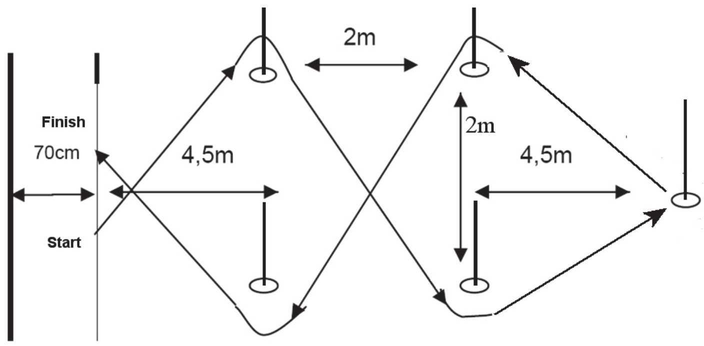

FIGURE 3 A diagram of the Agility test.

4.4.3 Aerobic capacity and endurance performance

Subjects' aerobic endurance capacity was determined by the maximal oxygen uptake (VO_2max) test and their endurance performance by the Yo-Yo endurance level 1 shuttle run test. Aerobic endurance capacity was measured on a treadmill. The treadmill was set at a constant 1° incline and speed was increased by 1 $km \cdot h^{-1}$ per minute (starting from 6 $km \cdot h^{-1}$) until exhaustion (Fairshter et al. 1983). The criteria used to determine VO_2max were a plateau in VO_2max despite an increase in running speed and a heart rate in excess of 90 %

of the predicted (220-subject age) maximal heart rate. Oxygen uptake was measured continuously breath-by-breath (Vmax series, Sensormedics Co., Yorba Linda, USA) and VO_2max was determined as the highest 30 seconds average of VO_2 during the test. The gas analyzer was calibrated before and after each experimental subject by using known gas content. Performance of the instrument was checked at regular intervals during the study. The accuracy of the O_2 and CO_2 analyzers of the instrument is reported to be ± 0.02 % (Sensormedics 2002). Endurance performance was measured using the Yo-Yo Endurance Test Level 1 -shuttle run test. The Yo-Yo test involves continuous running between two lines 20 m apart in time of the trigger signal played from CD. The test began at an initial running velocity of 8.5 km/hr and the speed increased by 0.5 km/hr each minute. The subject continued running between the two lines until the subject failed to reach the line for two consecutive ends at the onset of trigger signal. Heart rate was monitored during the Yo-Yo test to ensure that maximum effort was achieved. The result was expressed as distance covered during the test with a precision of 20 meters (III). An intraclass coefficient of 0.93 has been reported in the test-retest reliability measure for the 20m shuttle run test among 12 to 15 year-old children (Liu et al. 1992).

4.5 Skill tests

4.5.1 General perceptual-motor skills

General perceptual-motor skills were determined in terms of simple reaction time, peripheral awareness and eye-hand-foot coordination (Coffey & Reichow 1995, Erickson 2007). A number of different factors, such as type and intensity of stimulus and subject's arousal, may influence on reaction time measures (Sanders 1998). The variability in reaction time performance is less among young subject than among older (Hultsch et al. 2002). A one day interval test-retest correlation of 0.67 for simple reaction time and 0.92 for choice reaction time has been reported for middle age adults (Duncan et al. 2005). In the simple reaction time test, the subjects were instructed to extinguish a signal light switched into the same position on the Wayne Saccadic Fixator board (Wayne Engineering, USA) as quickly as possible with the index finger of their dominant hand (Figure 4). Reaction time was measured as the time between the onset of stimulus to the completion of the subject's response. A total of five trials were recorded and the average of three responses, excluding the best and the worst, was calculated as a final score. Peripheral awareness (= peripheral reaction time) was measured by using the Wayne Peripheral Awareness Trainer, in which participants stood 60 cm away from the central cylinder, with eight peripheral lights mounted on 50 cm long rods in the cardinal and ordinal directions (Figure 4). Participants were asked to concentrate on the central light in the middle of the cylinder and respond using a joystick as quickly as possible to eight peripheral lights that were illuminated in random order. An average time of the eight directions was calculated, with the best out of three trials being selected. In the eye-hand-foot test (Figure 4), the subjects extinguished as many randomly illuminated lights in the Wayne Saccadic Fixator board as possible in 30 seconds in a predetermined manner using their hands (29 lights) and feet (four lights). The open dots in Figure 4 illustrate hand positions to be pressed with the right or left index finger when the red light appeared in these positions. Black dots illustrate foot positions that were to be responded to with pedals on the ground when a red light appeared in these positions. The number of extinguished lights was counted and the best out of three trials was selected. The subjects were allowed to perform familiarization trials until stabilized performance was detected. This was followed by a short break and recording of the actual test trials (I, II, V).

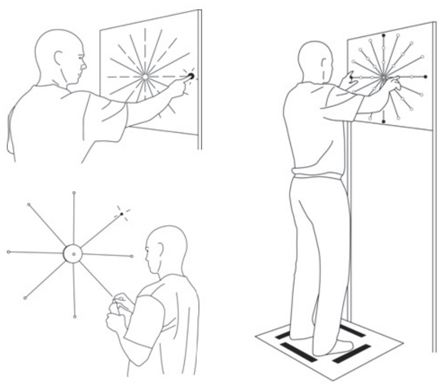

FIGURE 4 Illustration showing the simple reaction time test (upper left), peripheral awareness (lower left) test and eye-hand-foot coordination test (right).

4.5.2 Soccer skill tests

4.5.2.1 Dribbling test

The official dribbling test used in youth soccer skill competitions organized by the Football Association of Finland was used when players' technical dribbling skills were measured (Figure 5). In the test, player took the ball and ran straight to a pole which was set to 20 meters from the starting line. The rules obligates that the player must have at least 3 touches before the pole. Then players dribbled back to the starting line between the poles which were placed 4 m – 2 m – 2 m – 4 m – 2 m – 2 m – 4 m apart from each other. The same straight run-dribbling action was repeated from the other side to complete the test. Performance time was measured with a stopwatch with a precision of tenth of a second. One successful performance, which was always achieved by the fourth attempt, was required in the club team. When cross-sectional data from the nation-wide database was utilized, the best out of two attempts was selected for analysis unless player failed to perform the test in less than 50 seconds in which case 50 seconds was registered as the performance time (I, IV). The reliability of the dribbling test was tested with a one month interval test-retest (29.6 ± 3.2s vs. 30.0 ± 3.1 s) which showed a correlation coefficient of r = 0.82 (p<0.001) among a group of 87 young soccer players (12.0 ± 1.4 y).

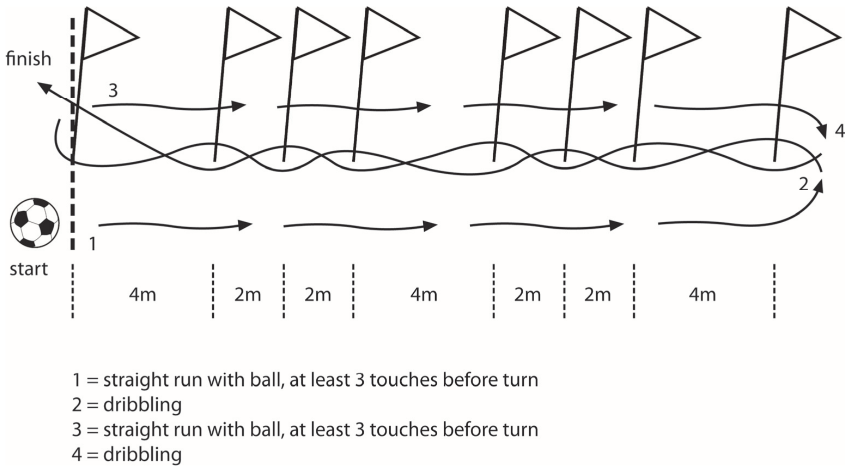

FIGURE 5 A diagram of the Dribbling test.

4.5.2.2 Passing test

The official passing test used in youth soccer skill competitions organized by the Football Association of Finland was used when players' technical passing skills were measured (Figure 6). The passing test layout included two cones 6 m apart from each other and 2 m wide passing walls placed 7 m apart from the cones. Performance time started when a player kicked the first pass against the wall. Then player repeated the cycle: pass - receive rebound - dribble between cones - pass to the other wall. The performance ended when the 10th pass hit the passing wall. Five of the passes were given with the right foot and five with the left foot. One successful performance, which was always achieved by the fifth attempt, was required in the test. When cross-sectional data from the nation-wide database was utilized, the best out of two attempts was selected for analysis unless the player failed to perform the test in less than 60 seconds in which case 60 seconds was registered as a result (I,IV,V). A one month interval test-retest (45.0 ± 6.7 s vs. 45.4 ± 6.7 s) correlation coefficient for the passing test was r = 0.81 (p<0.001) among a group of 87 young soccer players (12.0 ± 1.4 y).

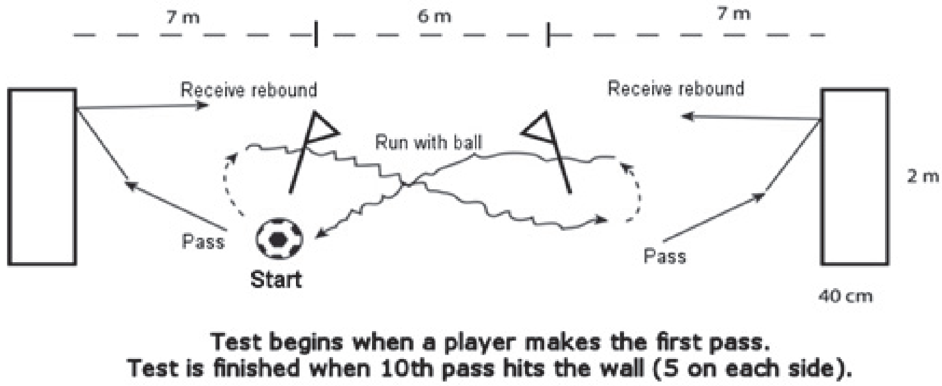

FIGURE 6 A diagram of the passing test.

4.5.3 Soccer-specific laboratory test

A laboratory test track (Figure 7) was constructed in order to measure soccer-specific perceptual-motor skills in simulated `on-the-ball` performance (I, V). The test included a chain of typical soccer actions: anticipation, receiving, dribbling, feinting and passing. Firstly, the player watched a near life-size video sequence (1) of a soccer player receiving the ball, running a short distance towards the participant, and passing to the right or left. The player correspondingly anticipated the pass and took the ball (2) located on his left or right hand side. Secondly, the player dribbled the ball between two cones (3) and through the photocell gate (4) which triggered a light (5) on the left or right hand side of a pole placed 5m in front of the photocell gate. The signal light determined which side of the pole the pass (6) should be given. Thirdly, the player was instructed to direct a pass between two switched lights in a running light track (7) proceeding at the speed of 4.17 m/s. The players were instructed to complete the entire performance as quickly and accurately as possible. In the soccer-specific laboratory test, the players had 4 familiarization and 16 actual test trials (8 on each side in a random order) with a resting period of 45 seconds between each trial. The trials were recorded with three 50 Hz camcorders and analyzed with the APAS motion analysis software (Ariel Dynamics Inc., USA). The analyzed variables were: Anticipation time = the moment from the pass on the video sequence to the first movement towards the ball; 1st touch = the moment from the pass on the video sequence to the first touch to the ball; Dribbling time = time from the first ball touch to the moment of entering the photocell-gate.; Selection time = time from illumination of the direction stimulus (triggered by photocell-gate) to the moment when the gaze moved away from the stimulus light; Feint-target = selection time + aiming time; Pass duration= the moment from passing impact to the moment when the ball entered the running light track.; Total performance time = 1st touch + dribbling time + feint-target + pass duration; Passing accuracy = “penalty points” according to the distance between the ball and switched light-pair when the ball entered the line of the running light track (0 points = hit, 1 point = one light-pair in front or behind, 2 points = two light-pairs in front or behind, etc.). Reliability of the soccer-specific laboratory test was examined by analyzing 10 adolescent soccer players (12.6 ± 1.6 y). The Pearson coefficient correlation was 0.93 for intra-observer, 0.86 ($p<0.001$) for inter-observer and 0.81 ($p<0.01$) for test-retest.

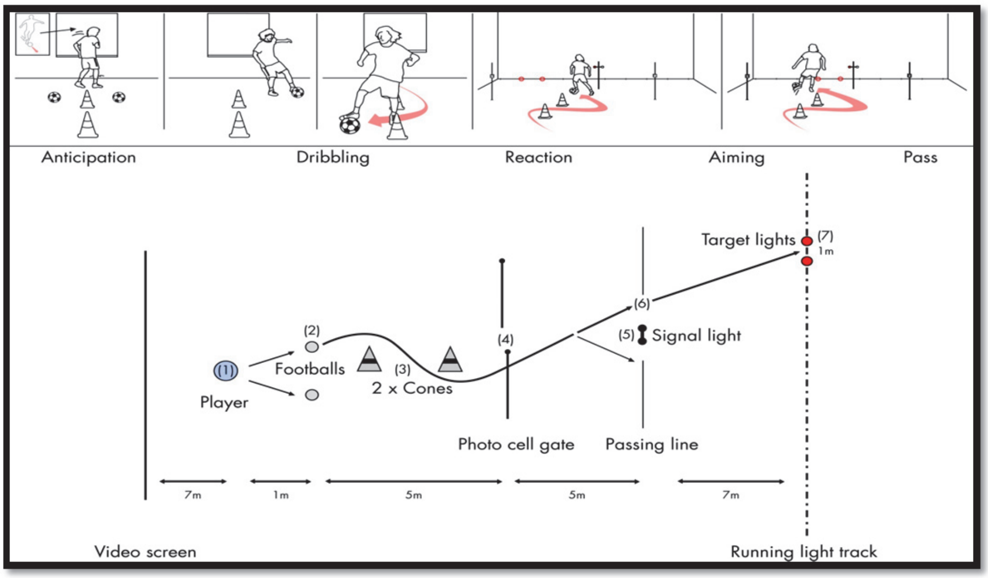

FIGURE 7 A diagram of the soccer-specific laboratory test.

4.6 Statistical methods

4.6.1 Follow-up data

When soccer players were compared to the control groups, the measured variables were analyzed in a 4 x 2 (Age x Group) analysis of variance. Effect sizes between players and cotrols were estimated using Cohen's d statistic, for which values of 0.2, 0.5, and 0.8 were considered small, moderate and large effects. A paired samples t-test was conducted to compare the effect of age on the measured variables within each soccer group during the two-year monitoring period. In order to examine differences between the soccer groups that are not related to age, the independent samples t-test was conducted to compare the measured variables of two different groups of soccer players at the overlapped age (Group 1 and 2 in the U13; Group 2 and 3 in the U15). Significance was set at $p<0.05$ for all tests.

4.6.2 Additional datasets

When the club team players were monitored over the two-year period, a one-way ANOVA was conducted to examine the effect of age on those variables which were measured only from soccer players. Within the groups, a paired samples t-test was performed to examine the changes in the measured variables during the follow-up. An independent samples t-test was used to detect differences between the different groups at the same age.

When skill development between the years 2000 - 2011 was described (IV), the data was treated in order to give a general overview of skill development across the decade. The data treatment procedure included four steps: 1) Only the most representative 10 to 14 year-old categories were selected for analysis; 2) Passing and dribbling test times were combined to describe skill per se and to simplify the analysis; 3) Only the better half of the combined results in each age group were annually accepted for further analysis in order to ensure that only successful trials were included; 4) One group consisting of the same number of players from every age group (based on the age group with the smallest sample size) was formed separately for each year in both genders. This was undertaken in order to eliminate bias arising from unequal sample sizes in different age groups. A combined skill variable was analyzed in a 2 x 12 (Gender x Year) analysis of variance. The effect of age in both genders was examined in a one-way analysis of variance using Tukey's post hoc test. Gender differences within the age groups were analyzed using the independent samples t-test.

When the differences in general perceptual-motor skills in the groups with different levels of soccer expertise were examined (II), a one-way ANOVA and Tukey's post-hoc test was applied to examine the statistical differences between the 16-year-old groups. An Independent Samples T test was applied to examine the differences between young adults and adolescent elite players (U16 vs. U19).

4.6.3 Correlation analysis

The Pearson correlation coefficient analysis was calculated for the most relevant variables in order to examine how different abilities are related to each other in different developmental stages. The correlation matrix named as "physical fitness" included height, muscle mass (Muscle), percentage of body fat (F%), serum testosterone concentration (Testo), isometric leg strength (Leg), countermovement jump (CMJ), 30m sprint time (30m), agility, Yo-Yo endurance test level 1 (YoYo), passing test time (Pass) and soccer-specific laboratory test time (Soc-Lab). The correlation matrix named as "perceptual-motor skill" included peripheral awareness (PAT), eye-hand-foot coordination (EHF) and performance time in passing skill test (Passing Test). Anticipation time, selection time, Feint-Target time, total performance time (Soc-Lab) and passing accuracy were selected to "perceptual-motor skill" matrix from soccer-specific laboratory test.

5 RESULTS

5.1 Anthropometrics, body composition and hormones

5.1.1 Height and weight

Height and weight of the soccer players and age-matched control groups are presented in Table 7. A significant main effect for age and for group was found in height (Age: $F_{3,117}$ = 103.51, $p<0.001$; Group: $F_{1,117}$ = 8.64, $p<0.001$) and in weight (Age: $F_{3,117}$ = 87.28, $p<0.001$; Group: $F_{1,117}$ = 18.61, $p<0.001$). Effect sizes between players and controls in the different age groups were categorized from moderate to large (d = 0.51 - 1.14) in height and large (d = 1.49 - 2.03) in weight. During the follow-up, soccer player's height increased as an average from 2.5 ± 1.6 % to 5.0 ± 1.8 % per year. The annual weight increase varied from 5.2 ± 6.2 % to 14.1 ±4.6 %. The lowest value was found between the two oldest ages and the greatest from U13 to U14 in both height and weight. Height and weight were significantly associated with each other in all other age groups except in the oldest U17 group. The strongest relationship was found in the U14 group (r = 0.90, $p<0.001$). No differences were found between the consecutive age classes at the same age in the U13 or U15 groups in height and weight. The average height and weight of the soccer players is plotted on the Finnish growth chart in Figure 8.

5.1.2 Muscle mass and body fat

The percentage of body fat and the total muscle mass is presented in Table 8. A significant main effect for age and for group was found in muscle mass (Age: $F_{3,117}$ = 133.52, $p<0.001$; Group: $F_{1,117}$ = 7.55, $p<0.01$) and for group in body fat ($F_{1,117}$ = 24.77, $p<0.001$). Effect sizes between players and controls in the different age groups were categorized from small to large (d = 0.11 - 0.88) in muscle mass and from moderate to large (d = 0.65 - 1.69) in the percentage of body fat. During the follow-up, soccer player's muscle mass increased as an average from

6.9 ± 6.9 % to 15.3 ± 7.4 % per year. The lowest value was found between the two oldest ages and the greatest increase occurred from U14 to U15. The relationship between muscle mass and height and muscle mass and weight was significant in all age groups. The strongest relationship between height and muscle mass was found in the U12 age group (r = 0.95, p<0.001) and between weight and muscle mass in the U14 age group (r = 0.97, p<0.001). The percentage of body fat increased most markedly between two youngest ages and the greatest decrease was observed between U14 to U15. The percentage of body fat correlated with weight in the three oldest age groups. This relationship was strongest (r = 0.82, p<0.01) in the oldest group. No differences were found between the consecutive age classes at the same age in the U13 or U15 groups in muscle mass and body fat.

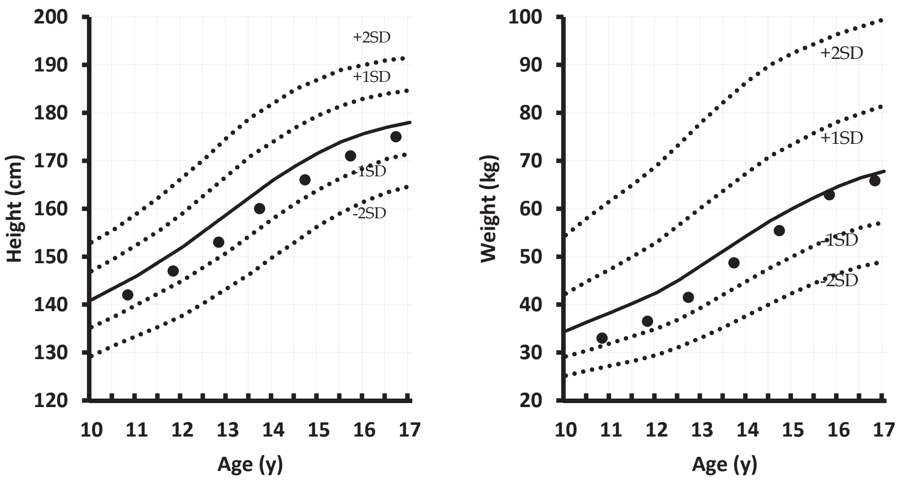

FIGURE 8 Soccer players' height and weight development plotted into Finnish growth charts, modified with permission from Dunkel et al. (2011).

5.1.3 Lean weight of the trunk, legs and arms

Lean weight of the trunk, legs and arms are presented in Table 9. A significant main effect for age and group was found in all lean weight variables: trunk (Age: $F_{3,117}$ = 119.30, p<0.001; Group: $F_{1,117}$ = 9.61, p<0.01), legs (Age: $F_{3,117}$ = 109.62, p<0.001; Group: $F_{1,117}$ = 5.05, p<0.05) and arms (Age: $F_{3,117}$ = 119.29, p<0.001; Group: $F_{1,117}$ = 10.36, p<0.01). Effect sizes between players and controls in the different age groups were categorized from small to large in trunk (d = 0.11 - 0.88), legs (d = 0.07 - 0.94) and arms (d = 0.04 - 1.25). During the follow-up, the greatest relative increase in the lean weight of arms was found between U12 to U13 (25.5 ± 16.3 %) and, respectively, in the trunk (12.8 ± 7.2 %) and legs (15.8 ± 8.0 %) between U13 to U14. The lowest increase was observed between two oldest ages in all cases. No differences were found between the consecutive age classes in the same age in the U13 or U15 groups in lean weight.

5.1.4 Serum testosterone and cortisol

The level of circulating testosterone and cortisol for soccer players and the control groups are presented in Table 10. A significant main effect for age was found in testosterone ($F_{3,117} = 84.76$, $p<0.001$) and in cortisol ($F_{3,117} = 3.10$, $p<0.05$) and for group in cortisol ($F_{1,117} = 27.36$, $p<0.001$). A significant difference in serum cortisol concentration was found between two oldest age classes at the same U15 age ($t_{24} = 3.80$, $p<0.01$). Effect sizes between players and controls in the different age groups were categorized from small to moderate (d = 0.06 - 0.30) in testosterone and from moderate to large in cortisol (d = 0.64 - 1.67). During the follow-up, soccer players' serum testosterone concentration increased, as an average, from 1.6 nmol/l to 5.8 nmol/l per year. The lowest increase was found between U15 to U16 and the greatest between U14 to U15. The level of serum cortisol was not significantly associated with any physical fitness variable in any soccer group. The relationships between serum testosterone and other selected variables are presented later in the Correlation matrices chapter.

TABLE 7 Age, height and weight of the soccer and control groups (Mean ± SD; minimum-maximum).

		Height (m)					Weight (kg)		
Soccer Players	Age	Range	Mean±SD	Controls	Cohen's d	Range	Mean±SD	Controls	Cohen's d
Group 1 (n=14)	U11	1.29-1.53	1.42±0.07	1.47±0.04	0.88	27.2-39.4	33.0±4.0	39.0±5.8^{++}	1.53
	U12	1.33-1.58	1.47±0.07***			29.5-46.0	36.5±5.1***		
	U13	1.37-1.69	1.53±0.09***	1.57±0.07	0.51	33.4-50.2	40.2±5.9***	47.4±5.9^{+}	2.03
Group 2 (n=14)	U13	1.44-1.78	1.52±0.10			30.9-62.6	42.6±7.5		
	U14	1.47-1.82	1.60±0.10***			34.3-70.2	48.7±9.1***		
	U15	1.53-1.87	1.68±0.10***			37.2-74.5	53.9±9.5***		
Group 3 (n=12)	U15	1.49-1.80	1.65±0.08	1.76±0.06^{+}	1.14	45.4-85.1	57.2±11.2	65.9±8.7^{++}	1.61
	U16	1.58-1.83	1.71±0.06**			52.1-84.9	62.8±10.4***		
	U17	1.66-1.84	1.75±0.04***	1.80±0.07	0.90	53.3-90.8	65.9±10.2***	69.5±7.4	1.50
Development (average/year)			3.9%	3.7%			16.6%	13.0%	

* = difference between two consecutive ages within the soccer group during a follow-up; $^{+}$ = difference between the soccer vs control group

TABLE 8 Percentage of body fat and total muscle mass of the soccer and control groups (Mean ± SD; minimum-maximum).

		Fat (%)					Muscle mass (kg)		
Soccer Players	Age	Range	Mean±SD	Controls	Cohen's d	Range	Mean±SD	Controls	Cohen's d
Group 1 (n=14)	U11	4.7-15.5	9.2±3.4	16.8±6.6^{++}	1.69	12.5-18.9	15.8±1.9	17.3±1.7^{+}	0.81
	U12	5.0-18.9	11.1±3.5**			12.6-21.4	17.2±2.5***		
	U13	3.0-19.3	10.1±4.1	16.7±6.9^{++}	1.34	14.4-25.0	19.7±3.3***	21.6±2.5	0.48
Group 2 (n=14)	U13	4.7-18.4	10.7±4.2			15.0-32.2	20.2±3.9		
	U14	6.2-19.4	10.7±4.3			15.8-35.9	24.0±5.3***		
	U15	3.4-14.0	8.8±2.9**			18.0-39.0	28.1±5.0***		
Group 3 (n=12)	U15	3.0-27.4	9.9±6.6	13.0±6.2^{++}	0.71	22.6-37.4	28.8±4.4	32.3±3.2^{++}	0.88
	U16	3.0-19.0	9.0±5.0			26.5-40.4	32.2±4.2***		
	U17	3.0-29.9	8.5±6.0	12.2±5.1^{++}	0.65	29.0-41.3	34.2±3.2**	34.6±4.1	0.11
Development (average/year)			-0.1%	-0.8%			19.4%	16.6%	

* = difference between two consecutive ages within the soccer group during a follow-up; $^{+}$ = difference between the soccer vs control group

TABLE 9 Lean body weight of trunk, legs and arms of soccer and control groups (Mean ± SD; minimum-maximum; Cohen's d).

Lean body weight														
Soccer players		Trunk (kg)				Legs (kg)				Arms (kg)				
	Age	Range	Mean±SD	Controls	d	Range	Mean±SD	Controls	d	Range	Mean±SD	Controls	d
Group 1 (n=14)	U11	11.1-15.8	13.6±1.4	14.7±1.3^{+}	0.80	6.8-11.1	9.0±1.3	9.8±1.1	0.64	1.5-3.1	2.3±0.4	2.8±0.4	1.25
	U12	11.2-17.6	14.6±1.8***			6.9-12.5	9.8±1.6***			1.7-3.4	2.6±0.5***		
	U13	12.2-19.6	15.7±2.5**	17.5±1.9	0.40	7.4-16.1	10.9±2.5**	11.7±1.9	0.08	2.3-4.6	3.2±0.9***	3.8±0.6	0.18
Group 2 (n=14)	U13	12.9-25.4	17.1±3.2			8.9-19.1	12.1±2.7			2.0-6.1	3.8±0.6		
	U14	13.5-27.8	19.3±3.8***			9.4-21.2	14.0±3.2***			2.2-6.8	4.1±1.2***		
	U15	14.2-29.7	21.3±3.9***			9.6-21.5	15.6±3.4***			2.7-7.7	5.0±1.3***		
Group 3 (n=12)	U15	18.4-28.6	22.9±3.2	25.5±2.2^{++}	1.03	13.1-22.6	16.8±2.6	18.8±1.9^{+}	0.93	3.9-6.9	5.2±1.1	5.9±0.8^{+}	0.26
	U16	21.0-31.4	24.9±2.7***			15.7-23.8	18.6±2.4***			4.7-8.1	6.0±1.1***		
	U17	22.0-38.8	26.0±2.4**	26.6±2.9	0.23	15.7-27.2	19.3±2.0**	19.6±2.3	0.14	5.1-10.7	6.5±0.9	6.7±1.1	0.04
Development (avg/year)			15.2%	13.5%			19.1%	16.7%			30.4%	23.2%	

* = difference between two consecutive ages within the soccer group during a follow-up; $^{+}$ = difference between the soccer vs control group

TABLE 10 Serum testosterone and cortisol concentration of soccer and control groups (Mean ± SD; minimum-maximum; Cohen's d).

Serum hormone concentrations									
Soccer players		Testosterone (nmol/l)				Cortisol (nmol/l)			
	Age	Range	Mean±SD	Controls	d	Range	Mean±SD	Controls	d
Group 1 (n=14)	U11	0.01-1.81	0.36±0.50	0.33±0.47	0.06	370-806	547±129	397±117^{++}	1.19
	U12	0.01-15.70	2.36±4.55			370-690	586±100		
	U13	0.24-24.30	5.76±8.21*	5.26±7.67	0.30	353-698	526±94	364±103^{+++}	1.64
Group 2 (n=14)	U13	0.01-22.60	9.31±7.15			287-825	552±121		
	U14	0.60-22.40	11.09±7.13			417-795	536±90		
	U15	5.30-29.50	16.84±6.76**			253-544	418±94**		
Group 3 (n=12)	U15	12.90-23.80	18.06±5.40	18.36±3.28	0.16	353-858	598±146	321±79^{++}	1.67
	U16	13.00-24.10	19.69±4.27			364-720	529±117		
	U17	17.90-31.30	22.48±4.39	23.90±5.28	0.30	397-737	538±107	466±121	0.64

* = difference between two consecutive ages within the soccer group during a follow-up; $^{+}$ = difference between the soccer vs control group

5.2 Physical fitness

5.2.1 Maximal strength

Maximal isometric strength of the legs (Figure 9), abdominal muscles, back muscles and grip are presented in Table 11. A significant main effect for age was found in all isometric strength tests: leg strength ($F_{3,117} = 47.55$, $p<0.001$), abdominal strength ($F_{3,117} = 40.24$, $p<0.001$), back strength ($F_{3,117} = 61.59$, $p<0.001$) and grip strength ($F_{3,117} = 100.72$, $p<0.001$). Correspondingly, for the group in all other strength tests except in grip strength: leg strength ($F_{1,117} = 13.35$, $p<0.001$), abdominal strength ($F_{1,117} = 14.99$, $p<0.001$) and back strength ($F_{1,117} = 6.66$, $p<0.05$); and for age x group: leg strength ($F_{3,117} = 3.73$, $p<0.05$) and abdominal strength ($F_{3,117} = 6.83$, $p<0.001$). Effect sizes between players and controls in the different age groups were categorized from small to large in legs (d = 0.02 - 1.06), abdominal (d = 0.14 - 1.54) and back (d = 0.05 – 0.85) and from small to moderate in grip (d = 0.03 - 0.35). During the follow-up, soccer player's maximal isometric leg strength increased from 5.8 ± 24.7 % to 24.1 ± 28.4 % per year. The lowest improvement was found between the two youngest ages and the greatest from U14 to U15. The greatest annual increase in abdominal (26.0 %) and back (17.7 %) strength occurred between U15 to U16. The players' grip strength increased 17.8 % per year in two consecutive age groups between U13 to U15. No differences were found between the consecutive age classes at the same age in the U13 or U15 groups in maximal strength variables.

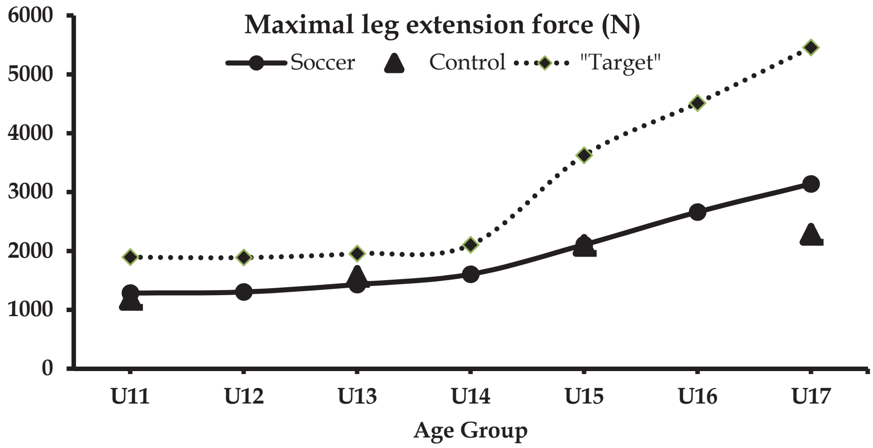

FIGURE 9 Development of bilateral isometric leg strength of soccer players (solid line), controls (triangles) and a "target" level (dashed line). "Target" curve was drawn based on the best value found in each age group.

5.2.2 Explosive strength and power of lower extremities

The results for the rate of force development in isometric leg press, countermovement jump (Figure 10) and 5-jump are presented in Table 12. A significant main effect for age and for group was found in all explosive strength tests: rate of force development (Age: $F_{3,117}$ = 49.78, p<0.001; Group: $F_{1,117}$ = 29.16, p<0.001), countermovement jump (Age: $F_{3,117}$ = 28.56, p<0.001; Group: $F_{1,117}$ = 22.08, p<0.001) and 5-jump (Age: $F_{3,117}$ = 67.65, p<0.001; Group: $F_{1,117}$ = 35.43, p<0.001). An interaction effect for age x group was found in the rate of force development in isometric leg press ($F_{3,117}$ = 7.88, p<0.01). Effect sizes between players and controls in the different age groups were categorized from small to large in the rate of force development (d = 0.01 - 1.98), from medium to large in the countermovement jump (d = 0.41 - 1.77) and large in the 5-jump (d = 0.90 - 1.36). During the follow-up, soccer players' rate of force development improved from 15.4 ± 17.3 % to 36.3 ± 30.3% per year. The slowest improvement was found between the two oldest ages and the greatest from U13 to U14. Annual improvement in the countermovement jump varied between 3.8 ± 10.6 % to 13.5 ± 10.4 %, the lowest between two youngest ages and the greatest from U14 to U15. The improvement in 5-jump was rather constant so that annual improvement varied from 4.2 % to 8.1 % per year. The greatest improvement in 5-jump was observed between U15 to U16. A significant difference in the countermovement jump (t_{26} = 2.54, p<0.05) and in the rate of force development (t_{26} = 2.87, p<0.01) was found between two youngest age classes at the same U13 age.

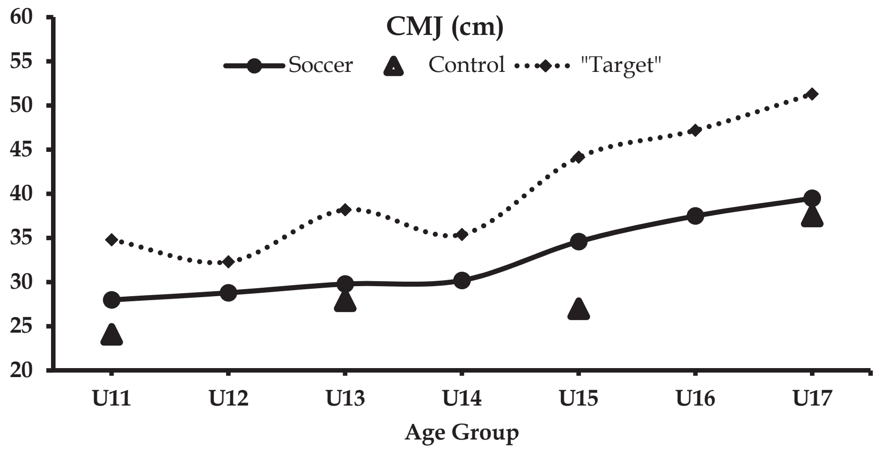

FIGURE 10 Development of explosive leg strength of soccer players (solid line), controls (triangles) and a "target" level (dashed line) determined with countermovement jump (CMJ). "Target" curve was drawn based on the best value found in each age group.

TABLE 11 Maximal isometric strength of the soccer and control groups (Mean ± SD; minimum-maximum).

Soccer players		Leg Press (N)			Abdominal (N)			Back (N)			Grip (N)		
	Age	Range	Mean±SD	Controls	Range	Mean±SD	Controls	Range	Mean±SD	Controls	Range	Mean±SD	Controls
Group 1 (n=14)	U11	690-1896	1287±355	1179±304	214-487	329±68	339±67	374-605	482±75	486±80	151-288	211±42	221±34
	U12	1014-1889	1305±270		297-526	362±60**		405-686	527±97*		155-298	224±63	
	U13	818-2187	1480±419*	1570±231	287-606	377±84	388±56	451-857	600±118***	624±83	136-334	242±63*	271±51
Group 2 (n=14)	U13	929-1724	1382±255		247-559	376±84		369-817	579±122		189-460	271±79	
	U14	1083-2104	1606±334**		294-560	441±77***		304-1112	665±192*		195-507	319±101**	
	U15	1140-3680	1984±619*		304-850	497±143*		388-1136	758±179**		222-536	372±102***	
Group 3 (n=12)	U15	1684-3571	2232±508	2094±415	362-631	513±77	470±51	473-1007	777±125	731±80	299-505	410±66	418±48
	U16	1942-4514	2663±743***		483-801	641±96***		706-1203	908±145***		336-535	446±69*	
	U17	1988-5457	3140±939**	2285±512^{+}	517-976	663±136	483±72^{+}	723-1360	983±181**	847±117^{+}	397-578	493±53**	491±77
Development (avg/year)			24%	15.6%		16.9%	7.1%		17.3%	12.4%		12.4%	20.4%

* = difference between two consecutive ages within the soccer group during a follow-up; $^{+}$ = difference between the soccer vs control group

TABLE 12 Explosive strength of lower extremities of the soccer and control groups (Mean ± SD; minimum-maximum).

Soccer players		RFD (N/s)			CMJ (cm)			5-jump		
	Age	Range	Mean±SD	Controls	Range	Mean±SD	Controls	Range	Mean±SD	Controls
Group 1 (n=14)	U11	4258-10471	7370±1969	7857±2541	20.1-34.8	28.0±4.7	24.1±4.5^{+}	7.57-10.13	8.93±0.62	8.02±0.79^{++}
	U12	6108-11156	8460±1784**		18.8-32.3	28.8±3.6		8.42-10.48***	9.53±0.70***	
	U13	7042-13672	10116±1688**	9082±1713	23.8-40.6	31.7±4.7**	27.9±4.7	8.22-11.78***	10.20±0.94***	8.77±0.60^{+++}
Group 2 (n=14)	U13	5153-11443	8059±2009		23.2-35.8	28.1±3.1		8.30-11.61	9.58±0.88	
	U14	6372-14553	10641±2200***		25.2-35.4	30.2±3.4**		9.14-11.68***	10.27±0.85***	
	U15	8098-21067	12243±3620		27.3-41.9	34.1±3.9***		9.55-12.97***	10.96±1.12***	
Group 3 (n=12)	U15	9526-21066	13467±3330	11831±2515	25.3-46.4	35.1±5.1	27.0±3.6^{+++}	9.69-12.11	10.93±0.66	10.14±0.90^{+}
	U16	11048-20584	16696±2895***		29.5-47.2	37.5±4.7*		10.55-12.80***	11.80±0.71***	
	U17	13242-25159	19124±3734**	12516±2539^{+++}	28.6-51.3	39.5±5.5*	37.3±5.1	10.70-13.36**	12.30±0.83**	11.28±1.07^{+}
Devevelopment (avg/year)			26.6%	9.9%		6.9%	9.1%		6.3%	6.8%

* = difference between two consecutive ages within the soccer group during a follow-up; $^{+}$ = difference between the soccer vs control group

5.2.3 Sprinting time and agility

Sprinting (Figure 11) and agility test results are presented in Table 13. A significant main effect for age and for group was found in both sprints and in agility: 10m sprint (Age: $F_{3,117} = 43.04$, p<0.001; Group: $F_{1,117} = 17.95$, p<0.001), 30m sprint (Age: $F_{3,117} = 49.35$, p<0.001; Group: $F_{1,117} = 31.17$, p<0.001) and agility (Age: $F_{3,117} = 21.13$, p<0.001; Group: $F_{1,117} = 52.77$, p<0.001). Effect sizes between players and controls in the different age groups were categorized from medium to large in 10m sprint (d = 0.36 - 1.44) and large in 30m sprint (d = 1.10 - 1.82) and agility (d = 1.46 - 2.32). The Pearson correlation coefficient between sprint tests (10 m vs 30 m) was over r = 0.90 (p<0.001) in all other age groups except in the U14 group (r = 0.73, p<0.01). During the follow-up, soccer players' annual improvement varied from 1.8 ± 2.2 % to 5.2 ± 3.8 % in 30 m sprint and from 1.0 ± 2.0 % to 3.8 ± 2.6 % in agility. The greatest improvement in 30 m sprint and in agility was observed at the same time frame between U13 to U14. A significant difference was found between two consecutive age classes in the 10 m sprint time ($t_{26} = -2.27$, p<0.05) and in the agility ($t_{26} = -2.70$, p<0.05) at the U13 age and in agility ($t_{26} = -2.62$, p<0.05) at the U15 age.

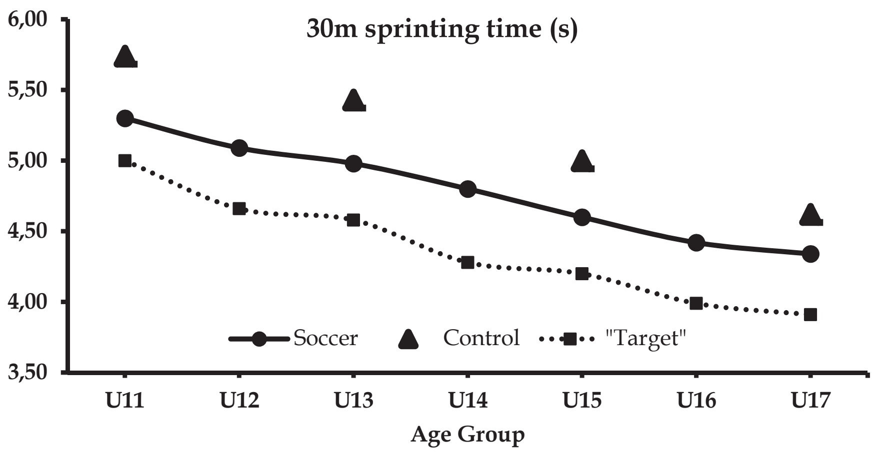

FIGURE 11 Development of sprinting speed (30 m sprint) of soccer players (solid line), controls (triangles) and a "target" level (dashed line). "Target" curve is drawn based on the best value measured in each age group.

TABLE 13 Sprinting time and agility of the soccer and control groups (Mean ± SD; minimum-maximum).

		10m (s)			30m (s)			8-track (s)		
Soccer players	Age	Range	Mean±SD	Controls	Range	Mean±SD	Controls	Range	Mean±SD	Controls
Group 1 (n=14)	U11	1.97-2.18	2.08±0.07	$2.21±0.14^{+}$	5.00-5.68	5.30±0.21	$5.74±0.52^{++}$	7.15-7.89	7.58±0.20	$8.30±0.54^{+++}$
	U12	1.87-2.15	$2.00±0.08^{***}$		4.66-5.54	$5.09±0.20^{***}$		6.98-7.78	$7.35±0.19^{***}$	
	U13	1.80-2.15	$1.96±0.10^{*}$	$2.11±0.12^{++}$	4.50-5.43	$4.91±0.25^{***}$	$5.43±0.41^{+++}$	6.91-7.48	$7.25±0.24^{**}$	$7.95±0.41^{+++}$
Group 2 (n=14)	U13	1.87-2.11	2.02±0.05		4.66-5.31	5.05±0.16		7.20-7.97	7.47±0.24	
	U14	1.64-2.01	$1.93±0.09^{***}$		4.28-5.26	$4.80±0.28^{***}$		6.86-7.42	$7.18±0.15^{***}$	
	U15	1.64-2.04	$1.86±0.09^{**}$		4.22-4.98	$4.56±0.23^{***}$		6.58-7.30	$7.03±0.21^{**}$	
Group 3 (n=12)	U15	1.72-2.07	1.91±0.10	$1.97±0.16^{++}$	4.18-4.98	4.64±0.23	$5.00±0.44^{+}$	6.83-7.47	7.22±0.21	$7.84±0.51^{+++}$
	U16	1.64-2.02	$1.83±0.10^{***}$		3.99-4.93	$4.42±0.23^{***}$		6.48-7.25	$7.03±0.21^{*}$	
	U17	1.62-2.04	1.80±0.12	1.84±0.09	3.91-4.82	$4.34±0.25^{*}$	$4.62±0.26^{+}$	6.56-7.34	6.96±0.19	$7.37±0.39^{++}$
Development (avg/year)			2.0%	2.8%		3.0%	3.3%		1.4%	1.9%

* = difference between two consecutive ages within the soccer group during a follow-up; $^{+}$ = difference between the soccer vs control group

TABLE 14 Aerobic capacity and endurance performance of the soccer and control groups (Mean ± SD; minimum-maximum).

		VO_2max (ml/kg/min)			Yo-Yo Endurance (m)		
Soccer players	Age	Range	Mean±SD	Controls	Range	Mean±SD	Controls
Group 1 (n=14)	U11	45.9-57.2	52.3±3.1	$46.9±3.9^{++}$	1580-2080	1768±169	$1002±289^{+++}$
	U12	46.9-59.4	$53.8±3.9^{*}$		1380-2300	$1906±253^{**}$	
	U13	47.0-59.7	53.7±3.5	$47.7±3.2^{+++}$	1640-2620	$2134±284^{***}$	$1246±287^{+++}$
Group 2 (n=14)	U13	48.0-58.6	53.1±3.0		1200-2420	1811±348	
	U14	44.1-59.5	53.6±4.2		1260-2640	$2033±327^{**}$	
	U15	50.9-62.4	$55.9±3.4^{**}$		1720-2640	2121±285	
Group 3 (n=12)	U15	43.8-61.5	54.4±4.9	$48.3±4.4^{+++}$	1580-2640	2297±321	$1146±391^{+++}$
	U16	48.4-62.3	55.0±3.9		2040-2880	2358±283	
	U17	42.4-65.9	54.8±5.3	$48.4±4.3^{++}$	1700-2860	2348±366	$1551±391^{+++}$
Development (avg/year)			0.8%	0.8%		5.5%	9.1%

* = difference between two consecutive ages within the soccer group during a follow-up; $^{+}$ = difference between the soccer vs control group

5.2.4 Endurance

5.2.4.1 Aerobic capacity (VO_2max)

The results of the maximal oxygen uptake test (VO_2max) are presented in Table 14 and Figure 12. A significant main effect for age and for group was found in VO_2max (Age: $F_{3,117} = 3.55$, $p<0.05$; Group: $F_{1,117} = 38.43$, $p<0.05$). Effect sizes between players and controls in VO_2max were categorized as large in all age groups (d = 1.29 - 1.76). During the follow-up, rather modest changes in soccer players' VO_2max were observed, the greatest 4.5 ± 5.1 % improvement was observed between U14 to U15. No differences were found between the consecutive age classes at the same age in the U13 or U15 group in VO_2max.

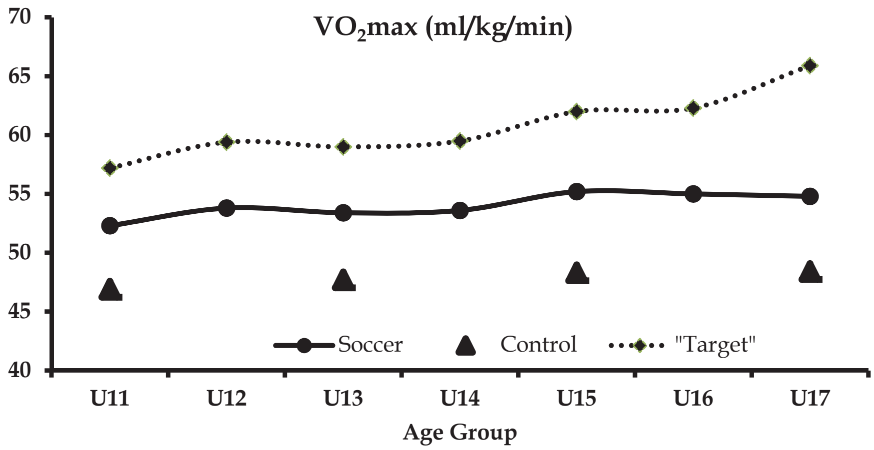

FIGURE 12 Development of aerobic capacity (VO_2max) of soccer players (solid line), controls (triangles) and a "target" level (dashed line). "Target" curve is drawn based on the best value measured in each age group.

The values of hemoglobin and hematocrit are presented in Table 15. In hemoglobin ($F_{3,117} = 25.16$, $p<0.001$) and in hematocrit ($F_{3,117} = 35.99$, $p<0.001$) a significant main effect was found only for age. Effect sizes between players and controls in the different age groups were categorized from small to moderate in hemoglobin (d = 0.09 - 0.56) and hematocrit (d = 0.12 - 0.73). The relationship between hemoglobin and VO_2max reached the level of significance only in the U12 group (r = 0.69, $p<0.01$). In the oldest U17 group, a negative relationship was found between VO_2max and hematocrit (r = -0.66, $p<0.05$) whereas the relationship between haemoglobin and VO_2max just failed to reach the level of significance (r = -0.56, p=0.058). A significant difference was found between two consecutive age classes in hematocrit ($t_{26} = -2.40$, $p<0.05$) at the same U13 age.

TABLE 15 Hemoglobin and hematocrit of the soccer and control groups.

Soccer players		Hemoglobin (g/l)			Hematocrit (%)		
	Age	Range	Mean±SD	Controls	Range	Mean±SD	Controls
Group 1 (n=14)	U11	122-156	139±8	138±7	35.6-43.2	39.6±1.7	39.8±1.4
	U12	129-149	138±7		37.6-43.3	39.7±1.5	
	U13	120-147	138±7	136±8	34.7-40.9	39.4±1.7	38.8±2.0
Group 2 (n=14)	U13	131-153	142±7		37.9-44.1	40.8±1.8	
	U14	131-158	144±8		38.1-46.5	41.5±2.2	
	U15	129-160	146±9		38.6-45.9	42.0±2.2	
Group 3 (n=12)	U15	141-165	150±8	152±12	40.1-47.5	42.9±2.1	43.6±2.4
	U16	129-167	151±10		38.1-46.7	43.3±2.6	
	U17	141-170	155±11	156±10	40.4-48.4	44.1±3.0	44.6±2.1

5.2.4.2 Performance (Yo-Yo Endurance Test Level 1)

The results for Yo-Yo endurance test level 1 shuttle run are presented in Table 14 and in Figure 13. A significant main effect for age and group was found in the Yo-Yo endurance test (Age: $F_{3,117} = 12.84$, $p<0.001$; Group: $F_{1,117} = 116.60$, $p<0.001$). Effect sizes between players and controls in endurance performance were categorized as large in all age groups (d = 2.12 - 3.68). VO_2max and Yo-Yo test were related to each other in all other age groups except in the U12 and U16 groups. In these groups the relationships between VO_2max and Yo-Yo test just failed to reach the level of significance. The strongest relationship between VO_2max and Yo-Yo test was found in U14 ($r = 0.85$, $p<0.001$). During the follow-up, the annual changes in the Yo-Yo endurance test varied from -0.4 ± 1.6 % decrease to 13.6 ± 14.8 % increase. The greatest improvement occurred between U13 to U14. A significant difference was found between two consecutive age classes in the Yo-Yo test ($t_{26} = -2.62$, $p<0.05$) at the same U13 age.

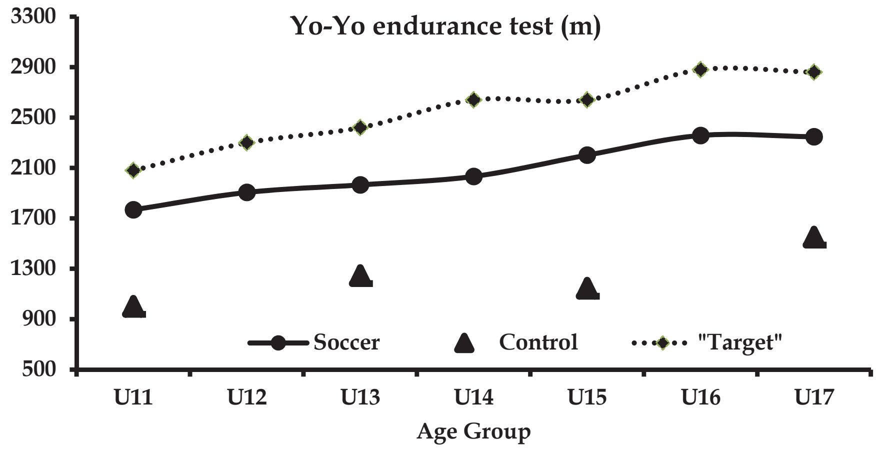

FIGURE 13 Development of endurance performance (Yo-Yo endurance level 1) of soccer players (solid line), controls (triangles) and a "target" level (dashed line). "Target" curve is drawn based on the best value measured in each age group.

5.3 Soccer skills

5.3.1 General perceptual-motor skills

5.3.1.1 Soccer expertise

When 16 year-old elite players, sub-elite players and controls were compared against each other in general perceptual-motor skills (Figure 14), a significant main effect for the level of soccer expertise was found in simple reaction ($F_{2,140}$ = 12.01, $p<0.001$) and in peripheral awareness ($F_{2,140}$ = 4.55, $p<0.05$). No significant differences were found between any groups in the eye-hand-foot coordination test. In peripheral awareness, there was a significant difference between the elite players and the non-playing group ($p<0.05$), while the difference between the sub-elite and elite players was close to attain a level of significance ($p=0.053$). The peripheral reaction time of the U-19 national team was shorter than that of the U-16 national team candidates ($p<0.01$).

5.3.1.2 Development in a regional soccer team

The results of the simple reaction time test, peripheral awareness test and eye-hand-foot coordination test are presented in Table 16. A significant main effect of age was found in all general perceptual-motor skill tests: simple reaction time $F_{3,76}$ = 14.52, $p<0.001$; peripheral awareness $F_{3,76}$ = 4.58, $p<0.01$; eye-hand-foot coordination $F_{3,76}$ = 40.60, $p<0.001$. During the follow-up, soccer players' simple reaction time improved, as an average, from 3.5 ± 5.8 % to 7.3 ± 12.2 % and eye-hand-foot coordination from 17.0% (±12.0) to 23.2 (±15.9) in two years. The greatest improvement in both of these abilities was observed in the youngest age group from U11 to U13. Peripheral awareness improved from 7.9 ± 9.7 % to 14.5 ± 15.1 %. The greatest improvement in peripheral awareness occurred in the middle group from U13 to U15. A significant difference was found between two consecutive age classes in the eye-hand-foot coordination (t_{24} = -2.54, $p<0.05$) at the same U15 age.

TABLE 16 Mean ± SD of general perceptual-motor skill tests.

		Simple Reaction (ms)		Peripheral Awareness (ms)		Eye-Hand-Foot (n/30s)	
	Age	Range	Mean±SD	Range	Mean±SD	Range	Mean±SD
Group 1	U11	196-294	236 ± 35	261-449	363±46	24-33	29.1±3.0
(n=14)	U13	190-244	222 ± 18***	245-438	326±46*	28-40	35.6±3.8***
Group 2	U13	184-240	216 ± 19	236-465	330±58	30-39	33.8±2.7
(n=14)	U15	158-230	206 ± 20*	239-473	307±59*	33-44	39.7±3.1***
Group 3	U15	162-220	203 ± 23	254-400	306±49	31-41	37.5±3.0
(n=12)	U17	154-226	189 ± 21*	244-339	279±30*	39-46	42.4±2.8***
Development (avg/year)			3.3%		3.9%		7.6%

* = difference between consecutive measurements within a group during the follow-up

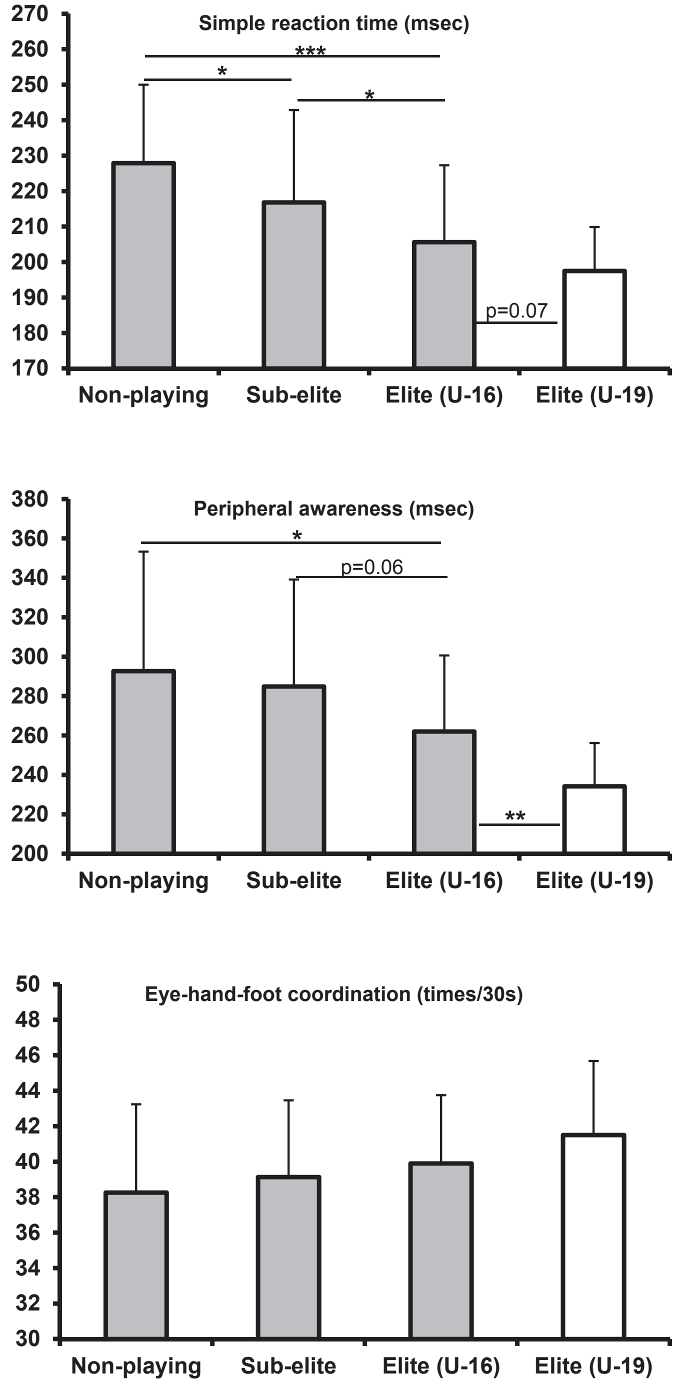

FIGURE 14 Simple reaction time (SRT), peripheral awareness (PAT) and eye-hand-foot coordination (EHF) by the level of soccer expertise.

5.3.2 Soccer skill tests

5.3.2.1 Development in a regional soccer team

Dribbling and passing test results in the monitored club team are presented in Table 17. A significant main effect was found for age in the one-way analysis of variance in the dribbling ($F_{6,111} = 11.52$, $p<0.001$) and passing test ($F_{6,111} = 18.51$, $p<0.001$). Technical skill tests were significantly associated with each other in all age groups. The strongest relationship was found in the U13 group ($r = 0.82$, $p<0.001$).

TABLE 17 Mean ± SD of the dribbling and passing test by age.

		Dribbling Test (s)		Passing Test (s)	
Soccer Players	Age	Range	Mean±SD	Range	Mean±SD
Group 1 (n=14)	U11	26.6-32.1	29.3±2.0	38.0-49.0	42.4±3.7
	U12	24.4-29.8	27.1±1.6***	36.5-44.0	39.4±2.1***
	U13	24.0-29.7	26.4±1.6*	33.3-41.6	37.1±2.1***
Group 2 (n=14)	U13	24.6-32.0	28.8±1.8	33.1-43.6	40.3±3.7
	U14	23.5-30.1	27.3±1.8**	31.5-42.5	38.1±3.7***
	U15	23.1-28.2	25.8±1.7**	29.2-41.2	35.5±2.7***
Group 3 (n=12)	U15	24.4-28.6	26.6±1.3	33.1-41.1	36.9±2.5
	U16	23.4-26.9	25.4±1.2**	32.6-38.4	35.0±1.9**
	U17	22.3-27.7	25.3±1.7	31.2-37.7	34.0±2.2

During the follow-up, soccer players' dribbling time improved from 0.8 ± 4.1 % to 8.5 ± 2.8 % per year and the passing test time between 2.8 ± 4.9 % to 7.8 ± 4.7 % per year. The greatest development in both skill tests was found between the two youngest ages from U11 to U12. As presented in Figure 15, a small adolescent acceleration could be observed in the skill tests in the pubertal age groups between U13 to U15. A significant difference was found between two consecutive age classes in the dribbling ($t_{26} = -3.34$, $p<0.01$) and passing test ($t_{26} = -2.39$, $p<0.05$) at the same U13 age.

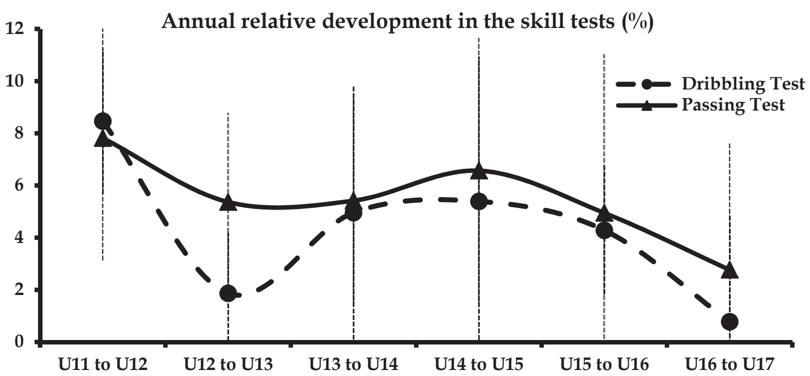

FIGURE 15 The relative development of the dribbling and passing test.

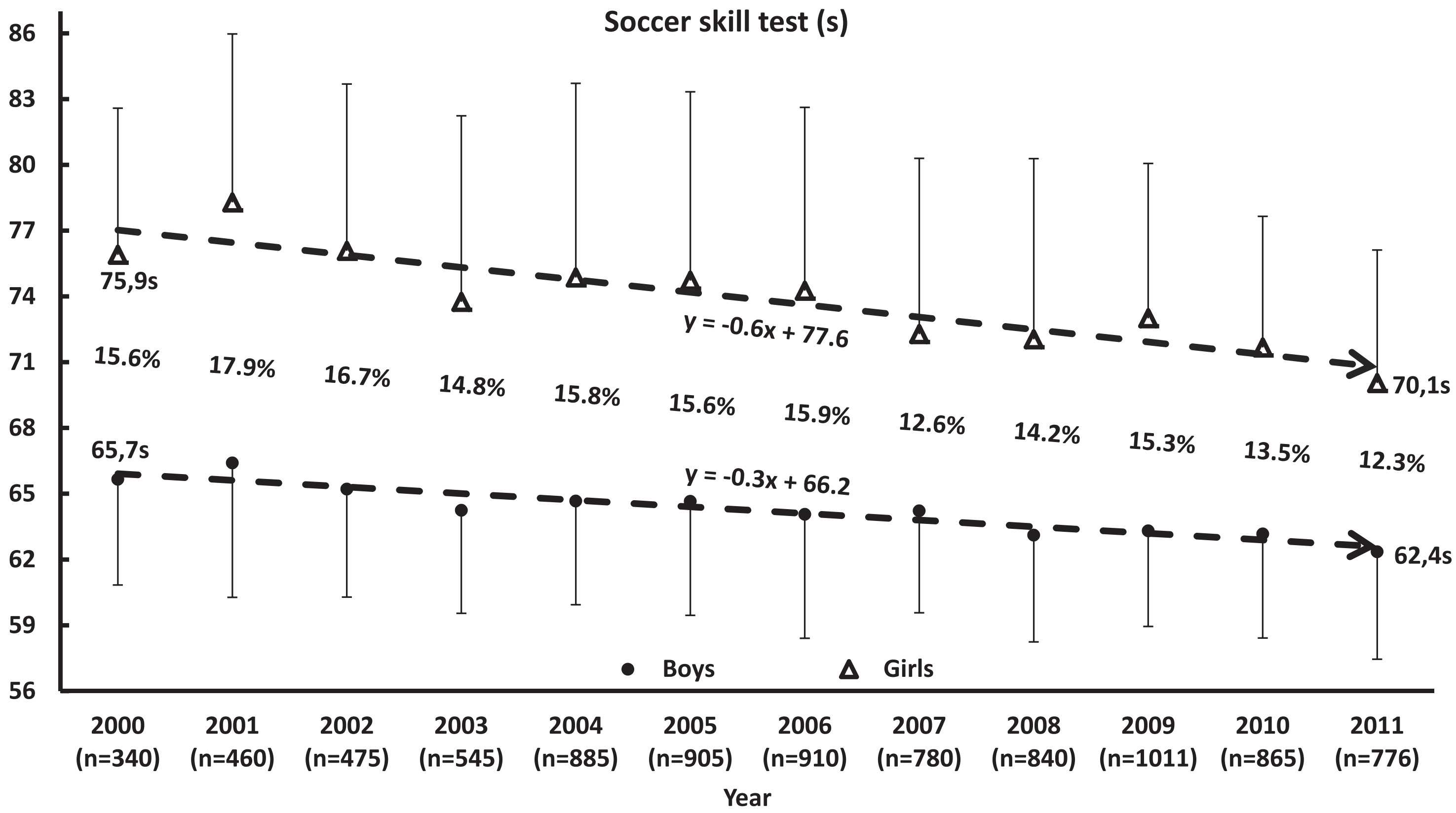

FIGURE 16 Development of soccer skills between the years of 2000-2011 and the relative difference between genders.

TABLE 18 Mean ± SD of the dribbling test time in soccer players and the relative difference between boys and girls by age.

		U9	U10	U11	U12	U14	U15	U16	U17
Boys	n	2627	3429	3807	3812	3580	2224	983	363
	Mean±SD	33.9±4.3	30.9±3.6***	29.2±3.1***	27.9±2.9***	26.9±2.4***	26.3±2.8***	25.8±2.9**	25.5±3.0
	Nat.	-	27.3±1.9	25.8±1.6***	25.4±2.7	24.9±1.4**	24.4±1.3	24.3±1.4	24.2±1.6
	Failure	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%
Girls	n	779	1545	1771	1945	1924	1427	783	327
	Mean±SD	40.2±5.8	36.0±5.0***	33.2±4.2***	31.3±3.7***	30.3±3.6***	29.3±3.0***	28.5±2.6***	27.8±2.8***
	Nat.	-	31.3±2.7	29.0±2.6	28.3±2.6	27.3±2.3	26.7±1.8	26.6±2.0	26.2±1.8
	Failure	1.7%	<1%	<1%	<1%	<1%	<1%	<1%	<1%
♂ vs. ♀	Dif.	18.6%	16.5%	13.7%	12.2%	12.6%	11.4%	10.5%	9.0%
	t	27.96†††	35.67†††	36.63†††	35.70†††	36.96†††	30.99†††	20.44†††	10.62†††
	d	1.14	1.09	1.05	0.99	1.05	1.05	0.98	0.81

TABLE 19 Mean ± SD of the passing test time in soccer players and the relative difference between boys and girls by age.

		U9	U10	U11	U12	U14	U15	U16	U17
Boys	n	2627	3429	3807	3812	3580	2224	983	363
	Mean±SD	52.6±5.8	47.8±6.3***	44.5±6.2***	41.9±5.9***	40.1±5.8***	37.8±4.6***	36.8±4.7**	35.7±4.6*
	Nat.	-	41.0±4.7	37.0±3.6***	36.0±3.8	35.3±4.6	34.1±2.9*	33.6±3.5	33.0±2.7
	Failure	22.5%	9.1%	4.7%	3.4%	3.5%	5.2%	4.4%	3.9%
Girls	n	779	1545	1771	1945	1924	1427	783	327
	Mean±SD	58.1±3.5	54.5±5.7***	50.9±6.4***	47.9±6.4***	45.5±6.3***	42.9±4.8***	41.5±5.0***	40.0±5.4**
	Nat	-	47.4±5.4	42.8±5.0	40.9±4.6	39.0±4.1	37.5±4.2	37.5±3.7	36.8±4.4
	Failure.	67.7%	34.1%	15.8%	8.7%	6.0%	12.3%	9.4%	7.6%
♂ vs. ♀	Dif.	10.5%	14.0%	14.4%	14.3%	13.5%	13.5%	12.8%	12.0%
	t	32.12†††	35.92†††	34.69†††	34.78†††	31.42†††	32.15†††	20.08†††	11.35†††
	d	1.31	1.10	1.00	0.97	0.89	1.09	0.96	0.87

Nat. = "the most skilful players" in the national championships; Failure = percentage of players failed the test in two attempts; * = difference between two consecutive age groups; Dif. = the relative difference between boys and girls; † = difference between genders

5.3.2.2 Soccer skills over time, across sex and by age

The univariate analysis of variance showed a significant main effect in the combined skill between 2000 and 2011 for Gender ($F_{1,8831}$ = 4214.32, p<0.001), Year ($F_{11,8831}$ = 42.27, p<0.001) and Gender x Year interaction ($F_{11,8831}$ = 5.67, p<0.001). The equation of the linear trend line model for the years 2000-2011 was y = -0.3x + 66.2 in boys and y = -0.6x + 77.6 in girls. As presented in Figure 16, the relative difference between boys and girls varied from 12.3 % (2011) to 17.9 % (2001) during the research period of 11 years. The results of the analysis of the national soccer skill database by age categories are presented in Tables 18 and 19. In boys, a significant main effect was found for age in the dribbling ($F_{7,20816}$ = 1820.17, p<0.001) and in the passing test ($F_{7,20816}$ = 2027.66, p<0.001). A significant main effect with regard to age was also found for girls in the dribbling ($F_{7,10362}$ = 988.13, p<0.001) and in the passing test ($F_{7,10362}$ = 854.54, p<0.001). The difference between the consecutive age groups in both genders reached the level of significance (p<0.05) between all age groups in the passing test and between all age groups except in boys between 15y and 17y in the dribbling test.

5.3.3 Soccer-specific laboratory test

5.3.3.1 Soccer-specific perceptual-motor skills

Soccer players' anticipation time to soccer-specific stimulus (Figure 17) and selection time to general stimulus during dribbling are presented in Table 20. A significant main effect for age was found in both anticipation time ($F_{3,76}$ = 41.14, p<0.001) and selection time ($F_{3,76}$ = 18.39, p<0.001). During the follow-up, soccer players' anticipation time improved from 14.8 ± 20.6 % to 57.6 ± 12.2 % and selection time from 8.0 ± 16.6 % to 17.0 ± 10.6 % in two years. The greatest improvement in the anticipation time was observed in the oldest age group and in the selection time in the middle group. No differences were found between the consecutive age classes at the same age in the U13 or U15 groups in the anticipation and selection time.

TABLE 20 Mean ± SD of the soccer-specific anticipation and selection time.

		Anticipation Time (ms)		Selection Time (ms)	
	Age	Range	Mean±SD	Range	Mean±SD
Group 1 (n=14)	U11	114-269	179±43	294-460	351±47
	U13	76-191	149±32*	278-390	324±26
Group 2 (n=14)	U13	106-220	161±36	250-403	328±53
	U15	61-133	99±20**	224-290	267±21**
Group 3 (n=12)	U15	38-151	91±37	214-395	278±57
	U17	-65-100	46±42**	189-280	243±29
Development (avg/year)			12.4%		5.1%

* = difference between consecutive measurements within the group during the follow-up

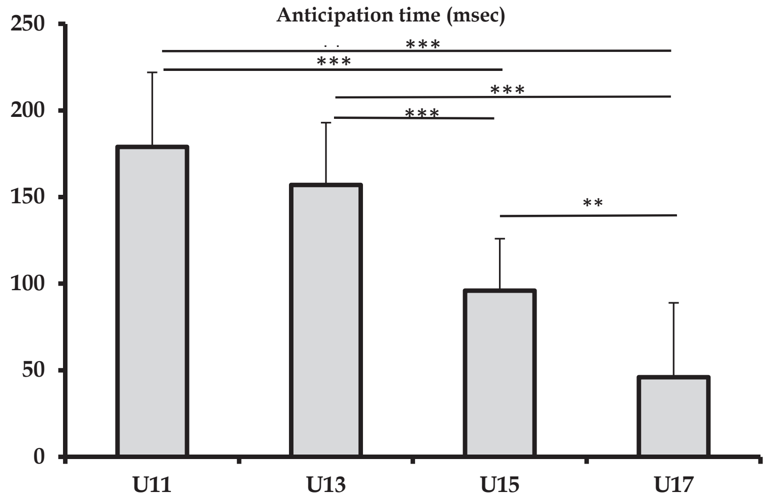

FIGURE 17 Soccer-specific anticipation time in different age groups.

5.3.3.2 Performance time and passing accuracy

Total performance time, performance divided to different stages and passing accuracy in the soccer-specific laboratory test is presented in Table 21. A significant main effect for age was found in 1st touch ($F_{3,75}$ = 33.64, p<0.001), dribbling ($F_{3,75}$ = 4.32, p<0.01), feint-target ($F_{3,75}$ = 5.40, p<0.01), pass duration ($F_{3,75}$ = 24.01, p<0.001), total performance ($F_{3,75}$ = 20.07, p<0.001) and passing accuracy ($F_{3,75}$ = 3.27, p<0.05). During the follow-up, soccer players' total performance time improved from 9.8 ± 3.5 % to 12.1 ± 4.8 % in two years. The greatest improvement was observed in the youngest group. Passing accuracy improved around 10 % in the two youngest groups and a 13.5 % decrement was observed in the oldest group. A significant difference was found between two consecutive age classes in the performance time in the U13 (t_{26} = -3.38, p<0.01) and in the U15 (t_{24} = 2.34, p<0.05).

TABLE 21 Total time and passing accuracy in the soccer-specific laboratory test.

Soccer-Specific Laboratory Test							
	Age	1st Touch	Dribbling	Feint-Target	Pass Duration	Total	Accuracy
Group 1 (n=14)	U11	1.13±0.09	1.85±0.12	1.78±0.18	0.80±0.10	5.57±0.33	1.53±0.43
	U13	1.01±0.07***	1.65±0.12***	1.55±0.11***	0.68±0.09***	4.89±0.27***	1.29±0.39
Group 2 (n=14)	U13	1.10±0.06	1.80±0.19	1.71±0.16	0.67±0.07	5.29±0.34	1.35±0.26
	U15	0.97±0.07***	1.64±0.23**	1.56±0.15*	0.60±0.09*	4.77±0.35***	1.19±0.31
Group 3 (n=12)	U15	0.95±0.07	1.76±0.17	1.77±0.25	0.61±0.09	5.10±0.37	1.19±0.38
	U17	0.85±0.10**	1.61±0.15**	1.50±0.12**	0.57±0.04	4.52±0.32***	1.22±0.26

* = difference between consecutive measurements within a group during a follow-up

5.4 Summary of the time periods of the greatest development

The timing of the greatest improvement in selected variables, calculated from players' relative annual development during the two-year monitoring period, is summarized in Figure 18.

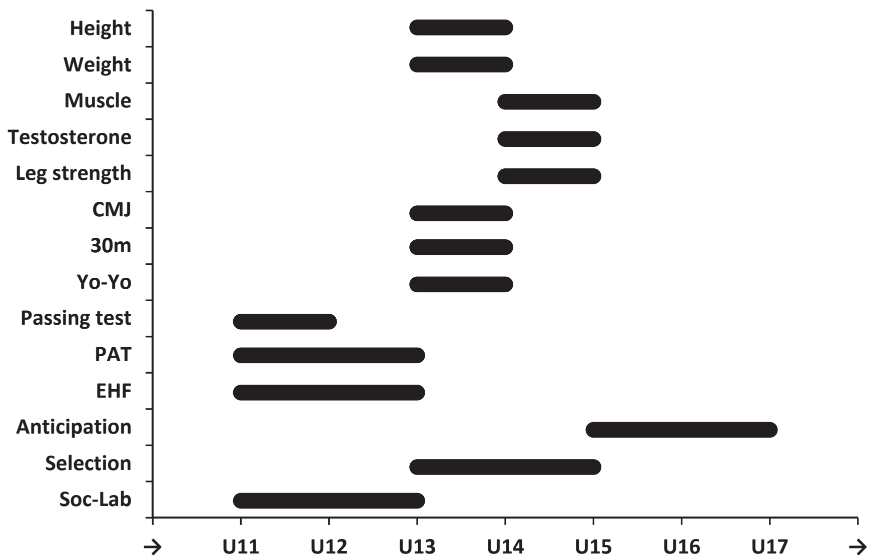

FIGURE 18 Timing of the greatest improvement in selected variables.

5.5 Correlation matrices

5.5.1 The relationships in the pre-pubertal U11 group

The Pearson correlation coefficients between selected variables for the pre-pubertal U11 group are presented in Tables 22 and 23. The pairs in which the explanatory power was more than 50 % were: height - muscle mass (86 %), CMJ - 30 m sprint (56 %) and PAT - Soc-Lab (50 %). A total of 12 significant associations were found between the variables in the U11 group.

TABLE 22 The physical fitness correlation matrix for the U11 group.

Pre-pubertal U11 Group										
	Height	Muscle	Fat%	Testo	Leg	CMJ	30m	Agility	YoYo	Pass
Height	---	-	-	-	-	-	-	-	-	-
Muscle	.93***	---	-	-	-	-	-	-	-	-
Fat%	ns.	ns.	---	-	-	-	-	-	-	-
Testo	.58*	bl.	ns.	---	-	-	-	-	-	-
Leg	ns.	ns.	ns.	ns.	---	-	-	-	-	-
CMJ	ns.	ns.	-.55*	ns.	ns	---	-	-	-	-
30m	ns.	ns.	.56*.	ns.	ns.	-.75**	---	-	-	-
Agility	ns.	ns.	ns.	ns.	ns.	ns.	ns.	---	-	-
YoYo	bl.	-0.65*	ns.	ns.	ns.	ns.	ns.	ns.	---	-
Pass	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	-.76**	---
Soc-Lab	-.58*	bl.	ns.	-.56*	ns.	bl.	.71**	ns.	ns.	ns.

ns. = non-significant; bl. = p<0.10; * = p<0.05; ** = p<0.01; *** = p<0.01

TABLE 23 The perceptual-motor skill correlation matrix for the U11 group.

Pre-Pubertal U11 Group					
	Passing Test	Anticipation	Feint-Target	Soc-Lab	Accuracy
PAT	ns.	ns.	.70**	.71**	ns.
EHF	ns.	ns.	ns.	ns.	ns.
Anticipation	ns.	---	ns.	ns.	ns.
Selection	ns.	ns.	ns.	ns.	ns.

ns. = non-significant; * = p<0.05; ** = p<0.01)

5.5.2 The relationships in the early-pubertal U13 group

The Pearson correlation coefficients between selected variables for the early-pubertal U13 group are presented in Tables 24 and 25. The pairs in which the explanatory power was more than 50 % were: height - muscle mass (80 %) and CMJ - 30 m sprint (59 %). A total of 20 significant associations were found between the variables in the U13 group.

TABLE 24 The physical fitness correlation matrix for the U13 group.

Early-pubertal U13 Group										
	Height	Muscle	Fat%	Testo	Leg	CMJ	30m	Agility	YoYo	Pass
Height	---	-	-	-	-	-	-	-	-	-
Muscle	.89***	---	-	-	-	-	-	-	-	-
Fat%	ns.	ns.	---	-	-	-	-	-	-	-
Testo	.64***	.69***	bl.	---	-	-	-	-	-	-
Leg	.46*	.51**	ns.	bl.	---	-	-	-	-	-
CMJ	.45**	ns.	-.41*	ns.	bl.	---	-	-	-	-
30m	-.41*	ns.	.43*	ns.	ns.	-.77***	---	-	-	-
Agility	ns.	ns.	.46*	ns.	ns.	-.40*	.43*	---	-	-
YoYo	ns.	ns.	-.58**	ns.	ns.	ns.	bl.	-.48*	---	-
Pass	ns.	ns.	ns.	ns.	ns.	ns.	ns.	bl.	-.53**	---
Soc-Lab	ns.	ns.	ns.	ns.	bl.	bl.	ns.	ns.	ns.	.64*

ns. = non-significant; bl. = p<0.10; * = p<0.05; ** = p<0.01; *** = p<0.001

TABLE 25 The perceptual-motor skill correlation matrix for the U13 group.

Early-pubertal U13 Group					
	Passing Test	Anticipation	Feint-Target	Soc-Lab	Accuracy
PAT	ns.	.48**	ns.	ns.	ns.
EHF	ns.	ns.	-.41*	ns.	ns.
Anticipation	bl.	---	.38*	bl.	ns.
Selection	ns.	ns.	ns.	ns.	ns.

ns. = non-significant; bl. = p<0.10; * = p<0.05; ** = p<0.01

5.5.3 The relationships in the pubertal U14 and U15 groups

The Pearson correlation coefficients between selected variables for the pubertal U14 and U15 groups are presented in Tables 26 - 28. The pairs with the explanatory power more than 50 % in the U14 group were: height - muscle mass (74 %) and the body fat - 30 m sprint (52 %). Correspondingly in the U15: height - muscle mass (72 %) and CMJ - 30 m sprint (59 %). A total of 26 significant associations were found between the variables in the U15 group.

TABLE 26 The physical fitness correlation matrix for the U14 group.

Pubertal U14 Group									
	Height	Muscle	Fat%	Testo	Leg	CMJ	30m	Agility	YoYo
Height	---	-	-	-	-	-	-	-	-
Muscle	.86***	---	-	-	-	-	-	-	-
Fat%	ns.	ns.	---	-	-	-	-	-	-
Testo	.67**	.74**	bl.	---	-	-	-	-	-
Leg	ns.	bl.	ns.	ns.	---	-	-	-	-
CMJ	.57*	.65*	bl.	.57*.	ns.	---	-	-	-
30m	-.68**	-.64*	.72**	-.69**	ns.	-.64*	---	-	-
Agility	ns.	ns.	.55*	bl.	ns.	ns.	bl.	---	-
YoYo	ns.	ns.	-.59*	ns.	ns.	ns.	-.67**	-.63*.	---
Pass	ns.	ns.	ns.	ns.	ns.	ns.	ns.	.61*	bl.

ns. = non-significant; bl. = p<0.10; * = p<0.05; ** = p<0.01

TABLE 27 The physical fitness correlation matrix for the U15 group.

Pubertal U15 Group										
	Height	Muscle	Fat%	Testo	Leg	CMJ	30m	Agility	YoYo	Pass
Height	---	-	-	-	-	-	-	-	-	-
Muscle	.85***	---	-	-	-	-	-	-	-	-
Fat%	ns.	ns.	---	-	-	-	-	-	-	-
Testo	.43*	.53**	ns.	---	-	-	-	-	-	-
Leg	ns.	ns.	ns.	ns.	---	-	-	-	-	-
CMJ	.44*	bl.	-.53**	bl.	bl.	---	-	-	-	-
30m	-.64***	-.52**	.47*	-.51**	bl.	-.77***	---	-	-	-
Agility	ns.	ns.	bl.	ns.	-.44*	-.48*	.66***	---	-	-
YoYo	ns.	ns.	-.47*	ns.	.46*	.67***	-.47*	ns.	---	--
Pass	ns.	ns.	ns.	ns.	ns.	ns.	ns.	.40*	bl.	---
Soc-Lab	ns.	ns.	ns.	ns.	ns.	ns.	bl.	.61*	ns.	.64*

ns. = non-significant; bl. = p<0.10; * = p<0.05; ** = p<0.01; *** = p<0.001

TABLE 28 The perceptual-motor skill correlation matrix for the U15 group.

Pubertal U15 Group					
	Passing Test	Anticipation	Feint-Target	Soc-Lab	Accuracy
PAT	ns.	ns.	bl.	ns.	ns.
EHF	-.41*.	ns.	-.40*	-.50**	ns.
Anticipation	.50*	---	ns.	.44*	ns.
Selection	ns.	ns.	bl.	.43*	ns.

ns. = non-significant; bl. = p<0.10; * = p<0.05; ** = p<0.01; *** = p<0.001

5.5.4 The relationships in the late adolescent U17 group

The Pearson correlation coefficients between selected variables for the late adolescent U17 group are presented in Tables 29 and 30. The pairs of variables in which the explanatory power was more than 50 % in the U17 group were: CMJ – 30 m sprint (53 %) and agility – passing test (67 %). A total of 12 significant associations were found between the variables in the U17 group.

TABLE 29 The physical fitness correlation matrix for the U17 group.

Late Adolescent U17 Group										
	Height	Muscle	Fat%	Testo	Leg	CMJ	30m	Agility	YoYo	Pass
Height	---	-	-	-	-	-	-	-	-	-
Muscle	.63*	---	-	-	-	-	-	-	-	-
Fat%	ns.	ns.	---	-	-	-	-	-	-	-
Testo	ns.	ns.	ns.	---	-	-	-	-	-	-
Leg	ns.	ns.	ns.	ns.	---	-	-	-	-	-
CMJ	ns.	ns.	-.61*	ns.	ns.	---	-	-	-	-
30m	ns.	ns.	ns.	ns.	ns.	-.73**	---	-	-	-
Agility	ns.	ns.	ns.	ns.	ns.	bl.	.68*	---	-	-
YoYo	ns.	ns.	-.62*	bl.	ns.	ns.	ns.	ns.	---	-
Pass	ns.	ns.	ns.	ns.	ns.	-.58*	.60*	.82**	-.58*	---
Soc-Lab	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.	ns.

ns. = non-significant; bl. = p<0.10; * = p<0.05; ** = p<0.01

TABLE 30 The perceptual-motor skill correlation matrix for the U17 group.

Late Adolescent U17 Group					
	Passing	Anticipation	Feint-Target	Soc-Lab	Accuracy
PAT	ns.	ns.	ns.	ns.	ns.
EHF	ns.	ns.	bl.	ns.	ns.
Anticipation	ns.	---	.69*	.67*	-.68*
Selection	ns.	ns.	bl.	ns.	ns.

ns. = non-significant; bl. = p<0.10; * = p<0.05

6 DISCUSSION

6.1 Development of anthropometrics and body composition

The present soccer players' height fit well into the standard deviation of the Finnish height chart (Dunkel et al. 2011) but a tendency was found that the players were slightly shorter than age-matched average males or age-matched controls from the same geographical area (III). The difference in height between the soccer players and control groups reached the level of significance only in one out of the four age groups. Taking into account that the players' height curve followed exactly the same path as median reference line in the height chart, it can be concluded that young soccer players' growth in height and the timing of maximal height spurt did not differ from an average young person. This was to be expected as previous studies have shown that height growth in young soccer players and physically active boys is similar to an average young person (Malina 1994, Malina 2003, Philippaerts et al. 2006).

The difference in total body mass between the players and controls (or the distance from the median reference line in the Finnish weight chart) seemed to be greater during pre-puberty and puberty compared to late adolescence. This means that soccer players' body mass increased relatively more than in the controls during the monitoring period (III). This was caused by two factors. First, the controls' body fat decreased 4.6 % between ages of 11-17 years, which is in agreement with the suggestion that the lowest percentage of body fat can be detected at the age of 16 to 17 years in males in the general population (Malina et al. 2004). The soccer players' percentage of body fat was lower than that of the controls in all age groups but it was already at such a low level in the U11 group that the normal growth related decrease in relative fat mass did not occur during puberty. Other studies have also shown that soccer players' percentage of body fat, regardless of age, is around 11 % which is lower than that of an average person (Gil et al. 2007a, Sutton et al. 2009, Carling et al. 2012). Second, the players' muscle mass increased more than in the controls. Ara et al. (2006) have shown that children who regularly participate at least 3 h per week in sports activities are protected against fat mass accumulation and they increase their total lean mass to a greater extent than children who do not participate in sport activities. It has also been suggested that muscle mass of the thigh is greater among young soccer players compared to general youths (Hoshikawa et al. 2013). In agreement with these suggestions, the present players increased their muscle mass, depending on body part, 1.5 - 7.0 % per year more than the controls between ages of 11 - 17 years. The proportion of the players' muscle mass in relation to total body weight increased from 48% to 52 % between U11 to U17. In the U17 group, the players' muscle mass was 2.1 % greater than that of the controls but was comparable with the values presented for young males in a pediatric textbook (Malina et al. 2004).

From a practical point of view, it is important to pay attention to inter-individual differences in body size. Muscle mass of the biggest player was more than double of that of the smallest player at the same chronological age in the pubertal age groups (III). It is easy to understand how unfair it would be arrange a martial arts match in which a 1.47 cm/35 kg boy is fighting against a 1.82 cm/70 kg boy. Even though the maturity status obviously affects to players' performance characteristics in a lesser extent in soccer, it can be argued that very little has been done in the last 10 years to provide equal opportunities for late maturating children to experience competence in soccer (Helsen et al. 2012). Therefore, it is high time for soccer practitioners working in football associations to take real actions in this well acknowledged but poorly managed issue.

6.2 Serum testosterone and cortisol concentration

Changes in the present young soccer players' serum testosterone concentration followed a well-known pattern so that a minor increase observed just before puberty turned to a drastic rise during actual puberty (Malina et al. 2004). At the end, serum testosterone level of the U17 players was at same level as found in adults (Bhasin et al. 1996). Several previous studies have found that young soccer players tend to have a bias towards early maturation (Cacciari et al. 1990, Malina et al. 2000, Hammami et al. 2013). In the present study, there were no significant differences between the soccer players and controls in serum testosterone level in any age group (III). This alongside anthropometrical findings suggests that young Finnish soccer players were not ahead in maturity status compared to their general age-matched counterparts. The soccer culture in Finland does not explicitly require players to be early maturated. Soccer in Finland is based on "All Sports" principle, which emphasizes the right for every child to participate rather than compete. In addition, soccer is not a fully professional sport in Finland which explains why there is no tradition for early selection processes in most of the Finnish soccer clubs.

Serum cortisol levels of the soccer players were higher than that of the controls in all age groups although the difference failed to reach significance in the oldest U17 group. Higher cortisol levels can be regarded as normal training adaptation since cortisol is known to enhance carbohydrate and fat metabolism (Malina et al. 2004, Välimäki et al. 2009), both of which are loaded in soccer (Bangsbo 1994). No effect of age was found in cortisol levels among the present soccer players. The levels were also similar to those reported for elite adult players (Lippi et al. 2009).

6.3 Development of physical fitness characteristics

6.3.1 Strength

6.3.1.1 Maximal strength

It is obvious that without specific strength training young soccer players' strength development is closely related to chronological age and hormonal maturity as muscle size during growth is mainly determined by the hormonal environment (Blimkie 1989, Hansen et al. 1999b, Matos & Winsley 2007, Nedeljkovic et al. 2007, le Gall et al. 2010, Hoshikawa et al. 2013). Maximal bilateral isometric leg strength of the present soccer players were at the same level with the controls during pre-puberty and puberty, but in late adolescence the soccer players were 37.4 % stronger than the controls (III). A significant proportion of the difference found in the U17 group arose from their strength training which according to training diaries started at the age of 15 years. Thus, the development of strength was influenced by testosterone mediated growth in muscle mass and the increased amount of strength training.

Isometric leg strength attained peak development (24.1 %) at the same time with the maximal muscle mass spurt between U14 to U15 and trunk strength (21.9 %) a year later between U15 and U16. These findings are in agreement with those reported by Beunen & Malina (1988) for general population and by Philippaerts et al. (2006) for young soccer players. On the contrary, Degache et al. (2010) has reported an earlier occurrence for peak strength development between 12 to 13 years of age in isokinetic strength measures of young soccer players. It is difficult to compare the strength development of Finnish young soccer players against their international counterparts because the methodology of strength measurements varies between different studies. However, Vicente-Rodriguez et al. (2003) demonstrated that maximal isometric leg strength of soccer players and controls did not differ in the pre-pubertal age groups as was also the case in the present study. Iga et al. (2009) found an apparent trend for both conventionally trained and resistance-trained English soccer players to be stronger than controls at the age of 15 years, although significant differences between the groups were found only in the non-dominant leg. Mero et al. (1990) have studied Finnish athletes between 11 to 15 years of age competing in individual sports with the same isometric leg press protocol as was used in the present study. Compared to these athletes competing in tennis, track and field and weightlifting, it was found that the absolute level and the longitudinal development of strength in the present players was about the same over 11 – 13 years of age but somewhat less over 14 – 15 years of age.

Although the results confirmed that the development of strength during puberty is driven heavily by general growth (Hoshikawa et al. 2013), it does not mean that strength training should be ignored. It has been shown that with specific strength training young soccer players can achieve substantial strength gains which are beyond those attained just by normal growth (Christou et al. 2006). Actually, it seems that more effort should be placed on long-term strength development in soccer as even elite adult players has been shown to attain great increases in their leg strength with specialized training lasting only for 8 weeks (Helgerud et al. 2011). Based on the present results, it can also be recommended to use experienced strength and conditioning coaches in the planning of strength training. This recommendation can be justified by the fact that neither the absolute level of strength nor the rate of strength development was particularly impressive in the oldest soccer class during those two years when supervised strength training was executed.

6.3.1.2 Explosive leg strength of lower extremities

According to Philippaerts et al. (2006) young soccer players' explosive strength attains maximal development at the same time with the maximal height spurt at the age of around 14 years. Among general population the peak development has been suggested to occur later, at the same time with the maximal growth of muscle mass (Beunen & Malina 1988, Malina et al. 2004). In the present study, the timing of the greatest improvement of explosive leg strength depended on the test used so that the greatest improvement in the rate of force development was attained between U13 and U14, in the countermovement jump between U14 to U15 and in the 5-jump between U15 and U16 (III). Therefore, it seemed that neural, muscular and anthropometrical requirements of the tests affected the precise timing of the greatest improvement. It can be concluded that overall explosive leg strength increases clearly due to pubertal changes in the hormonal status and body composition.

Explosive leg strength in the young players was at the higher level compared to controls when the results were considered in their entirety but the development varied depending on which test, time period or age class was examined (III). Players' rate of force development in the isometric leg press improved more than that of controls in all age classes so that the difference between the players and controls reached the level of significance in the oldest U17 group. A similar tendency in all age classes was observed in the 5-jump but the difference between the players and controls seemed to be greater in the younger U11 and U13 groups than in the older U15 and U17 groups. Regarding the 5-jump, the U16 group's value of 11.8 meters was almost identical to that of 11.9 meters reported for young Tunisian soccer players at the corresponding age (Hammami et al. 2013). In contrast to the rate of force development and 5-jump, the age-matched school controls improved more than the players in the countermovement jump so that the difference between the players and controls failed to reach significance anymore in the U17 group. On the other hand, the differences between the soccer players and controls in the countermovement jump were smaller than could have been expected based on the values presented in previous literature (Buchheit et al. 2010b, le Gall et al. 2010, Focke et al. 2013). The reason for this was that the present controls demonstrated above average jumping abilities compared to general reference values (Focke et al. 2013) and soccer players lower than those reported for age-matched elite players, particularly in the U15 to U17 groups (Buchheit et al. 2010b, le Gall et al. 2010).

It is worth noting that elite soccer players' performance in countermovement jump is not always exceptional by any means. Actually, the present U17 players jumping height of 39.5 cm was almost the same as the values of around 40 cm reported for Italian U20 and U21 national team players and for Norwegian men's national team (Castagna & Castellini 2013, Haugen et al. 2013). These findings at the elite level indicate that soccer does not provide very strong stimulus for explosive strength development. However, explosive strength is required in many match-winning actions such as sprinting, change of speed direction and jumping (Meylan & Malatesta 2009). During pre-puberty, plyometric exercises has been recommended to use when improving soccer players' explosive leg strength (Diallo et al. 2001, Meylan & Malatesta 2009, Thomas et al. 2009, Sedano et al. 2011, Michailidis et al. 2013). From puberty onwards explosive strength exercises (Gorostiaga et al. 2004, Mujika et al. 2009, Lopez-Segovia et al. 2010, Maio Alves et al. 2010, Wong et al. 2010, Loturco et al. 2013) and high-resistance strength training have also been used successfully alongside soccer training (Kotzamanidis et al. 2005, Christou et al. 2006, Chelly et al. 2009, Wong et al. 2010, Helgerud et al. 2011).

6.3.2 Sprinting time

The present soccer players were faster than their age-matched school controls in the sprint test but a tendency was observed for this difference to decrease with age (III). This finding was a logical continuation to similar results found in the countermovement jump. These findings suggest that speed related abilities are likely to be in a pronounced role in soccer during early puberty than later when the growth equalizes these differences. In agreement with this suggestion, Gravina et al. (2008) found that sprint speed was the most important physiological factor associated with being selected for the first team instead of reserves among young Portuguese players between the ages of 10 and 14 years. This suggestion receives further support from Vaeyens et al. (2006) who found that speed was one of the strongest factors that discriminated elite and sub-elite players at the ages of 13 and 14 years, whereas aerobic endurance become more important later in the 15- and 16-year age groups.

The peak development of sprinting speed was observed between U13 to U14 which is in agreement with the results presented both for young soccer players and for general population (Haubenstricker & Seefeld 1986, Philippaerts et al. 2006). The annual development of around 5 % among the present players was rather comparable to that presented for young elite players (Vaeyens et al. 2006, Buchheit et al. 2010b, le Gall et al. 2010). It was also surprising to note that the 10 m sprint time of 1.84 seconds in the present control group at the age of 17 years was actually quite comparable with the values of 1.80-1.83 presented for elite adult players in the literature (Cometti et al. 2001, Wisloff et al. 2004, Little & Williams 2005). As none of the controls in the 17 year-old group participated in supervised sport activities, the results indicate that heredity and genotype (proportion of fast twitch muscle fibers) greatly affects person's speed-related abilities (Mero et al. 1981). Nevertheless, special attention should be placed on speed training in soccer as normal training does not give adequate stimulus for optimal speed development. The focus should be on improving acceleration phase since more than 95 % of the sprints in the game are less than 20 m long (Mohr et al. 2003, Di Salvo et al. 2010).

6.3.3 Agility

Soccer players are known to perform particularly well in various agility tests (Gil et al. 2007a, Figueiredo et al. 2009, Kaplan et al. 2009, Chan et al. 2011, Rebelo et al. 2013). This was also the case in the present study in which a successful agility performance was explained better by soccer participation than by age (III). The present soccer players' superiority over controls can be highlighted by comparing the U11 soccer players against the 17 year-old controls. The 17 year-old controls were almost half of a second faster than U11 players in the 30 meter straight sprint but in the agility test the U11 players were quicker than 17 year-old controls. Soccer players' superiority in agility originates from normal soccer training in which agility is constantly stressed and, therefore, players receive constant high-quality practice for this ability (Reilly et al. 2000, Kaplan et al. 2009). As the deceleration before changing direction plays a key role in agility performance (Sayers 2000), it could be "suggested" that soccer players are not necessarily very good at sprinting but they surely are good at stopping.

As expected, the present soccer players' fastest development in agility occurred between U13 to U14 (Philippaerts et al. 2006, Nedeljkovic et al. 2007). The fastest annual improvement (3.8 %) was rather modest which suggests that agility is likely to develop better already in the younger age groups than those measured in the present study. This assumption is based on general pediatric literature which suggests that the fastest development in agility occurs during pre-puberty, after which, the improvement slows down during adolescence to reach the final level at early adulthood (Malina et al. 2004). Although the development of agility during adolescence might be modest, agility is one of the most important factors to be monitored in all age groups in soccer. This has been suggested, because agility tests can provide useful information in terms of preceding future career progression (Gonaus & Muller 2012). Another standpoint supporting agility testing is that the biological maturation affects motor coordination tests less than e.g. morphology or other fitness tests (Vandendriessche et al. 2012). However, it is also important to remember that there is no agreement on a precise definition of agility in the sport sciences

(Sheppard & Young 2006) which needs to be taking into account when generalizing the data collected from different agility tests.

6.3.4 Endurance

6.3.4.1 Aerobic capacity (VO_2max)

VO_2max of the present players was higher than that of controls in all age groups (III). Among soccer players, only small differences between the age groups were observed but the results revealed that average VO_2max in the age groups below U14 was always less and in all age groups above U14 more than 54 ml/kg/min. This difference has very little physiological importance but might be a detectable reflection of those drastic hormonal and other maturational changes that young males undergo during puberty. The present players' VO_2max values between 52 - 56 ml/kg/min can be considered the level that is attained by playing soccer at the sub-elite level (Hansen & Klausen 2004). This level is lower than approximately 60 ml/kg/min demonstrated for young and adult elite players (Reilly et al. 2000, Metaxas et al. 2006, Fernandez-Gonzalo et al. 2010, le Gall et al. 2010, Boone et al. 2012, Tonnessen et al. 2013) but the difference is actually rather small as it has been shown that soccer players' VO_2max can be improved with reasonable effort up to 10 % in about 8 weeks with specialized training (Impellizzeri et al. 2006, Helgerud et al. 2011). Regarding to training, it can also be suggested that improving VO_2max closer to 65 ml/kg/min could be beneficial for midfield players and full-backs because work-load during the game is the highest in these playing positions (Bloomfield et al. 2007, Bradley et al. 2009).

Hemoglobin and hematocrit have potential explanatory power on endurance performance being related to the transport of oxygen to be used for energy production in the muscles (Malina et al. 2004). The present soccer players' hemoglobin increased from 139 g/l to 155 g/l and hematocrit from 39.6 % to 44.1 % between U11 to U17. These increases were likely caused by increased hematopoiesis mediated by increased testosterone secretion (Malina et al. 2004, Välimäki et al. 2009). The players' hemoglobin values were at the same level with the control groups even though the players demonstrated higher maximal oxygen uptake capacity. The reason why trained persons with higher VO_2max do not necessarily demonstrate higher hemoglobin values is that even though the number of red blood cells increases due to training so does the plasma volume which means that the relative proportion of the particles in the blood do not change (Convertino 1991). Therefore, it is not surprising that previous studies have also shown that hemoglobin and hematocrit values of soccer players are similar to that of an average person in all age groups (Nikolaidis et al. 2003, Hansen & Klausen 2004, Silva et al. 2008).

6.3.4.2 Endurance performance

The greatest difference between the present young players and controls amongst all the measured physical performance abilities was found in endurance performance (III). The performance in the shuttle run test is mainly influenced by aerobic capacity (VO_2max), agility (turns) and intrinsic motivation. As these were the abilities in which the players were particularly ahead of the controls, the Yo-Yo test can be considered to combine soccer players' best features into one performance. Depending on the age group, the soccer players covered 50 – 100 % more than age-matched controls in the Yo-Yo endurance test. Actually, even the youngest U11 players outperformed the oldest 17 year-old controls by more than 200 meters in the endurance test. This remarkable difference found in the endurance performance demonstrated that soccer training improves greatly general working capacity of young persons and may lead to long-term health benefits (Krustrup et al. 2010). These general health aspects have particular importance in Finland where soccer facilities are mostly funded and administered by governmental bodies.

The endurance performance of the present players was measured with the Yo-Yo endurance test which was chosen because it was recommended by the national football association. This makes the comparisons between Finnish young soccer players and elite young players across world difficult because the Yo-Yo intermittent recovery test is the most common field test in other countries. However, Metaxas et al. (2006) compared soccer players' VO_2max values with different field and laboratory tests including the Yo-Yo EL1 test used in the present study. The players of the Greek U20 national team covered 2420 m in the Yo-Yo EL1 test which is only 3 % more than that covered by the present U16 and U17 players. This suggests that continuous endurance performance characteristics of young Finnish soccer players seemed to be rather comparable with young elite players.

According to the 5-scaled reference table used by the Football Association of Finland (Vilkki 2012), the present players' endurance performance in the youngest and in the oldest age class was classified to the second highest category ("good") in all three measurements during the monitoring period. The endurance performance of the middle age class was classified to the third category ("average") in all three years during the monitoring period. These results indicated that compared to age standards, the endurance performance abilities in each age class remained at the same level during the whole monitoring period which, in turn, indicates that the development within age classes was likely related to general growth. This assumption was further supported by the fact that the relative development of the control groups was greater than in the players. The fastest development in endurance performance occurred at the same time with the maximal rate of growth between U13 and U14 which was in line with previous reports concerning the development of continuous and intermittent endurance performance among young soccer players (Philippaerts et al. 2006, Mujika et al. 2009b, Valente-Dos-Santos et al. 2012).

Even though the development within each soccer class was related to growth, endurance performance was the least age-dependent of the all physical fitness abilities if the results are compared across different age classes. For example, when the players in the youngest age class were in the U13 age category, they covered a greater distance in the endurance performance test than the previous age class in the U15 age category. This indicates that endurance performance tests reveal more about the groups' training status than other physical fitness tests. The players of this study did not do any serious endurance training besides regular soccer training. This means that the players' endurance performance characteristics were most likely related to the amount of high-intensity periods during regular soccer training sessions. It has been shown that players spent only a very small fraction of the time in the high-intensity zone during training but only this time is related to changes in aerobic fitness (Castagna et al. 2011, Jastrzebski et al. 2013). Therefore, the most practical way for soccer practitioners to improve young soccer players' endurance performance is to keep the tempo of soccer training adequately high so that it provides training stimulus for endurance abilities. Small-sided games with different variations have been suggested for these purposes for young soccer players (Hill-Haas et al. 2009, Casamichana & Castellano 2010, Koklu et al. 2011, Abrantes et al. 2012, Brandes et al. 2012, Koklu et al. 2012, Casamichana et al. 2013).

6.3.5 Development of skills

6.3.5.1 General perceptual-motor skills

Puberty in males is characterized by hormonal changes, especially increased testosterone secretion (Malina et al. 2004). As testosterone is known to promote the functional and anatomical development of the nerves and brain (Sakai & Woody 1988, Stocker et al. 1994, Tan 1996, Steinberg 2005, Cahill 2006), it is clear that every three stages of the simplified information-processing chain (perception-processing-execution) undergoes marked changes during growth (Welford 1968, Whiting 1969). In the present study, general perceptual-motor skills were examined using two different approaches which examined the effects of soccer expertise and age. The results of the first approach revealed that general perceptual-motor skills improved with soccer expertise. However, the difference between the controls and players or between sub-elite players and elite players in the simple and peripheral reaction time tests were counted only in the range of hundredths of a second and no differences were found in the general eye–hand–foot coordination test. Furthermore, the only test in which the young adult elite players (U-19) performed better than the adolescent elite players (U-16) was the peripheral reaction time test but the difference in practical terms was again negligible. These findings confirm the earlier suggestion that athletes, including soccer players do not perform outstandingly in general measures of perceptual-motor performance (Starkes & Deakin 1984, Schmidt & Lee 2005, Ward et al. 2007, Gonaus & Muller 2012).

According to the literature, development of general perceptual-motor skills during growth approximates the process of neural maturation (Fulton & Hubbard 1975, Thomas et al. 1981). The present players' simple and peripheral reaction time measuring mainly visual skills improved around 20 % from U11 to U17, while eye-hand-foot coordination demanding more information processing and motor execution improved over 45 % between the corresponding age groups. This was in agreement with the suggestion that the effect of age is more marked for complex than for simple reaction tasks (Luchies et al. 2002, Der & Deary 2006). However, the complexity of the task did not seem to be related to the timing when the greatest improvement in different tasks occurred. The greatest relative improvement in simple reaction time and in eye-hand-foot coordination occurred between U11 and U13 and in peripheral reaction time between U13 and U15. To summarize, the effect of age was greater in the task pressuring information processing and motor execution but soccer expertise was characterized better by the tasks measuring visual skills (II, V).

6.3.5.2 Soccer skills

One of the most important variables to evaluate in youth soccer is players' technical skills (Rosch et al. 2000, Ali 2011). Technical skills should be included when young players' development is monitored and their future potential is evaluated (Huijgen et al. 2009). In the present study, skill development was examined over time, sex and age. The first two approaches utilized national skill competitions database which was built specifically for the present study by gathering all the results that could be traced from regional competitions and national championships held in Finland during the current century. The effect of age was examined by using the nationwide database and mixed-longitudinal measures from the monitored players.

In order to improve soccer skills, players need to receive specialized coaching and training and to have access to appropriate training facilities (Ericsson & Lehmann 1996, Cote et al. 2006). All these three factors have improved in Finland during the current century. The Finnish coach education programme fulfilled the UEFA's license requirements in 2002 and more than 650 licensed coaches are working in Finnish soccer at the moment (Ukkonen 2013). The present results revealed that technical skills in young Finnish soccer players have improved between the years of 2000 and 2011 (IV). Accordingly, among the monitored club players, the younger age classes performed better in skill tests than the previous one. These findings indicated that training procedures have improved over recent years, as it is justified to predict that the number of naturally gifted players remains somewhat constant across time in Finland. The tempo of contemporary soccer has increased compared to previous decades, which means that players' skills need to adapt constantly in order to respond to the growing demands of the game (Huijgen et al. 2009). Therefore, the evolution of the game itself is also an on-going process and provides increasingly better training stimulus for skill development. Regarding training facilities, it must be noted that Finland is located on both sides of the Arctic Circle. This means that more than half of the year soccer training takes place in indoor soccer halls or outside on heated artificial turf pitches. The number of these facilities has more than doubled in Finland during the current century (LIPAS 2010).

There are approximately 29 million female players in the world and 12% of youth players are female (FIFA 2012). However, female soccer players' skill development has been studied scarcely. The present study demonstrated that girls were 9 % to 20 % slower than boys in the dribbling and passing tests in different age groups, with a weak tendency showing the difference to decrease with age. A small acceleration in the skill test results was detected in girls just after the predicted growth spurt between 12 and 13 years of age. The growth spurt occurs at the age of 12 years in Finnish females (Välimäki et al. 2009). From a practical point of view, the results revealed that the performance time of the U11 boys in skills tests was comparable with that of U17 females. Based on the previous research, 17-year-old female players' physical performance capacity is better than that of the U12 male players in the present study (Vescovi et al. 2011). This suggests that the observed difference between the genders arose from actual ball-handling skills. Therefore, a special attention should be placed on skill training during childhood and adolescence among female soccer players (IV).

In males, the dribbling and passing test time improved around 30 % between 9 to 17 years of age which was similar in magnitude compared to development that has been presented for elite young players in previous research reports (Rosch et al. 2000, Vaeyens et al. 2006, Huijgen et al. 2009). The greatest improvement in both skill tests occurred during pre-puberty between 9 to 11 years of age (IV). During puberty, a slightly different development pattern was detected between the dribbling and passing test. Acceleration between U13 and U15 was observed in the passing test in all skill levels but only among the monitored club players in the dribbling test. This difference between the passing and dribbling test was not surprising as previous studies have shown that the effect of age and maturity varies in skill tests depending on the test used (Malina et al. 2005, Valente-Dos-Santos et al. 2012). Overall, it was also likely that a significant proportion of the improvement in skill tests was related to players' improved physical performance abilities, such as power, speed and agility which are known to improve markedly during adolescence (Philippaerts et al. 2006, Vaeyens et al. 2006, Buchheit et al. 2010b, le Gall et al. 2010). These abilities developed markedly also among the present regional players during the monitoring period as already discussed earlier.

In both skill tests, the most skilful players competing in the national championships showed a lower relative annual improvement compared to players competing in the regional level or compared to the club players monitored for two years (IV). It was likely that the most skilful players were already at a high level at the age of 12 years, so that any further progression was inevitably slow. Actually, the national championship players were at the same level at the age of 12 years as the regional competition players at the age of 17 years, and they were at least 2 years ahead of the monitored club players in both tests.

These results are consistent with previous suggestions that skill tests seem to be sensitive in detecting differences between elite and sub-elite players during childhood and adolescence (Vaeyens et al. 2006, Huijgen et al. 2009). In addition, the fact that marked differences in players' skill levels were found already at the age of 12 years addresses two important practical aspects of soccer. Firstly, as skill differences in the U12 groups cannot be explained by maturity, a lot of high quality practice is needed in order to become a skilful player, especially because training is known to be the most important factor explaining the development of soccer skills (Helsen et al. 2000, Malina et al. 2005). Secondly, players need to follow the early specialization and early engagement pathway, if they are aiming for elite level in soccer (Roca et al. 2011, Ford et al. 2012).

6.3.5.3 Soccer-specific perceptual-motor skills

Soccer involves perceptual-motor skills that operate simultaneously in a changing environment which means that the players need well-developed perceptual and decision making skills in order to succeed in the game (Bullock et al. 2012). Therefore, a number of authors have addressed that skill tests in soccer should attempt to include perceptual and decision making components with technical and physical tasks (Sheppard & Young 2006, Ali 2011, Roca et al. 2011, Bullock et al. 2012). In the present study, a specific laboratory test was developed in order to simulate "game-like" soccer performance requiring perceptual and decision making skills alongside with technical skills.

General physiological development cannot be neglected when interpreting the changes in soccer-specific perceptual-motor skills. The central nervous system develops markedly up to around the age of 12 years, and moreover, the visual system develops throughout childhood to reach the adult functional level by the age of 15 years (Ishigaki & Miyao 1994, Fukushima et al. 2000, Crognale 2002, Malina et al. 2004). At the same age, children are able to select relevant information from various sources in the environment, and their ability to process information becomes more efficient (Ross 1976, Kail 1991). Thus, from general physiological development it could be expected that the tasks requiring mainly visual skills are likely to develop steadily with age whereas tasks requiring information processing will be accelerated during adolescence. Overall, the results of the present study suggested that this kind of development pattern might be true when considering the development of soccer-specific perceptual-motor skills (I, V).

The relative development of total performance time in the laboratory test was rather similar to that found in the traditional dribbling and passing test. However, the effect of age was more evident in the perceptual and decision making variables than in the motor execution variables. Anticipation time to soccer-specific stimulus and selection time during dribbling improved by age across different age classes whereas the dribbling phase in the laboratory test improved more within each age class. Similar findings in visual anticipatory capabilities to those found in the present study have been reported in previous studies. These studies have suggested that skilled-based differences occur at an early age but perceptual and cognitive skills discriminate players according to their level of expertise better in the older age groups (Abernethy 1988, Tenenbaum et al. 2000). Regarding motor execution, the development pattern observed in the dribbling phase was in line with those in the traditional technical skill tests in which the fastest development occurred at the pre-pubertal age groups and the slowest during late adolescence.

The results indicated that soccer-specific perceptual-motor skills improved more than general perceptual-motor skills during the two year monitoring period (V). Depending on the age class, the reaction time to general peripheral stimulus improved from 9.0 % to 14.3 %, while at the same time soccer-specific anticipation time improved from 14.6 % to as much as 57.6 %. Comparison between general and soccer-specific reaction time also revealed that soccer-specific anticipation time was shorter than simple reaction time even in the youngest U11 group. This means that regardless of age the players were able to anticipate the direction of the pass and decided their movement based on player's postural cues before the actual passing impact. It is worth noting that this game-reading skill seemed to improve as players grew from pre-puberty towards adulthood. These findings confirm earlier suggestions that sport-specific perceptual-motor skills develop through extensive task-specific training and these skills become increasingly important as athletes become older (Helsen & Starkes 1999, Tenenbaum et al. 2000, Vaeyens et al. 2007a).

6.3.6 Performance traits

6.3.6.1 The pre-pubertal U11 age group

The pre-pubertal years just preceding the growth spurt are characterized by relatively small changes in body composition and in performance characteristics (Malina et al. 2004). The results of the present study showed that the greatest improvement in the pre-pubertal age groups was attained in peripheral reaction time, general eye-hand-foot coordination and technical soccer skills. These were the tests in which the results are suggested to be less affected by maturation and in which neural control plays a key role in the final outcome (Luchies et al. 2002, Malina et al. 2005, Der & Deary 2006).

Based on Pearson's correlation co-efficient analysis, the smaller players in the pre-pubertal age group covered greater distances in the endurance performance test likely because these players were midfielders. Midfield players are known to cover the greatest distances of all players in games and training sessions (Di Salvo et al. 2013). This means that they also receive the greatest amount of endurance training which, in turn, leads to better endurance performance. The leaner players performed better in the countermovement jump and sprint tests. It is widely acknowledged that all athletes regardless of their age can improve their physical performance by reducing "useless" fat mass (Viitasalo et al. 1987, Reilly et al. 2009).

The endurance test explained almost 60 % of the variance in the passing test which indicated that the duration of the passing test used in Finland is long enough to pressure players' endurance capabilities. The same tendency for the relationship between the passing and endurance test was also observed in other age groups. As the performance time in the passing test was over 30 seconds in all age groups, it can be estimated that approximately 20-30 % of the energy was derived from aerobic and 70-80 % from anaerobic metabolism (Åstrand et al. 2003). From the anaerobic metabolism more than half was produced via the anaerobic glycolysis (lactic acid system). Thus, the present passing test was also an excellent soccer-specific endurance test highlighting at the same time that many factors influence performances on skill tests and these factors vary depending on the test used (Malina et al. 2005).

The players who had faster general peripheral reaction time were also faster in the laboratory skill test in the U11 group. This indicated that differences in general visual abilities, which were large enough to have an influence on soccer performance, may have existed in the pre-pubertal age groups. The same kind of visual differences among young players has been reported earlier by Loran & Griffiths (1998) who found that all U14 players rejected by the English professional club showed deficiencies in visual skills. However, if visual skills really have some potential to affect soccer performance, it is likely to happen in the younger age groups where players' visual skills are still under development. The visual system is known to develop up to around 15 years of age (Ishigaki & Miyao 1994, Fukushima et al. 2000, Crognale 2002).

6.3.6.2 The early-pubertal U13 age group

The relationships found between different variables in the early-pubertal U13 group indicated that growth mediated differences in players' performance characteristics started to emerge. Taller players with higher testosterone values and muscle mass demonstrated higher maximal and explosive leg strength and they performed better in the sprint test. The players with higher testosterone concentrations also tended to have less body fat which was likely related to fat-mobilizing effects of testosterone (Välimäki et al. 2009). This was still another mechanism which favored early maturated boys over the late ones because the lower percentage of fat, in turn, was related to better performance in the countermovement jump, sprint, agility and endurance test.

The same players who succeeded in the predictable passing test were also good in the unpredictable laboratory test. This indicated that the players' ball skills in the U13 group had reached skill stage where the motor performance can be transferred to different environment without detectable changes (Magill 2007). In addition, the players with faster general peripheral reaction time were also good at anticipating passing direction based on other player's postural cues. This suggests that general and soccer-specific perceptual-motor skills may have a common physiological foundation which, however, will be overwhelmed by task-specific practice with increasing experience. Overall, it can be summarized that the early-pubertal U13 group demonstrated features that showed a logical shift from childhood to adolescence had started (III, V).

6.3.6.3 The pubertal U14 and U15 groups

Grumbach (1975) has defined puberty as a ”trasitional period between the juvenile state and adulthood”. This process is characterized by alternations in body size, body composition and physical fitness abilities in response to actions of sex steroids, mainly testosterone in males (Rowland 2005). This was observed in the results of the present study. The greatest development in height, weight, countermovement jump, sprint time and endurance performance occurred between ages of U13 to U14 when testosterone concentration in these players exceeded the level of 10 nmol/l (III). These findings were in agreement with those presented by Philippaerts et al. (2006) who found that explosive strength, running speed, agility and endurance attained maximal rate of improvement at the age of 13.8 years among Flemish young soccer players. The present players peak development of muscle mass and maximal strength was attained a year later between ages of U14 and U15. The development of these variables showed similarity with findings in general population studies suggesting that the maximal spurt of strength and power occurs after the height spurt (Beunen & Malina 1988, Malina et al. 2004).

The growth spurt occurs, as an average, at the age of 13.5 years in Finnish males (Välimäki et al. 2009). This is the time period when performance differences between boys of contrasting maturity status of the same age are most apparent and children who are advanced in maturity are likely to perform better in almost all measures of physical abilities (Malina et al. 2004). The same players tended to perform better in most of the physical performance tests in the pubertal U14 and U15 groups also in the present study. The bigger players with higher testosterone levels and lower percentage of body fat were better in explosive leg strength, sprinting speed and agility. These variables, in turn, explained successful performance in the endurance test and skill tests. However, endurance performance and soccer skills were not directly related to players' size or hormonal status which indicated that these variables were less affected by players' maturity. The effect of age is known to be smaller in skill tests but maturity could be expected to influence on endurance performance to the same extent as in other fitness variables (Malina et al. 2005, Gil et al. 2007a, Valente-Dos-Santos et al. 2012, Vandendriessche et al. 2012). Actually, it has been proposed that a probability for an accelerated improvement in aerobic endurance is between 11 to 15 years due to sexual maturation (Viru et al. 1998). Nevertheless, the results of the present study suggested that in a small group of players the training including earlier discussed effects arising from different playing position affected to endurance performance more than maturity.

Based on the soccer-specific laboratory skill tests, the U15 players had reached the point when soccer-specific perceptual-motor skills started to play an important role in successful soccer performance (I, V). This was supported by the significant relationships found between soccer-specific anticipation and selection time and total performance time in the laboratory test. At the age of 15 years, the players of the present study had been engaged in soccer for 7 to 8 years. This time period required before the soccer-specific perceptual-motor skills showed the first signs of the ability to characterize soccer expertise was rather similar to that of 6 - 7 years proposed by Tenenbaum et al. (2000) for tennis players. Even though the most important factors explaining soccer expertise is deliberate practice and play activities (Roca et al. 2011), a part of the development was likely related to maturational brain processes. These processes are known to take place during puberty and continue further through adolescence up to early adulthood (McGivern et al. 2002, Steinberg 2005, Paus 2005). However, it is impossible to explain how much these variables contributed to the development of soccer expertise, since the present players' training history or their brain development was not specifically investigated.

Although soccer-specific perceptual-motor skills started to become more important during puberty, the differences in the players' motor execution capabilities were the leading features in the pubertal age groups. This was evident as the same players were better performers in tasks requiring motor coordination, no matter whether the task was general or soccer orientated (I, III, V). Because motor coordination seemed to be particularly important, it is worth noting that two factors exist which have opposite influences on motor coordination during the period of rapid growth. A period of rapid growth is suggested to produce temporal clumsiness in certain individuals, a phenomenon also known as adolescent awkwardness, owing to the differential timing of growth spurts of the lower limbs and muscle mass (Beunen et al. 1989). On the other hand, most of the physical abilities are suggested to show the fastest improvement at peak height velocity (Philippaerts et al. 2006). These aspects further highlight the fact that monitoring development during puberty is complex phenomenon, because it is influenced by many physiological, biomechanical and psychological factors as well as maturity status and the tests used (Malina et al. 2005).

6.3.6.4 The late adolescent U17 group

It has been demonstrated that the greatest changes in person's body size and physical performance characteristics occur by the age of 17 years (Haubenstricker & Seefeld 1986, Beunen et al. 1989, Malina et al. 2004). This means that the relationships between different body composition variables and physical performance abilities in the U17 group are likely to reflect closely to those found among adult players. The significant relationships found between physical performance variables in the U17 group were as expected: the lean players jumped higher and ran more in the endurance test (Viitasalo et al. 1987, Nikolaidis 2012), the players with better explosive leg strength were faster in sprints and tended to be faster in the agility test (Wisloff et al. 2004, Cronin & Hansen 2005). In addition, the players with better physical fitness, especially agile players, succeeded in the passing test (Huijgen et al. 2010).

The late adolescence was characterized by the declined rate of improvement in physical fitness variables and accelerated rate of improvement in soccer-specific perceptual-motor skills (III, V). The only variable showing the greatest development during late adolescent was soccer-specific anticipation time. As a consequence, anticipation time explained over 40% of the variation in performance time in the laboratory test. This means in practice that in the U17 group it was almost impossible to compensate for inefficient decision-making with skilful motor performance, something which was still possible in the younger age groups. This finding confirms earlier suggestions that sport expertise is characterized by a superior ability to make more accurate predictions as to what others are likely to do in any given situation (Raab & Johnson 2007, Vaeyens et al. 2007a, Ward et al. 2007, Roca et al. 2011) and that cognitive skills play a crucial role in the final outcome of soccer performance (Roca et al. 2012).

6.4 Methodological strength and limitations

The strength of this study was that it followed the same soccer players with the mixed-longitudinal and multi-factorial approach in the age groups between U11 to U17. The age groups covered wide range of different developmental stages and the measured variables included many of the variables that have been suggested to measure when monitoring long-term development in young soccer players (Reilly et al. 2000, Vaeyens et al. 2006). The fact that the players were monitored for two years made the present data more valuable. This was especially true for soccer-specific perceptual-motor skills. These studies are overall pretty rare and the lack of longitudinal datasets is apparent. Regarding the methods, the study trusted mainly the measurement protocols which have a long tradition in soccer or in sport sciences. This was probably the reason why very few methodological problems occurred during the monitoring period. The number of "lost" subjects during the two-year monitoring period was also rather small, less than 10 %.

The main limitation concerning the results of this study arises from the well-acknowledged issue that children and youths are more variable in performance and the methodological issues are known to be unique in developmental research (Thomas 1984). Regarding methodological limitations, the sample size of soccer players and controls was small in the longitudinal design. This increases the risk of failure to reject a false null hypothesis (Type II). It is inappropriate to list all general error sources arising from human or from measuring devices used in the present study. However, the aspects related specifically to the present study can be listed as follows: 1) The soccer players in each age class were heterogeneous that is why the difference between the best and the worst performance was noticeable; 2) The controls were recruited on voluntary basis which means that the groups included mostly boys whose attitude towards exercise was positive; 3) Hormone analyses were based on a single sample which is not optimal due to the episodic secretion pattern of hormones (Ankarberg-Lindgren & Norjavaara 2004) ; 4) The players were inherently more motivated than the controls to give their best in the endurance tests; 5) The players' precise birth days were not recorded in the national youth skill competitions (cross-sectional dataset); 6) Although the soccer-specific test was repeated at intervals of two years, a learning effect may have occurred.

6.5 Practical applications and suggestions for future research

The results of this study showed that the physical fitness of Finnish youth soccer players was clearly better than their age-matched counterparts not engaged in soccer. It is evident that participation in soccer greatly improves the working capacity of players, which can be assumed to lead to long-term health benefits (Krustrup et al. 2010). On the other hand, a tendency was seen for the differences between the soccer players and control groups to decrease with age in speed-related tasks, to remain the same in endurance performance and to increase in strength (due to the strength training program carried out by the soccer team). These results emphasize the need for long-term training programs with proper periodization for strength, speed, and endurance training to maximize players' potentiality. Special attention is recommended to be paid to speed training because it seems that normal soccer training does not give adequate stimulus for optimal speed development. Nevertheless, although training in a regional soccer team is not fully optimized, it seems to provide sufficient training stimulus for players to gain physical fitness level that is not a limiting factor to reach the level needed in elite soccer.

Even though a relationship was found between soccer expertise and general perceptual-motor skills, it is unlikely that general perceptual-motor skills are the limiting factor for an individual who is progressing toward the elite level. More likely, general perceptual-motor skills can set potential limits on performance in sport, but once those limits are exceeded, soccer-specific skills differentiate elite players from sub-elite players (Ferreira 2002). The differences in general perceptual-motor skills in the present study between sub-elite and elite players were in the range of hundredths of a second. Previous research suggests that more significant differences between adolescent sub-elite and elite players can be found, for example, in agility, endurance, soccer skills and soccer-specific cognitive skills (Reilly et al. 2000, Savelsbergh et al. 2002, Vaeyens et al. 2006, Gil et al. 2007a, Vaeyens et al. 2007a, Vaeyens et al. 2007b, Huijgen et al. 2009, Rebelo et al. 2013). This means that the minor differences found in general perceptual-motor skills between the groups with different soccer expertise are not meaningful enough for soccer practitioners to test these abilities on a large scale as part of their talent-identification processes. General measures of motor abilities can be recommended when individual deficits are suspected.

Even though "skill" *per se* is proposed to be too difficult to measure at this moment in time (Ali 2011), measuring "technique" is easy and, if monitored over a prolonged period of time, can provide valuable information for soccer practitioners (Huijgen et al. 2009, Meylan et al. 2010). In fact, measuring “technique” instead of “skills” can be justified in a number of ways in the prepubertal age groups. First, a certain level of technical skill is needed before a player is able to direct his or her gaze from the ball into the environment without losing ball control. Second, it has been suggested that children are not able to select the relevant information from various sources in the environment until the age of 12 years (Kail 1991). Third, adolescence is a time of rapid cognitive development towards more efficient decision-making (McGivern et al. 2002, Paus 2005, Steinberg 2005, Smith S.R. 2006).

The results suggested that there is no urgent need to emphasize decision-making skills too strongly in soccer training before puberty. This standpoint was supported by the fact that the development of soccer-specific perceptual and decision making skills was rather modest in the pre-pubertal age groups and was related more to general development than it was later on. Therefore, it can be argued that a relatively low cognitive load can be used at the beginning of supervised perceptual and decision-making training in order to ensure that the amount of information and interactions that need to be processed meet children's working memory capacity, and cognitive overload does not occur (Paas et al. 2004). A safe way to improve children's soccer-specific cognitive skills is to practice these skills unconsciously through games. In particular, small-sided games, in which cognitive skills are constantly stressed, have been recommended for young soccer players (Reilly 2005, Unnithan et al. 2012). Unconscious learning is useful in the sense that it does not load working memory. It has also been suggested that skill acquisition through unconscious learning leads to more robust performance that does not break down under psychological pressure (Masters 1992, Hardy et al. 1996).

There is no doubt that perceptual and decision-making skills are particularly important in elite soccer (Reilly et al. 2000, Roca et al. 2012). The results of the present study suggested that the soccer-specific perceptual and decision-making skills became more important with age leading to a point where insufficient decision-making skills were impossible to compensate with skilful motor execution. Therefore, decision-making skills should be emphasized strongly in soccer training from puberty onwards. The timing of more demanding supervised decision-making training around puberty can be physiologically rationalized by the fact that the brain is reorganized for better decision-making during puberty and early adulthood (McGivern et al. 2002, Steinberg 2005, Paus 2005). The importance of efficient decision-making skills can be further emphasized by arguing that in a real game, a player with advanced anticipation skills will receive the ball, and a player with poor anticipation skills will end up defending, regardless of the players' physical condition or technical skills.

A few perspectives for talent development can be suggested based on the experiences gained during the present study. The results confirmed earlier suggestions that talent development needs to be seen as long-term process (Balyi & Way 1995) in which the most essential component of an effective training programme is the concept on individualization (Norris & Smith 2002). That is, soccer practitioners need to be aware that players' biological age has a huge effect on their trainability and current performance profile. In addition, it is important to recognize players' individual strengths and weaknesses because they are likely to, sooner or later, determine the players' playing positions (Di Salvo et al. 2007). This information, in turn, can be used when preparing players' far-sighted for their future challenges.

An infinite number of recommendations for future research could be proposed when thinking about the two main variables of the present study: growth and soccer. However, at this point only one broader perceptive will be warranted. It is recommended that future research is directed to measure soccer skills in more game-like simulations or preferably in the game itself. This way the ecological validity of the testing could be increased since in the real game the players actions and decisions are affected by the actions of teammates and opponents as well as by the team's playing style and tactics selected.

7 PRIMARY FINDINGS AND CONCLUSIONS

1. *Anthropometrics and body composition.* The young soccer players' height and weight fit well into the standard deviation of the Finnish growth charts but a tendency was found that the players were slightly shorter and lighter than age-matched average persons (Dunkel et al. 2011). The soccer players' percentage of body fat was lower than that of the controls and their muscle mass increased more than in the controls during the monitoring period (III). These advantages in body composition can be considered as indirect evidences from those substantial health benefits that are to be achieved when children engage to soccer.

2. *Serum testosterone and cortisol.* It is important for soccer practitioners to understand the meaning of the huge differences in serum testosterone levels within the same chronological age group during puberty (II, III). These differences in hormonal maturity status are reflected in players' body composition and, in turn, performance characteristics. It has been shown that very little has been done to provide equal opportunities for late maturating children to experience competence in soccer (Helsen et al. 2012), it is recommended that soccer associations should place more effort on creating better competitive systems that take into account players' real biological age instead of chronological age.

3. *Physical performance characteristics.* The results of this study showed that the physical fitness of Finnish regional youth soccer players was better than their age-matched counterparts not engaged in soccer (III). A tendency was observed for the differences between the soccer players and control groups to decrease with age in speed-related tasks, to remain the same in endurance performance and to increase in strength. These results emphasize the need for long-term training programs which take into account the windows of accelerated adaptation in different physical abilities in different age groups (Viru et al. 1998). In addition, a proper periodization for strength, speed, and endurance training is required in

order to maximize players' potential. Special attention is recommended to focus on speed training, because it seems that normal soccer training does not give adequate stimulus for optimal speed development.

4. *General perceptual-motor skills.* The general perceptual-motor skills improved with age and with soccer expertise (I, II, V). The effect of age was greater in the task pressuring information processing and motor execution but soccer expertise was characterized better by the tasks measuring visual skills. However, the differences in general perceptual-motor skills were not meaningful enough to encourage practitioners to test these skills on a large scale but general measures of motor ability can be considered when individual deficits are suspected.

5. *Technical soccer skills.* Technical skill development was examined over time, sex and age (I, IV). The results showed that technical skills in young Finnish soccer players have improved between the years of 2000 and 2011, actual ball-handling skills in boys were better than in girls and the performance in technical skill tests improved with age. The greatest improvement in skill tests occurred during pre-puberty under 11 year-old age groups. During puberty, signs of acceleration between U13 to U15 were observed in the skill tests. It was likely that a significant proportion of the improvement in skill tests during puberty was related to players improved physical performance abilities, such as power, speed and agility. It can be recommended that technical skill tests should be emphasized strongly in the pre-pubertal age groups and special attention should be placed on skill training during childhood and early adolescence, particularly among female soccer players

6. *Soccer-specific perceptual-motor skills.* The results indicated that soccer-specific perceptual-motor skills improved with age (I, V). During the two-year monitoring period, this improvement was greater in the oldest U15 group than that of general perceptual-motor skills or physical fitness variables. This meant that in the U17 group it was almost impossible to compensate for inefficient decision-making with skilful motor performance, something which was still possible in the younger age groups. Therefore, decision-making skills should be emphasized strongly in soccer training at the beginning of puberty and thereafter. The timing of more demanding supervised decision-making training around puberty can be physiologically rationalized by the fact that the brain is reorganized for better decision-making during puberty and early adulthood (McGivern et al. 2002, Steinberg 2005, Paus 2005).

YHTEENVETO (FINNISH SUMMARY)

Jalkapallo on maailman harrastetuin urheilumuoto, minkä vuoksi sitä onkin tutkittu globaalissa mittakaavassa varsin paljon. Sen sijaan Suomessa akateemista jalkapallotutkimusta on tehty verrattain vähän. Kansalliselle jalkapallotutkimukselle on kuitenkin olemassa kaksi merkittävää perustelua. Ensinnäkin, jalkapallo on lasten ja nuorten parissa Suomen harrastetuin urheilumuoto. Kilpa- ja huippu-urheilun tutkimuskeskuksen vuonna 2010 tekemän selvityksen mukaan jalkapalloseurassa lajia harrasti aikuiset mukaan lukien 168 000 pelaajaa. Toiseksi, jalkapallon kansallista tutkimusta voidaan perustella sillä, että jalkapallokulttuuri on jokaisessa maassa erilainen. Tämä tarkoittaa sitä, että kansainvälisten tutkimusten löydökset eivät välttämättä ole suoraan siirrettävissä suomalaiseen toimintaympäristöön. Suomalainen urheilukulttuuri on 2000-luvulla perustunut osallistumista painottavaan lähtökohtaan, jossa tavoitteena on taata jokaiselle lapselle tasapuolinen mahdollisuus osallistua urheiluharrastuksiin. Tämän vuoksi suomalaisessa jalkapallossa käytössä oleva ”Kaikki pelaa” -ideologia poikkeaa lähtökohdiltaan useimpien muiden maiden systeemeistä, joissa painotetaan aikaista erikoistumista ja nuorten jalkapalloharjoittelun päätavoitteena on tuottaa ammattilaispelaajia. Tämän tutkimuksen päätarkoituksena olikin seurata, kuinka juniorijalkapalloilijat kehittyvät fyysisissä, taidollisissa ja havaintomotorisissa ominaisuuksissa 11–17 ikävuosien välillä suomalaisessa jalkapallokulttuurissa.

Tämä tutkimus suunniteltiin siten, että mittaustuloksia käsiteltiin sekä poikkileikkaus- että seuranta-aineistoina. Tutkimuksen koeryhminä toimivat poikajalkapallopelaajat ikäryhmissä U11 (n = 14), U13 (n = 14) ja U15 (n = 12). Kontrolliryhminä ei-lajispesifissä mittauksissa toimivat U11 ja U15 ikäryhmiä vastaavat koululaisryhmät. Tutkimukseen osallistuvien lasten ja nuorten kehittymistä kahden vuoden seurantajakson aikana tutkittiin antropometrisilla mittauksilla, kehonkoostumusanalyyseillä ja hormonimäärityksillä. Koehenkilöiden fyysistä suorituskykyä mitattiin nopeus-, ketteryys-, kimmoisuus-, voima- ja kestävyysmittauksilla. Jalkapallon lajitaitojen kehittymistä seurattiin taitotestiradoilla. Lajitaitojen kohdalla aineistoa laajennettiin kansallisen taitotestitietokannan tuloksilla. Havaintomotorisia ominaisuuksia mitattiin yleisillä reaktio- ja havainnointitesteillä sekä lajispesifillä taitotestiradalla. Reaktio- ja havainnointikykyaineistoa laajennettiin U16 ja U19 nuorisomaajoukkueiden sekä suuremmalta määrältä seurajoukkuepelaajia ja koululaisia U16 ikäryhmässä.

Jalkapalloilijoiden pituuden ja painon kehittyminen U11 ja U17 ikäryhmien välillä seurasi melko tarkasti suomalaisen kasvukäyrästön antamia viitearvoja. Suurin ero jalkapallopelaajien ja kontrollien välillä kehonkoostumusta määrittävissä mittauksissa löytyi suhteellisessa rasvanmäärässä, joka oli jalkapalloryhmissä pienempi kuin kontrolliryhmissä. Seurannan aikana nuorten jalkapalloilijoiden lihasmassa kasvoi hieman enemmän kuin kontrollihenkilöiden, mutta lihasmassan absoluuttinen määrä vanhimmassa U17 ikäryhmässä oli ryhmien välillä lähes samansuuruinen. Näitä kehonkoostumukseen liittyviä positiivi-

sia tekijöitä yhdessä parempien suorituskykyominaisuuksien kanssa voidaan pitää myös osoituksina niistä terveydellisistä hyödyistä, joita lapset ja nuoret saavuttavat harrastaessaan jalkapalloa.

Pelaajien ja kontrollihenkilöiden välillä ei havaittu eroja seerumin testosteronipitoisuuksissa. Tärkeämpää nuorisourheilun parissa toimivien henkilöiden olisi kuitenkin tunnistaa, että samanikäisten pelaajien välillä on puberteetin aikana suuria eroja biologisessa kehityksessä. Puberteetin aikana lisääntyvä testosteronin eritys johtaa pojilla lihasmassan nopeaan lisääntymiseen ja sitä kautta suuriin eroihin pelaajien suorituskykyominaisuuksissa. Tässä tutkimuksessa havaittiin, että U13 - U15 ikäryhmien sisällä suurimman pelaajan lihasmassa oli kaksi kertaa niin suuri kuin pienimmän. On melko epäreilua olettaa 147 cm pitkän ja 35 kg painavan pojan kykenevän fyysisesti samanlaiseen suoritukseen kuin pojan, jonka pituus on 182 cm ja paino 70 kg. Voidaankin väittää, että jalkapallossa ei ole tehty juuri mitään sen eteen, että myöhemmin kehittyvillä nuorilla olisi yhdenmukaiset mahdollisuudet kokea pätevyyttä verrattuna aikaisin kehittyviin yksilöihin. Tämän vuoksi jalkapallotoimijoiden tulisikin kehittää harjoitus- ja kilpailujärjestelmiä sellaisiksi, että ne ottavat paremmin huomioon pelaajien biologisen iän nykyisen kronologisen iän sijaan.

Suorituskykytestit osoittivat, että jalkapallopelaajat olivat pääsääntöisesti kontrolliryhmiä parempia kaikissa fyysisiissä ominaisuuksissa. Tuloksista oli havaittavissa, että kontrollihenkilöiden suorituskyky nopeuteen liittyvissä ominaisuuksissa parani seurantajakson aikana suhteellisesti enemmän kuin pelaajien kun taas voima kasvoi pelaajilla enemmän kuin kontrolleilla. Kestävyydessä kumpikin ryhmä kehittyi suhteellisesti melko samankaltaisesti. Näiden löydösten perusteella pelaajien fyysisten suorituskykyominaisuuksien harjoittaminen ei ollut optimaalista. Koska puberteetin aikana sekä nopeuden, kestävyyden että voiman harjoittamisen edellytykset paranevat hormonaalisten muutosten vaikutuksista, tulisi eri ominaisuuksien harjoittamisen jaksottamiseen kiinnittää myös erityistä huomiota. Tulosten perusteella tämä on erityisen tärkeää pyrittäessä kehittämään pelaajien nopeusominaisuuksia.

Tulosten mukaan yleiset havaintomotoriset kyvyt paranivat iän mukana ja olivat yleisesti ottaen jalkapallopelaajilla paremmat kuin kontrollihenkilöillä. Tulokset viittasivat niin ikään siihen, että iän vaikutus oli suurempi tehtävässä, jossa vaadittiin informaation prosessointia ja vaativampaa motorista suoritusta kun taas eritasoiset pelaajat erottuivat toisistaan paremmin visuaalisten kykyjen perusteella. Erot reaktioaikatesteissä olivat kuitenkin niin pieniä pelaajien ja kontrollihenkilöiden välillä, ettei yleisiä havaintomotorisia testejä voida suositella käytettäväksi jalkapallossa suuressa mittakaavassa. Yleisiä havaintomotorisia testejä voidaan käyttää yksittäistapauksissa, mikäli pelaajan visuaalisissa kyvyissä epäillään olevan poikkeavuuksia, jotka estävät pelaajaa kehittymästä.

Tässä tutkimuksessa jalkapallon teknisten taitojen kehittymistä lähestytettiin kolmesta eri näkökulmasta. Nämä näkökulmat olivat aika, sukupuoli ja ikä. Ajallisessa tarkastelussa havaittiin, että suomalaisten nuorten jalkapalloilijoiden taidot ovat taitotestien perusteella kehittyneet vuosien 2000 ja 2011 välisenä aikana, tytöillä hieman enemmän kuin pojilla. Tyttöjen todelliset pallonkäsittelytaidot olivat kuitenkin heikommat kuin pojilla. Nopeinta taitojen kehittyminen oli molemmilla sukupuolilla kymmenen ikävuoden tietämillä. Lisäksi taitotestituloksissa havaittiin murrosiän huippukasvun tietämillä hieman parempaa kehitystä kuin esi- tai myöhäispuberteetin aikana. Tämä kehityspyrähdys oli todennäköisesti yhteydessä yleisten suorituskykyominaisuuksien kehittymiseen. Tulosten perusteella voidaan suositella, että taitotestejä tulisi käyttää esimurrosiässä kehityksen seuraamisen tärkeimpänä mittarina ja nousujohteisen taitoharjoittelun tulisi näissä ikäryhmissä olla erityisasemassa, erityisesti tytöillä.

Tulosten mukaan jalkapalloon liittyvät havaintomotoriset ominaisuudet kehittyivät iän mukana. Kahden vuoden seurantajakson aikana kehitys oli nopeinta vanhimmassa U15 ikäryhmässä. Tämän seurauksena tulokset antoivat viitteitä siitä, että jalkapallo-spesifit havainnointi- ja päätöksentekokyvyt olivat vanhimmassa U17 ikäryhmässä niin tärkeässä osassa, ettei heikkouksia näissä ominaisuuksissa pystytty enää kompensoimaan motorisilla kyvyillä mikä oli mahdollista vielä nuorimmissa ikäryhmissä. Jalkapallo-spesifejä havainnointi- ja päätöksentekotaitoja tulisikin tämän vuoksi korostaa jalkapalloharjoittelussa puberteetista lähtien. Systemaattisemman ja vaativamman harjoittelun aloittamista nimenomaan murrosiän seutuvilla voidaan perustella myös keskushermoston yleisellä kehittymisellä.

Tässä tutkimuksessa keskityttiin seuraamaan ominaisuuksia, jotka ovat tärkeitä yksilötason taustatekijöitä jalkapallossa. Tutkimuksessa ei analysoitu pelaajien toimintaa pelitilanteissa, minkä vuoksi voidaankin suositella, että seuraavat tutkimukset pyrkivät selvittämään kuinka peli- ja taktiset taidot kehittyvät Suomalaisessa jalkapallokulttuurissa ja kuinka nuoret suomalaispelaajat eroavat näissä ominaisuuksissa kansainvälisiin ikäverrokkeihin verrattuna.

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ORIGINAL PAPERS

I

DEVELOPMENT OF BODY COMPOSITION, HORMONE PROFILE, PHYSICAL FITNESS, GENERAL PERCEPTUAL MOTOR SKILLS, SOCCER SKILLS AND ON-THE-BALL PERFORMANCE IN SOCCER-SPECIFIC LABORATORY TEST AMONG ADOLESCENT SOCCER PLAYERS

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Research article

Development of body composition, hormone profile, physical fitness, general perceptual motor skills, soccer skills and on-the-ball performance in soccer-specific laboratory test among adolescent soccer players

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Abstract
The aim of the present study was to examine the development of on-the-ball skills in soccer-specific laboratory test and to examine how traditional measures of body composition, hormone profile, physical fitness, general perceptual motor skills and soccer skills were related to performance measured in open skill environment among 10, 12, and 14-year-old regional male soccer players (n = 12/group). The measured variables were height, weight, fat, muscle mass, testosterone, 10m sprint, agility, counter movement jump, peripheral awareness, Eye-Hand-Foot coordination, passing skill, dribbling skill and on-the-ball skills (performance time and passing accuracy) in soccer-specific laboratory test. A significant main effect by age was found in all measured variables except in fat, in peripheral awareness and in passing accuracy. In discriminant analysis 63.9% ($\lambda = 0.603$, $F = 4.600$, $p < 0.01$) of the players were classified correctly based on physical fitness and general perceptual motor skills into three ability groups originally classified with performance time in soccer-specific laboratory test. Correlation co-efficient analysis with-in age groups revealed that variables associated with performance time in soccer-specific laboratory test were peripheral awareness ($r = 0.72$, $p < 0.01$) in 10-year-olds; testosterone ($r = -0.70$, $p < 0.05$), dribbling skill ($r = 0.73$, $p < 0.01$) and passing skill ($r = 0.73$, $p < 0.01$) in 12-year-olds; agility ($r = 0.79$, $p < 0.01$), counter movement jump ($r = -0.62$, $p < 0.01$), dribbling skill ($r = 0.80$, $p < 0.01$) and passing skill ($r = 0.58$, $p < 0.05$) in 14-year olds. Corresponding relationships with passing accuracy were weight ($r = 0.59$, $p < 0.05$), fat ($r = 0.66$, $p < 0.05$), 10m sprint ($r = 0.71$, $p < 0.01$) and countermovement jump ($r = -0.64$, $p < 0.05$) in 10-year-olds; Eye-Hand-Foot coordination ($r = 0.63$, $p < 0.05$) in 14-year-olds. The relationship between soccer-specific anticipation time and performance time in soccer-specific laboratory test was significant only in the 14-year-old age group ($r = 0.76$, $p < 0.01$). To conclude, on-the-ball skill performance in soccer-specific laboratory test improved with age and it seemed that soccer-specific perceptual skills became more and general perceptual motor skills less important with age in soccer-specific laboratory test.

Key words: Football, youth, perception, growth, puberty.

Introduction

The most important variables for measuring performance in soccer are physical condition, technical skills and tactical performance (Rosch et al., 2000). General development of physical performance capacity during puberty is well documented in paediatric exercise literature. In research literature, adolescent growth spurt or, more precisely, peak height velocity is used as a milestone for timing the peak development of various physical performance abilities. In western societies, adolescent growth spurt in males occurs at approximately the age of 14. Studies of adolescent males in the general population suggest that speed tasks (e.g. running speed and agility) attain maximal gain before peak height velocity is reached, aerobic power at peak height velocity and power and strength afterwards (Beunen and Malina, 1988; Malina et al., 2004; Tanner et al., 1966). Similar findings, with only minor differences in timing of power and strength gains, have also been reported for both adolescent athletes and soccer players (Mero et al., 1989; Philippaerts et al., 2006).

Perceptual and decision-making factors are essential parts of motor performance in soccer and shouldn`t be ignored when players development is examined (Vaeyens et al., 2007; Ward and Williams, 2003). In general, the ability to process information becomes more efficient with increasing age (Kail, 1991). The actual visual system develops throughout childhood to reach the adult functional level at the age of 10-15 years (Crognale, 2002; Fukushima et al., 2000; Ishigaki and Miyao, 1994). At the same age, children are able to select the relevant information from various sources in the environment (Ross, 1976). On the other hand, expert-novice comparisons have indicated that perceptual motor skills are task-specific and the level of expertise attained by extensive task-specific practice is considered to be more important than the age itself in the development of task-specific skills. (Helsen and Starkes, 1999; Thomas, 1999). Research evidence about task-specificity is also available from youth soccer as Ward and Williams (2003) found elite soccer players to be better than sub-elite counterparts as early as age 9 in soccer-specific but not in general perceptual motor skills.

As a player's physical fitness capacity during puberty is mainly related to that player`s maturity, it has been suggested that the focus in youth soccer should be placed on ball-handling and game skills (Lindquist and Bangsbo, 1991). This suggestion receives support from skill research which has shown that the effect of age and maturation is less obvious in skill tests than in physical fitness tests (Eisenmann and Malina, 2003; Malina et al., 2005; Rosch et al., 2000; Vaeyens et al., 2006). Unfortunately, the measurements of skill development are also more problematic than those of physical fitness since performance in skill tests also depends on physical fitness abilities. Thus, it is difficult to separate the development of actual ball-handling skills from the development of physical performance. This is the case especially in many

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dribbling and passing tests which include a substantial proportion of running. Therefore, it is not surprising that the predictors of successful performance in various skill tests have been shown to depend on measured tasks (Malina et al., 2005).

Previous research has shown that physiological, technical and cognitive skills improve with age when these factors are measured with specific tests that do not include uncertainty. However, it is not clear how young soccer players open skills develop or how traditional tests are related to soccer-specific skills measured in open skill environment. The aim of the present study was to examine the development of on-the-ball skills in soccer-specific laboratory test and to examine how traditional measures of body composition, hormone profile, physical fitness, general perceptual motor skills and soccer skills were related to on-the-ball skills measured in soccer-specific laboratory test. Secondary purpose of the present study was to monitor young soccer players development in body composition, hormone profile, physical fitness, general perceptual motor skills and soccer skills during early puberty.

Methods

The participants of this study were 10-, 12- and 14-year-old male field soccer players (n = 12/group) representing a local club in a city of 160.000 inhabitants. The players' soccer abilities ranged from recreational to international level which means that the players in each age group were more heterogeneous in soccer abilities compared to youth teams in professional clubs. Participants' height was measured by wall-mounted stadiometer. Weight, body fat and muscle mass were analyzed with the body composition analyzer (Inbody 720, Biospace Co., Korea). Serum testosterone concentration was analyzed from venous blood samples (sensitivity 0.5 nmol/l) taken between 7.30 and 8.30 a.m. after 12 hours of fasting (Immulite 1000, DPC Diagnostics Corporation, USA).

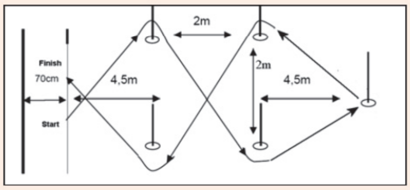

Figure 1. **Illustration showing agility test.**

Speed (10 m), agility (a figure 8 run) and explosive leg strength (counter movement jump = CMJ) were measured in order to examine players' physical fitness characteristics. A 10m all-out run from a stationary start and agility test were measured with photo cells (Newtest Oy, Finland). A test track recommended by the football association of Finland, in which the participant run forwards a 8-figure, was used as a agility test (Figure 1). Explosive leg strength was measured with CMJ on a jump mat (Newtest Oy, Finland). The best out of three trials was selected for further analysis in all physical fitness tests.

Participants' general perceptual motor skills were measured with peripheral awareness (PAT) and Eye-Hand-Foot coordination (EHF) tests (Coffey and Reichow, 1995; Erickson, 2007). PAT was measured using the Wayne Peripheral Awareness Trainer (Wayne engineering, USA) in which participants stood 60 cm away from the central cylinder, with eight peripheral lights mounted on 50 cm long rods in the cardinal and ordinal directions (Figure 2). Participants were asked to concentrate on the central light in the middle of the cylinder and, using a joystick, respond as quickly as possible to eight peripheral lights that were illuminated in random order. An average time of the eight directions was calculated, with the best out of three trials being selected. In the EHF test (Figure 2), the participants extinguished, in 30 seconds, and in a predetermined manner using their hands (29 lights) and feet (four lights), as many as possible of the randomly illuminated lights in the Wayne Saccadic Fixator (Wayne engineering, USA). Hand positions were pressed with the right or left index finger and foot positions by pressing pedals on the ground (North=forward, East=right, South=back, West=left). The number of extinguished lights was counted and the best out of three trials was selected.

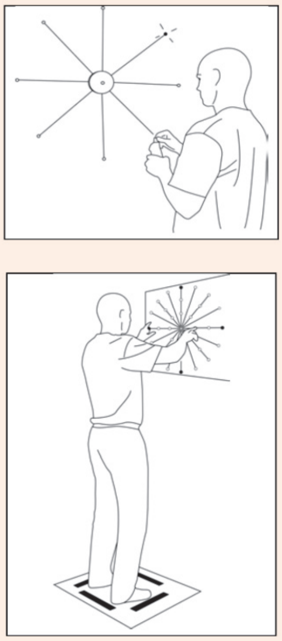

Figure 2. **Illustration (top) showing peripheral awareness (PAT) test. Illustration (bottom)showing Eye-Hand-Foot coordination (EHF) test.**

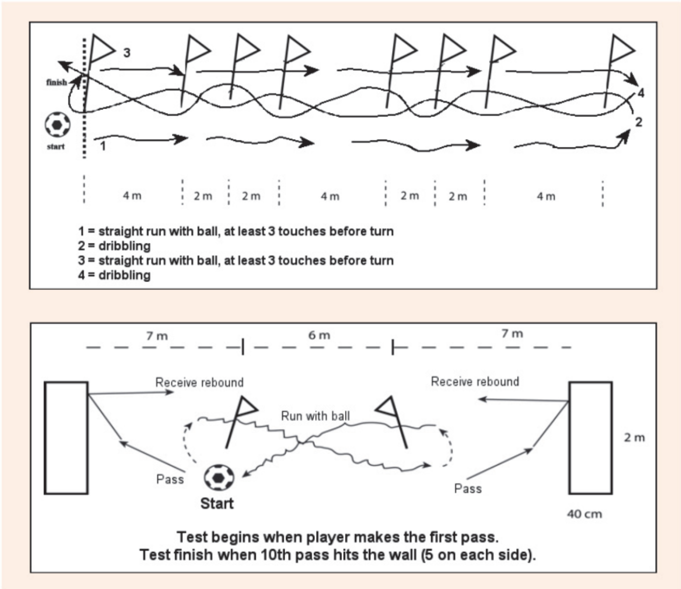

Figure 3. **Illustration (top) showing dribbling test. Illustration (bottom) showing passing test.**

Soccer skills were measured with the dribbling (Figure 3) and passing (Figure 3) tests used in the youth skill competitions in Finland. In traditional soccer skill tests, the participants were also instructed to perform three trials but at least one successful trial was required from each player. Trail was stopped immediately if the ball was lost. More than three trials was needed in 8 cases out of 72 (dribbling + passing) and every player succeeded in five trails. The results of the dribbling and passing test were also combined to variable ∑skill (=passing + dribbling) which was used in part of the statistical analysis and is shown in Table 1.

A laboratory test track (Figure 4) was constructed in order to measure soccer-specific perceptual motor skills in simulated `on-the-ball` performance. The test included a chain of typical soccer actions: anticipation, receiving, dribbling, feinting and passing. Firstly, the participant watched a near life-size video sequence (1) of a soccer player receiving the ball, running a short distance towards the participant, and passing to the right or left.

Table 1. **Mean (± SD) for anthropometrical, hormone profile, physical fitness, general perceptual motor skill, soccer skill and soccer-specific labora tory test variables.**

		10y	12y	14y
Anthropometrics	**Height (m)**	1.44 (.06)	1.57 (.11)	1.68 (.08)
	Weight (kg)	33.2 (4.0)	42.3 (8.4)	54.0 (7.8)
	Fat (%)	9.4 (3.5)	9.7 (3.8)	7.8 (3.5)
	Muscle Mass (kg)	15.9 (1.9)	20.8 (4.8)	28.0 (4.1)
Hormone Profile	**Testosterone (nmol/l)**	.15 (.52)	9.78 (7.05)	17.18 (5.72)
Physical Fitness	**10m (s)**	2.08 (.07)	2.02 (.05)	1.90 (.09)
	Agility (s)	7.57 (.22)	7.38 (.17)	7.17 (.16)
	CMJ (cm)	27.8 (4.2)	29.5 (3.4)	35.8 (4.2)
General Perceptual Motor Skills	**PAT (s)**	.36 (.07)	.33 (.06)	.32 (.07)
	EHF (times/30s)	28.8 (3.0)	34.2 (2.5)	36.5 ± 3.3
Soccer Skills	**Dribbling (s)**	29.4 (1.7)	29.0 (1.8)	26.5 (1.3)
	Passing (s)	42.2 (2.8)	39.4 (2.9)	36.6 (2.4)
	∑ Skill (s)	71.6 (4.1)	68.4 (4.5)	63.1 (3.5)
Soccer-Specific Laboratory Test	**Time (s)**	5.62 (.30)	5.54 (.30)	5.28 (.39)
	Anticipation (s)	.17 (.04)	.15 (.04)	.09 (.04)
	Dribbling (s)	2.84 (.25)	2.84 (.20)	2.66 (.19)
	Reaction (s)	.36 (.07)	.33 (.06)	.29 (.07)
	Aiming (s)	1.43 (.26)	1.53 (.16)	1.61 (.33)
	Passing (s)	.82 (.10)	.69 (.09)	.62 (.10)
	Accuracy (penalty pts.)	1.75 (.58)	1.47 (.32)	1.32 (.50)

CMJ = counter movement jump, PAT = peripheral awareness, EHF = Eye-Hand-Foot Coordination

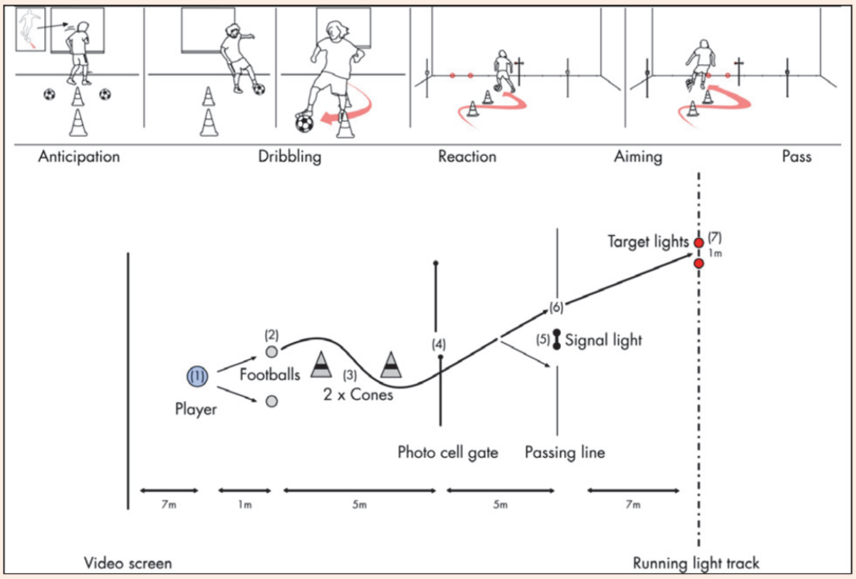

Figure 4. Illustration showing soccer-specific laboratory test.

The player correspondingly anticipated the pass and took the ball (2) located on his left or right hand side. Secondly, the participant dribbled the ball between two cones (3) and through the photocell-gate (4) which triggered a light (5) on the left or right hand side of a pole placed 5m in front of the photo-cell gate. The signal light determined which side of the pole the pass (6) should be given. Thirdly, the participant was instructed to direct a pass between two switched lights in a running light track (7) proceeding at the speed of 4.17 $m \cdot s^{-1}$. The participants were instructed to complete the entire performance as quickly and accurately as possible. In the soccer-specific laboratory test, the participants had 4 familiarization and 16 actual test trials (8 on each side in a random order) with a resting period of 45 seconds between each trial. The trials were recorded with three 50 Hz camcorders and analyzed with the APAS motion analysis software (Ariel Dynamics Inc., USA).

The analyzed variables were:

Anticipation time = the moment from the pass on the video sequence to the first movement towards the ball (video 1; Available from URL http:// http://www.jssm.org/ vol9/n4/video/1).

Dribbling time = time from the first ball touch to the moment of entering the photocell-gate (video 2; Available from URL http:// http://www.jssm.org/vol9/n4/video/2).

Reaction time = time from illumination of the direction stimulus (triggered by photocell-gate) to the moment when the gaze moved away from the stimulus light (video 3; Available from URL http:// http://www.jssm.org/vol9/n4/video/3).

Aiming time = the moment of removing the gaze from the stimulus light to the moment of passing impact (video 4)

Passing time = the moment from passing impact to the moment when the ball entered the running light track (video 4; Available from URL http:// http://www.jssm.org/ vol9/n4/video/4).

Passing accuracy = "penalty points" according to the distance between the ball and switched light-pair when the ball entered the line of the running light track (0 points = hit, 1 point = one light-pair in front or behind, 2 points = two light-pairs in front or behind , etc.; video 4; Available from URL http:// http://www.jssm.org/ vol9/n4/video/4).

The validity of the test track was examined by comparing adult players of the highest national level (n = 9, 19.7 ± 3.8y) to regional level players (n = 9, 18.8 ± 3.5y) and comparing adolescent players selected (n = 12; 12.5 ± 1.5y) for regional talent camp organized by the national football association with age-matched players not selected (n = 12, 12.6 ± 1.7y). Selection for talent camp was done by youth national team coaches. According to independent samples t-test elite adult players (4.10 ± 0.20s) performed significantly better than sub-elite players (4.73 ± 0.29s) in the soccer-specific laboratory test (t = 6.106, $p < 0.001$, 95%CI 0.41-0.86) and according to discriminant analysis 87.5% (λ = 0.503, χ^2 = 14.758, $p < 0.001$) of the adolescent players were classified correctly into the appropriate soccer expertise group based on performance time in the soccer-specific laboratory test. Reliability of the soccer-specific laboratory test was examined by analyzing twice the trials from 10 adolescent soccer players (12.6 ± 1.6y). The Pearson coefficient

Table 2. Effects of age for anthropometrical, hormone profile, physical fitness, general perceptual motor skill, soccer skill and soccer-specific laboratory test variables.

		Main Effect			Between age groups (p<)		
		$F_{(2,33)}$	p<	η^2	10y-12y	12y-14y	10y-14y
Anthropometrics	**Height (m)**	22.604	.001	.57	.01	.01	.001
	Weight (kg)	27.937	.001	.63	.01	.01	.001
	Fat (%)	1.203	ns.	.07	-	-	-
	Muscle Mass (kg)	30.866	.001	.65	.01	.001	.001
Hormone Profile	**Testosterone (nmol/l)**	31.778	.001	.66	.001	.01	.001
Physical Fitness	**10m (s)**	21.639	.001	.57	ns.	.001	.001
	Agility (s)	14.023	.001	.46	.05	.05	.001
	CMJ (cm)	13.903	.001	.46	ns.	.01	.001
General Perceptual Motor Skills	**PAT (s)**	1.555	ns.	.09	-	-	-
	EHF (times/30s)	21.371	.001	.56	.001	ns.	.001
Soccer Skills	**Dribbling (s)**	12.102	.001	.42	ns.	.01	.001
	Passing (s)	12.623	.001	.43	.05	.05	.001
	∑ Skill (s)	13.407	.001	.45	ns.	.01	.001
Soccer-Specific Laboratory Test	**Time (s)**	3.378	.05	.17	ns.	ns.	.05
	Anticipation (s)	15.012	.001	.48	ns.	.01	.001
	Dribbling (s)	1.087	ns.	.06	-	-	-
	Reaction (s)	2.895	ns.	.15	-	-	-
	Aiming (s)	1.581	ns.	.09	-	-	-
	Passing (s)	11.402	.001	.41	.05	ns.	.001
	Accuracy (penalty pts.)	2.504	ns.	.15	-	-	-

CMJ = counter movement jump, PAT = peripheral awareness, EHF = Eye-Hand-Foot Coordination

correlation for intra-observer (5.48 ± 0.62s vs. 5.49 ± 0.62s), inter-observer (5.48 ± 0.62s vs. 5.46 ± 0.60s) and test-retest (5.48 ± 0.60s vs. 5.42 ± 0.52s) reliability for the performance time in the soccer-specific laboratory test were 0.93 ($p < 0.001$), 0.86 ($p < 0.001$) and 0.81 ($p < 0.01$), respectively.

Tests were carried out in three separate days during preparation season. First testing day included anthropometrical, hormone profile and physical fitness tests. Second testing day included traditional soccer skill tests and third day general perceptual motor skill tests and soccer-specific laboratory test. Testing days were scheduled to teams training program so that no training took place in the day preceding the tests.

One-way ANOVA with Tukey's post hoc test was applied to detect differences between the age groups. Effect sizes determined with eta-squared (η^2) are reported for interpretative purposes with 0.01 regarded as a small effect, 0.06 a moderate effect and 0.14 a large effect. A stepwise discriminatory analysis (with probability of F: entry = 0.05, remove = 0.10) was applied to determine if combined variables could predict group membership of performance time or passing accuracy in the soccer-specific laboratory test when all players were treated as one group. A grouping variable for discriminant analysis was constructed by categorizing the players in each age group into three groups based on their performance time or passing accuracy in the soccer-specific laboratory test: good (best 25%, n = 9), average (50%, n = 18) and poor (last 25%, n = 9). Combined variables were used as independent variables. These variables were constructed by ranking players in each age group in each of the measured variables (from 1 = best result to 12 = worst result) and combining variables by averaging ranked values to describe muscle-hormone profile (muscle mass, testosterone), physical fitness (10m, agility, counter movement jump), general perceptual motor skills (peripheral awareness, Eye-Hand-Foot coordination) and soccer skills (dribbling, passing). With-in each age group Pearson's correlation coefficient was applied to examine the relationships between single variables and performance time in the soccer-specific laboratory test and between single variables and passing accuracy in the soccer-specific laboratory test. In addition, a linear regression was applied to examine the relationship between anticipation time and performance time in the soccer-specific laboratory test in order to estimate the role of soccer-specific perceptual skills in different age groups.

Approval from the ethical committee of the University of Jyvaskyla and written permission from parents were received before under-age participants were allowed to participate in the tests.

Results

Results of the measured variables are presented in Table 1. A significant main effect by age was found in other measured variables except in percentage of body fat and in peripheral awareness (Table 2). More detailed analysis between consecutive age groups revealed that all other measured anthropometrical, hormone profile, physical fitness, general perceptual motor skill and soccer skill variables improved with age but the differences in 10m, CMJ and dribbling skill in the 10 to 12-year age group, and in EHF in the 12 to 14-year age group failed to attain statistical significance (Table 2).

In the soccer-specific laboratory test, a significant main effect by age was found in performance time, anticipation time and passing time (Table 2). In reaction time, the differences just failed to attain a level of significance ($p = 0.069$). More detailed analysis between age groups revealed that in performance time ($p < 0.05$) and in passing time ($p < 0.001$), the 14-year age group was faster than the 10-year age group and, in anticipation time, was faster than the 10-year age group ($p < 0.001$) and the 12-year age group ($p < 0.01$). Only significant

Table 3. Correlation coefficients between soccer-specific tests variables (time and accuracy) and anthropometrical, hormone profile, physical fitness, general perceptual motor skill and soccer skill variables in different age groups.

		Performance time			Passing accuracy		
		10y	12y	14y	10y	12y	14y
Anthropometrics	**Height**	-.53	-.36	.10	.30	.06	.38
	Weight	-.31	-.24	.18	.59*	-.10	-.28
	Fat	.21	.02	-.02	.66*	-.47	-.24
	Muscle Mass	-.41	-.25	.17	.39	-.00	-.18
Hormone Profile	**Testosterone**	-.22	-.70 *	-.10	.07	-.17	-.11
Physical Fitness	**10m**	.57	-.05	.52	.71 **	-.26	.07
	Agility	.34	.03	.79 **	.35	-.02	-.21
	CMJ	-.35	.21	-.62 *	-.64 *	-.21	.03
General Perceptual Motor Skills	**PAT**	.72 **	.48	.33	-.13	.25	.08
	EHF	.17	-.35	-.44	-.43	-.10	.63 *
Soccer Skills	**Dribbling**	.13	.73 **	.80 **	-.01	-.27	-.26
	Passing	-.04	.73 **	.58 *	-.06	-.21	-.24
	∑ Skill	.02	.75 **	.70 *	-.04	-.24	-.26

CMJ = counter movement jump, PAT = peripheral awareness, EHF = Eye-Hand-Foot Coordination, * $p < 0.05$, ** $p < 0.01$.

difference between 10 and 12-year groups was found in passing time ($p < 0.05$). An example of 10-year-old and 14-year-old players' performance in the soccer-specific laboratory test is presented in video 5, in which overlay video technique is used to demonstrate typical differences between these two age groups (Video 5; Available from URL http://http://www.jssm.org/vol9/n4/video/5). In overlay video, players' performances were time synchronized to the moment when the passing impact on the video screen coincided with the original videos.

Based on discriminant analysis 63.9% ($\lambda = 0.603$, $F = 4.600$, $p < 0.01$) of the players were classified correctly based on physical fitness and general perceptual motor skills into three ability groups originally classified with performance time in the soccer-specific laboratory test. Combined variables were not able to classify group membership of passing accuracy. With-in each age group the relationships between single variables and performance time in the soccer-specific laboratory test as well as the relationships between single variables and passing accuracy in the soccer-specific laboratory test are presented in Table 3. The relationship between anticipation time and performance time was significant only in the oldest, 14-year age group ($r = 0.764$, $p < 0.01$) as presented in Figure 5.

Discussion

Hormonal changes during growth, especially increased testosterone secretion at the age of around 12 years (Winter, 1978), leads to peak height and weight velocity in boys at the age of around 14 years (Tanner et al., 1966). Increased testosterone secretion also promotes nerve conduction velocity by neural growth and myelination (Tan, 1996). As adult-like vision and the brain structure also develop well through adolescence (Crognale, 2002; Fukushima et al., 2000; Ishigaki and Miyao, 1994; McGivern et al., 2002), it is clear that every part of the simplified information-processing chain (stimulus detection - information processing - motor response; Schmidt and Lee, 2005) undergoes marked changes during growth. Changes in body composition and hormone profile among regional soccer players in the present study followed a well-known pattern. Serum testosterone concentration increased from practically zero to approximately 75 % of that found in adults and the muscle mass was almost doubled between 10 and 14 years. At the same time, physical fitness, general perceptual motor skills and soccer skills improved but differences were observed concerning the timing and magnitude of this improvement in different measured variables.

A significant difference between 12 and 14 year groups was found in all measured physical fitness variables (speed, agility and explosive leg strength) but only in the agility between 10 and 12 year groups. Acceleration in the development of speed and explosive leg strength between 12 to 14 years was likely to be related to changes in body composition, especially growth of the muscle mass, which increased almost 35% from 12 to 14 years. More constant development pattern in agility can be explained with coordination skills which were required more in the agility test than in the speed or in the explosive leg strength test. If nothing else, a significant difference found in agility between younger age groups was in line with the results of Eye-Hand-Foot coordination test in which a significant difference was found only between younger age groups. Nevertheless, results of the physical fitness tests suggested that the improvement was faster between 12 and 14 years compared to 10 to 12 years which are in agreement with the previous research data suggesting an adolescent acceleration after 13 years of age in physical fitness (Malina et al., 2004).

Contrary to the tendency found in physical fitness, the results in the 12 and 14 year groups were close to each other and better than the 10 year group in general perceptual motor skills. Development of general perceptual motor skills was likely related to the development of the nervous system which is known to attain more than 95% of its total size before 12 years of age (Malina et al., 2004). It was also worth noting that no significant differences between age groups were found in peripheral awareness requiring mostly stimulus detection, but the difference existed in the more demanding Eye-Hand-Foot coordination task in which information processing and motor responses were pressured. This indicated that the two older groups were more efficient than the 10-year group in processing information (brains) and/or producing faster motor responses (nervous system + muscles).

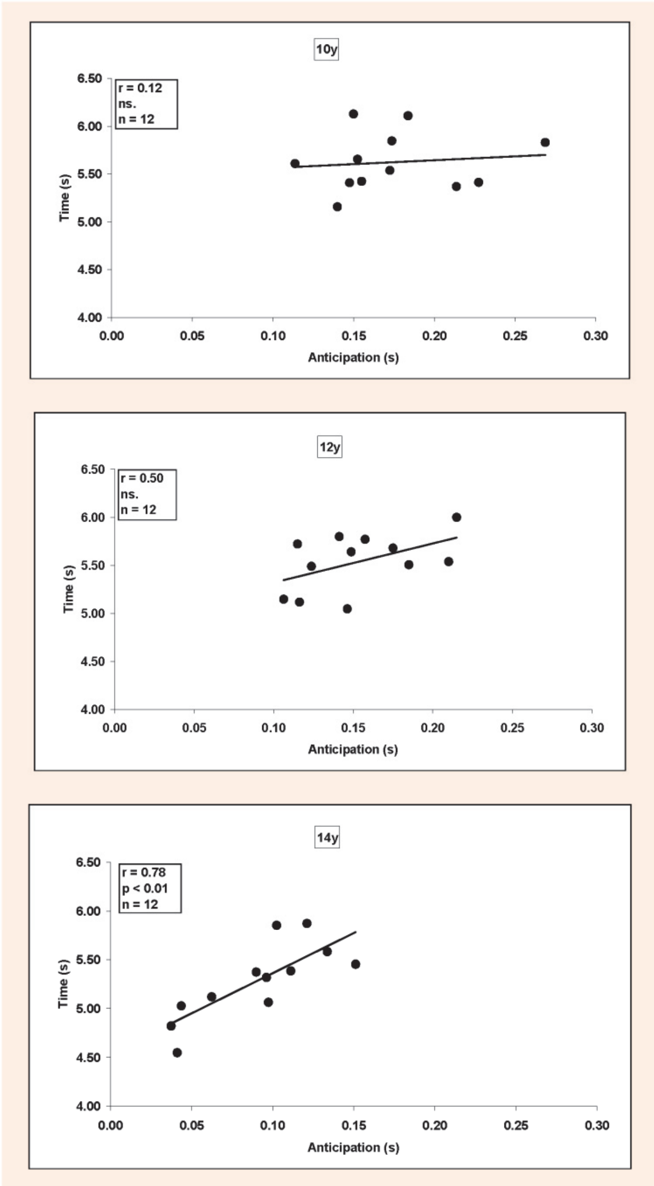

Figure 5. Relationship between soccer-specific perceptual skill (anticipation time) and performance time in soccer-specific laboratory test in different age groups.

Performance in soccer skill tests is influenced by many physiological, biomechanical and psychological factors as well as chronological age, playing experience, maturity status and tests used (Malina et al., 2005; Rosch et al., 2000). Because both traditional soccer skill tests used in the present study involved at least a moderate amount of running, it is likely that a substantial proportion of improvement was growth related development in physical fitness rather than improvement in ball-handling skills. However, individual differences in ball-handling skills were also observed. The most skilful player in the 10-year and 12-year group was also among the top three performers in the upper age group. This indicated that these players possessed more than a two-year advance in actual ball-handling skills since a similar advance was not present in the physical fitness capacity. In the process of identifying talent, the importance of measuring basic ball-handling skills at early puberty needs to be emphasized, because previous research has shown that time spent in individual practice reaches its maximum approximately at the age of 12 years (Ward et al., 2007). After that, training will be orientated more on game skills and the tactical aspects of the game, which means that the basic ball-handling skills required in elite-level soccer will be difficult to attain.

In the soccer-specific laboratory test, a significant difference between age groups was found in total performance time, in anticipation time and in passing time. Anticipation time to soccer-specific stimuli was almost twice as long in the 10-year age group as it was in the 14-year age group. Similar improvement during growth in the ability to anticipate intentions based on postural cues, have also been reported in racket sports (Abernethy, 1988; Tenenbaum et al., 2000). Reaction time to stimuli evoked during dribbling was approximately the same as that found in the general peripheral awareness test, which suggests that simultaneous ball-handling did not weaken the ability of the 10 to 14-year-old soccer players to perceive information from the environment. Aiming time was the only phase in the soccer test in which the performance time increased with age which was probably one reason why passing accuracy also improved slightly, although not significantly, with age. Thus it seemed that older players were able to make a better strategic decision in balancing their performance between speed and accuracy, which is consistent with previous findings suggesting that experienced athletes are better in monitoring performance and using regulatory strategies than novices (McPherson and Vickers, 2004). Passing time decreased with age, i.e. older players gave faster passes than younger ones. However, the difference in passing time between 12 and 14 year group was not significant which was contrary to be expected based on results in physical fitness and traditional soccer skill tests. It might be that the 14 year players used better regulatory strategy also in this phase of the soccer-specific laboratory test and deliberately reduced passing speed in order to achieve better outcome.

Passing into a constant speed target like in the soccer-specific laboratory test used in the present study is something that is not actually done very much in real soccer which was likely one reason why differences between age groups in passing accuracy were not significant. In real game successful passing event requires co-operation between two players - one giving the pass and one receiving the ball. This means that the player receiving the ball can also adjust his/her speed with the game flow and the player who is passing must predict teammates` speed with relation to game flow. However, even though current soccer-specific laboratory test failed to demonstrate differences between age groups, it is obvious that passing the ball to moving player is important skill in soccer and should be considered when skill tests are developed.

When all players were treated as one group, it was found that physical fitness and general perceptual motor skills were the best variables to predict performance time in the soccer-specific laboratory test. Physical fitness characteristics is widely acknowledged to be important factor in soccer (Reilly et al., 2000; Rosch et al., 2000) but divergent conclusions about the role of general perceptual motor skills are found in the research literature. According to cognitive sport psychology research, the motor abilities are task-specific and therefore experts do not possess superior general perceptual motor skills (Ericsson and Lehmann, 1996; Helsen and Starkes, 1999; Henry, 1958; Starkes and Deakin, 1984; Ward and Williams, 2003) but sport optometric research suggests otherwise (Loran and Griffiths, 1998; Sillero Quintana et al., 2007; Stephenson, 2007; Stine et al., 1982; West and Bressan, 1996). The results of the present study suggested that deficits in general motor abilities may partly explain why certain players do not progress as fast as others in regional-level soccer team but the rationality to test these skills on full-scale is doubtful because their importance seemed to diminish with age as will be discussed later.

Correlation coefficient analysis with-in age groups revealed that in the 10 year group the peripheral awareness was only variable to be associated with performance time in the soccer-specific laboratory test. This suggest that the development of basic information processing still underpins the effects of soccer-specific training, especially, if the players training background is rather similar. Passing accuracy in the 10 year group was found to be associated with tasks requiring speed, i.e. 10m sprint and counter movement jump. As younger players strategy tended to be more into "full speed than correct timing", it might be that only the quickest players were able to create enough time for themselves to attain balanced passing posture which then led to better passing accuracy. In the 12 year group, the players who were skilful and demonstrated more matured hormone profile performed better in the soccer-specific laboratory test. Similar results have been found in previous research which has shown that parameters associated with physical maturity are also associated with players` performance profile (Gil et al., 2007). In the 14 year group, physical fitness tests and traditional soccer skill tests were associated with performance time in the soccer-specific laboratory test which suggests that the 14 year players were able to transfer their existing potentiality into real-like action performed in open skill environment.

The results of the present study also suggested that soccer-specific perceptual skills became more important with age and general perceptual motor skills less so. In the 10-year-old group, general peripheral awareness explained 50 %, but soccer-specific anticipation time only 1 %, of the variance in performance time in the soccer-specific laboratory test. By the age of 14 years, these relationships had reversed. Soccer-specific anticipation time explained 61 %, and general peripheral awareness only 11%, of the variance in corresponding performance time. In practice, this means that the 10-year-old players were able to compensate weaker game-reading skills with better motor skills, but this was no longer the case with the 14-year-old age group. In addition, in the 14 year group better Eye-Hand-Foot coordination was actually associated with worse passing accuracy. These results confirms earlier suggestion that specific types of activities in sport training lead to the acquisition and development of sport-specific perceptual motor skills which are not directly related to general perceptual motor skills (Ward et al., 2007; Ward and Williams, 2003).

Conclusion

To conclude, a well-known, age-dependent development pattern in physical fitness and in soccer skills among adolescent soccer players was found in the present study. Although general and soccer-specific perceptual motor skills also developed with age, it seemed that soccer-specific perceptual skills became more important with age and general perceptual motor skills less important. Nevertheless, more research is warranted in order to understand the development of general and soccer-specific perceptual motor skills during growth. In addition, research lay-out in the soccer-specific laboratory test used in the present study was very simple compared to those situations that players have to face in the real game. Soccer-specific laboratory test involved some uncertainty compared to traditional soccer skill tests but was still a test from pre-determined start to pre-determined finish. In real game each player possess unique starting situation which is then followed by decisions and motor actions affected by the actions of teammates and opponents. Decisions and actions in the game are also influenced by the team`s playing style and tactics selected. Therefore, more research is also needed in order to develop tests that measures essential soccer skills in more game-like simulation or even in the game itself.

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Key points

- Physical fitness characteristics and general perceptual motor skills predicted performance time of the open skill soccer-specific laboratory test in the group of 10-14 year-old regional soccer players.
- Before puberty the players were able to compensate weaker soccer-specific skills with better general physical performance abilities.
- Soccer-specific skills became more important with age and at the age of 14 the players were not able to compensate soccer-specific skills with general physical performance abilities.
- Beside basic ball-handling skills it also important to recognize the importance of soccer-specific perceptual skills (anticipation and reaction) as a part of successful soccer performance.

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II

EFFECTS OF AGE AND THE LEVEL OF SOCCER EXPERTISE ON GENERAL PERCEPTUAL MOTOR SKILLS AMONG ADOLESCENT SOCCER PLAYERS

by

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EFFECTS OF AGE AND SOCCER EXPERTISE ON GENERAL TESTS OF PERCEPTUAL AND MOTOR PERFORMANCE AMONG ADOLESCENT SOCCER PLAYERS[1]

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Summary.—This study of perceptual and motor skills in soccer players was conducted on adolescent males. The goals were to monitor the development of general perceptual motor skills in nonsoccer-playing and soccer-playing groups ($n=245$), to examine the relationship between physical maturity and general perceptual motor skills ($n=41$), and to compare the differences in general perceptual motor skills between groups with different soccer expertise ($n=142$). The measured variables were simple reaction time, peripheral awareness, eye–hand–foot coordination, and testosterone blood level. The results suggested that general perceptual motor skills improved with age, the development of these skills was related to participants' blood testosterone concentration (especially between 12 and 14 years), and general perceptual motor skills improved with soccer expertise. However, the differences between subelite and elite soccer players were not meaningful enough to encourage practitioners to test general perceptual motor skills on a large scale when evaluating the potential of young players.

Soccer performance has many requirements, which means that the talent identification process requires a multidisciplinary approach (Reilly, Williams, Nevill, & Franks, 2000). According to Rosch, Hodgson, Peterson, Graf-Baumann, Junge, Chomiak, *et al.* (2000), the most important variables to measure when evaluating the potential of young soccer players are physical condition, technical skills, and tactical performance. On the other hand, in such open skill sports, the players must respond to sensory stimuli around them before physical action or technical skill can be executed (Sheppard & Young, 2006). Therefore, several authors have highlighted the importance of perceptual and decision-making factors in ball games (Young, James, & Montgomery, 2002; Ward & Williams, 2003; Vaeyens, Lenoir, Williams, Mazyn, & Philippaerts, 2007).

A common argument is that athletes need better visual functions to fulfill the demands of their sport (Gardner & Sherman, 1995). As early as the 1920s, Abel (1924) and Fullerton (1925) studied Babe Ruth, the famous baseball player, and concluded that one reason for his exception-

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al hitting ability was his superior vision. These were probably the first modern sport studies to demonstrate that top athletes performed better than ordinary people on general reaction time tasks. Since then it has been believed that general reaction-time tests can offer valuable information about an athlete's ability to succeed in sport. For example, after reviewing several studies, Stine, Arterburn, and Stern (1982) concluded that athletic groups possess abilities that are superior to those of nonathletic groups. A number of later studies have found better distance visual acuity, stereoscopic vision, horizontal visual fields, higher incidence of central dominance, visual reaction time, eye–hand reaction time, and eye–foot reaction time in athletes (Christenson & Winkelstein, 1988; Sillero Quintana, Refoyo Roman, Lorenzo Calvo, & Sampedro Molinuevo, 2007; Stephenson, 2007). Studies examining soccer players have also suggested that they have better reaction time, eye–hand reaction time, and eye–foot reaction time than the general population (Montes-Mico, Bueno, Candel, & Pons, 2000; Ando, Kida, & Oda, 2001; Luhtanen, Blomqvist, & Vänttinen, 2005). Loran and Griffiths (1998) found that visual skills might be even more important than is generally recognized, noting that there was a connection between visual performance and playing skill in a group of 14-year-old soccer players. In addition, Sherman (1980) concluded that visual abilities can be trained and enhanced by optometric visual training. Therefore, it may be the case that individuals with high visual abilities engage in sports or sports activities that help develop these capacities.

Although visual-perceptual abilities are necessary to sporting performance, cognitive factors are also essential for expertise in sports (Garland & Barry, 1990). The consensus among cognitive sports psychology researchers is that motor abilities are task specific and that experts do not necessarily possess superior general perceptual and motor skills (Henry, 1958; Starkes & Deakin, 1984; Ericsson & Lehmann, 1996; Ward & Williams, 2003). Accordingly, differences between elite and nonelite athletes could not be expected to occur in general measures of motor ability, such as reaction time (Schmidt & Lee, 2005). According to Ward and Williams (2003), this is also true for adolescent soccer players; their tests of visual function did not discriminate between players in various skill groups at any age. Researchers in cognitive sports psychology have concluded that athletes do not possess better vision, nor can visual abilities be trained and enhanced by optometric visual training (Wood & Abernethy, 1997; Williams, Davids, & Williams, 1999; Abernethy & Wood, 2001).

As noted, the previous studies—especially those conducted with younger soccer players—have reached varied conclusions about the meaningfulness of measuring general perceptual and motor skills when evaluating players' potential. The aims of the present study were: (1) to monitor the development of general perceptual motor skills in both non-soccer-playing and soccer-playing groups during adolescence, (2) to examine how hormonal status ("maturity") is related to general perceptual and motor skills, and (3) to monitor the differences in general perceptual and motor skills between groups with different soccer expertise.

Method

The present study consists of three research designs. Written permission from parents and approval from the University of Jyväskylä ethics committee were required before the youth were allowed to participate. Three general perceptual or motor skills were measured in each of the research designs (see Coffey & Reichow, 1995; Erickson, 2007): simple reaction time, peripheral awareness, and eye–hand–foot coordination. Participants all had normal visual acuity (no eyeglasses) and performed an unlimited number of familiarization trials until stabilized performance was achieved. This was followed by a short break and recording of the actual test trials.

Simple reaction time test.—Simple reaction time measures the time required to perceive and respond to visual stimulation (Planer, 1994). Participants were instructed to extinguish a signal light switched into the same position on the Wayne Saccadic Fixator board (Wayne Engineering, USA) as quickly as possible with the index finger of their dominant hand (Fig. 1). Reaction time was measured as the time between the onset of stimulus to the completion of the participant's response. A total of five trials was recorded and the average of three responses, excluding the best and the worst, was calculated as a final score.

Peripheral awareness.—Peripheral awareness is an athlete's ability to pay attention to what is in front of him (central), yet to also be aware of and use information from peripheral vision, without having to move his eyes from the central object (Planer, 1994). The present study measured peripheral awareness using the Wayne Peripheral Awareness Trainer, in which participants stood 60 cm away from the central cylinder, with eight peripheral lights mounted on 50-cm long rods in the cardinal and ordinal directions (Fig. 1). Participants were asked to concentrate on the central light in the middle of the cylinder and respond, using a joystick, as quickly as possible to eight peripheral lights that were illuminated in random order. An average time for the eight directions was calculated, with the best out of three trials being selected.

Eye–hand–foot coordination.—Eye–hand–foot coordination is the ability to integrate the use of eyes, hands, and feet. The eyes lead and guide the motor system (Planer, 1994). Participants extinguished as many randomly illuminated lights in the Wayne Saccadic Fixator board as possi-

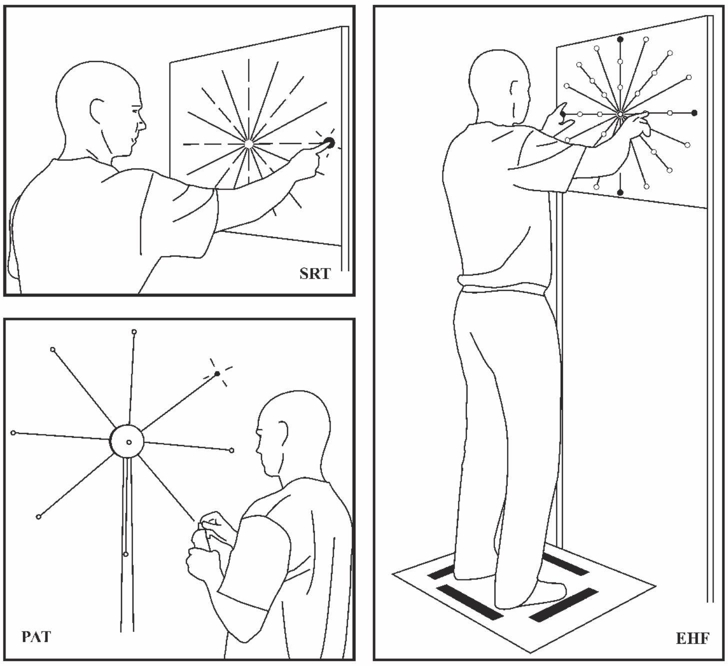

FIG. 1. Schematic presentations of simple reaction time (SRT), peripheral awareness (PAT), and eye–hand–foot coordination tests (EHF)

ble in 30 sec. in a predetermined manner using their hands (29 lights) and feet (four lights), as seen in Fig. 1. The open dots illustrate hand positions to be pressed with the right or left index finger when the red light appeared in these positions. Black dots illustrate foot positions that were to be responded to with pedals on the ground (North = forward, East = right, South = back, West = left) when a red light appeared in these positions. The number of extinguished lights was counted and the best out of three trials was selected.

Research Designs

The first research layout measured the simple reaction time, peripheral awareness, and eye–hand–foot coordination of 245 participants. Half of the participants were subelite soccer players ($n = 123$) and the other half were age-matched children ($n = 122$) who did not play soccer. All participants were males from a city of 160,000 inhabitants and the soccer players were recruited from a local club team. General results were analysed using a 4 × 2 (age × group) analysis of variance (ANOVA) and Tukey's *post hoc* test was applied to examine the differences between the age groups. An independent samples t test was applied to examine the differences between the soccer players and the nonsoccer playing age mates in each age group.

In addition to the cross-sectional approach, players from regional soccer teams in the 10-, 12-, and 14-year-old age groups ($n=41$) were followed for two years. The purpose of the second research layout was to deepen the cross-sectional analysis with a hormonal analysis to reflect the players' maturity status. The players were measured using three previously explained general perceptual and motor skill tests and blood testosterone concentration was analysed (Immulite 1000, DPC Diagnostics Corporation, USA; analysis sensitivity 0.5 nmol/l) from venous blood samples taken between 7:30 a.m. and 8:30 a.m. after 12 hr. of fasting. The same measurements were repeated two years later for the same subjects. A paired samples *t* test was applied to examine the development of general perceptual and motor skills within the groups. Linear regression analysis and Pearson correlation were also applied to examine the relationship between general perceptual and motor skills and blood testosterone concentration.

The purpose of the third research layout was to monitor the differences in general perceptual motor skills in groups with different soccer expertise. The participants ($n=142$) were youths who were not engaged in soccer, subelite players (regional team), and elite players (national team candidates) at the age of 16 years, which is the first age group for which a national team is formed. In addition, young adult elite soccer players (U-19 national team; $n=16$) were compared to adolescent elite players (U-16 team candidates; $n=40$) to examine whether further differences in terms of general perceptual and motor skills could be observed with age among the most skilled soccer players. A one-way ANOVA and Tukey's *post hoc* test were applied to examine the statistical differences between the 16-year-old groups. An independent samples *t* test was applied to examine the differences between young adults and adolescent elite players (U-16 vs U-19).

Results

Study 1

In the first research design, statistically significant main effects were observed for age (Simple reaction time: $F_{3237}=8.69$, $p<.001$, $\eta^2=0.07$; Peripheral awareness: $F_{3237}=15.66$, $p<.001$, $\eta^2=0.15$; Eye–hand–foot coordination: $F_{3237}=59.45$, $p<.001$, $\eta^2=0.40$) and for group (Simple reaction time: $F_{1237}=5.90$, $p<.05$, $\eta^2=0.13$; Peripheral awareness: $F_{1237}=6.15$, $p<.05$, $\eta^2=0.18$; Eye–hand–foot coordination: $F_{1237}=10.34$, $p<.01$, $\eta^2=0.45$), but not for the age × group interaction in any of the three tests.

The results for simple reaction time, peripheral awareness, and eye–

TABLE 1

MEANS AND STANDARD DEVIATIONS OF SIMPLE REACTION TIME (SRT), PERIPHERAL AWARENESS (PAT), AND EYE–HAND–FOOT (EHF) COORDINATION TESTS FOR DIFFERENT AGE GROUPS AND EXPERTISE LEVELS, WITH COMPARISON STATISTICS

Test and Group	10-yr.-old		12-yr.-old		14-yr.-old		16-yr.-old	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Simple reaction time (msec.)	244	27	228	26	230	28	219	24
Nonsoccer players	242	21	236	30	236	24	226	23
Subelite	247	32	225	24	225	30	205	21
Expertise comparison	$t_{27}=0.489$ $p=.629$ $d=.18$		$t_{40}=1.255$ $p=.217$ $d=.41$		$t_{105}=1.917$ $p=.058$ $d=.37$		$t_{65}=3.668$ $p<.001$ $d=.95$	
Peripheral awareness (msec.)	363	53	324	60	324	54	282	54
Nonsoccer players	367	59	342	49	336	60	290	60
Subelite	356	50	314	73	314	59	267	37
Expertise comparison	$t_{27}=0.689$ $p=.497$ $d=.25$		$t_{40}=1.272$ $p=.211$ $d=.41$		$t_{105}=1.818$ $p=.072$ $d=.35$		$t_{65}=1.981$ $p=.052$ $d=.44$	
Eye–hand–foot coordination (*n*/30 sec.)	28.5	2.7	34.2	3.3	35.9	4.0	39.2	4.5
Nonsoccer players	27.9	2.7	33.7	2.7	34.5	4.3	38.2	4.9
Subelite	29.0	2.9	34.2	3.3	37.0	3.3	41.0	3.0
Expertise comparison	$t_{27}=1.142$ $p=.263$ $d=.42$		$t_{40}=0.712$ $p=.481$ $d=.23$		$t_{105}=3.435$ $p=.001$ $d=.67$		$t_{65}=2.852$ $p=.006$ $d=.63$	

Age Comparisons

10- vs 12-yr.-old			10- vs 14-yr.-old			10- vs 16-yr.-old			12- vs 14-yr.-old			14- vs 16-yr.-old		
SRT	PAT	EHF	SRT	PAT	EHF	SRT	PAT	EHF	SRT	PAT	EHF	SRT	PAT	EHF
$p=.056$	$p=.032$	$p<.001$	$p=.054$	$p=.011$	$p<.001$	$p<.001$	$p<.001$	$p<.001$	$p=.972$	$p=.999$	$p=.066$	$p=.033$	$p<.001$	$p<.001$

hand–foot coordination are presented in Table 1. In terms of simple reaction time, a significant difference between consecutive age groups was found between the 14- and 16-year-old age groups. The difference between 10- and 12-year-old groups was not statistically significant. Although the simple reaction time of the soccer players was slightly faster than their nonsoccer-playing age mates in every age group except the 10-year-old group, the difference was significant only in the 16-year-old group. In terms of peripheral awareness, a significant difference was found between 10- and 12-year-old groups and between 14- and 16-year-old groups. Even though the soccer players' mean reaction time to peripheral stimuli was shorter than that of the nonsoccer-playing age mates in all age groups, the difference was not statistically significant in any age group. In terms of eye–hand–foot coordination, a significant difference was found between 10- and 12-year-old groups and between 14- and 16-year-old groups. The difference between the 12- and 14-year-old groups was not statistically significant. The soccer players performed better in the eye–hand–foot coordination tests than the controls in every age group but a significant difference was found only in the 14- and 16-year-old groups.

Study 2

An overview of the individual results and the general development path from the second research design is presented in Fig. 2. During a two-year follow-up, simple reaction time (t_{14} = 2.284, p = .038; d = 0.59) and eye–hand–foot coordination (t_{14} = 6.873 , $p = 7.6 \times 10^{-6}$; d = 1.77) improved significantly from 10 to 12 years of age. The improvements from 12 to 14 years of age and from 14 to 16 years of age were significant in terms of peripheral awareness (t_{13} = 4.590, p = .001; d = 1.23; t_{11} = 5.050, $p = 3.7 \times 10^{-4}$; d = 1.46) and for eye–hand–foot coordination (t_{13} = 11.865, $p = 2.4 \times 10^{-8}$; d = 3.17; t_{11} = 5.000, $p = 4.0 \times 10^{-4}$; d = 1.44). The blood testosterone concentration rose from 0.6 (SD = 1.1) to 6.2 (SD = 8.2 nmol/l; t_{14} = 2.792, p = .015; d = 0.75) in the initially 10-year-old group; from 9.3 (SD = 7.1) to 16.8 (SD = 6.8 nmol/l; t_{13} = 5.329, $p = 1.3 \times 10^{-4}$; d = 1.42) in the initially 12-year-old group and from 18.1 (SD = 5.4) to 22.5 (SD = 4.4 nmol/l; t_{11} = 3.052, p = .011; d = 0.88) in the initially 14-year-old group over the two-year period. When the players were treated as a single group, regardless of age, a significant relationship was found between blood testosterone concentration and every general perceptual and motor skill test:

Simple reaction time = 243.61 – 1.79 × testosterone (R = .58, F = 40.38, p < .001);

Peripheral awareness = 344.59 – 2.94 × testosterone (R = .33, F = 9.50, p < .01);

Eye–hand–foot coordination = 31.46 + 0.37 × testosterone (R = .66, F = 62.14, p < .001).

Within age groups, the relationship between blood testosterone concentration and simple reaction time was significant in the 12-year-old (r = –.68, $p = 4.3 \times 10^{-5}$; 95%CI = –.42, –.84) and in the 14-year-old (r = –.49,

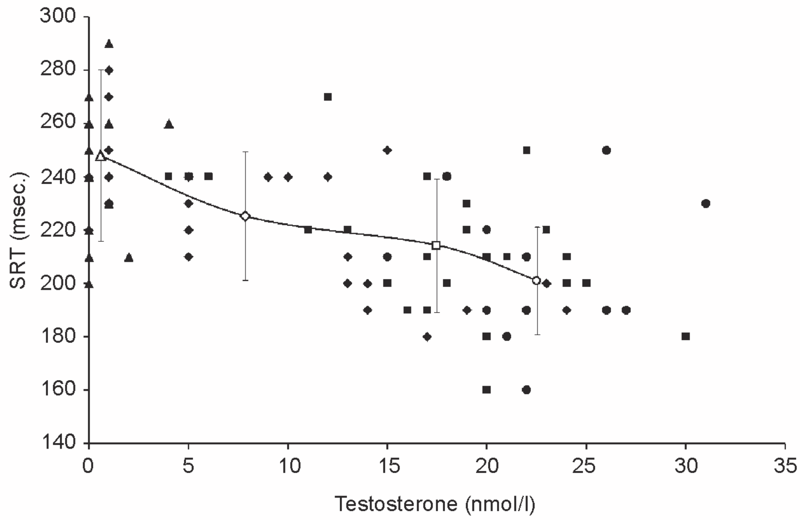

FIG. 2a. A general overview of the relationship between serum testosterone concentration and simple reaction time (SRT) in adolescent subelite soccer players. Individual results: 10-yr.-old group (▲), 12-yr.-old group (♦), 14-yr.-old group (■), and 16-yr.-old group (●); age average and development path (–○–).

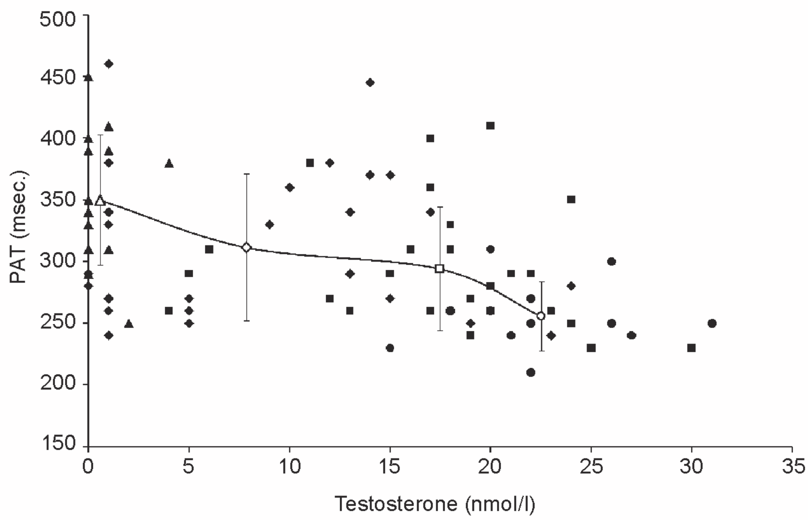

FIG. 2b. A general overview of the relationship between blood testosterone concentration and peripheral awareness (PAT) in adolescent subelite soccer players. Individual results: 10-yr.-old group (▲), 12-yr.-old group (♦), 14-yr.-old group (■), and 16-yr.-old group (●); age average and development path (–○–).

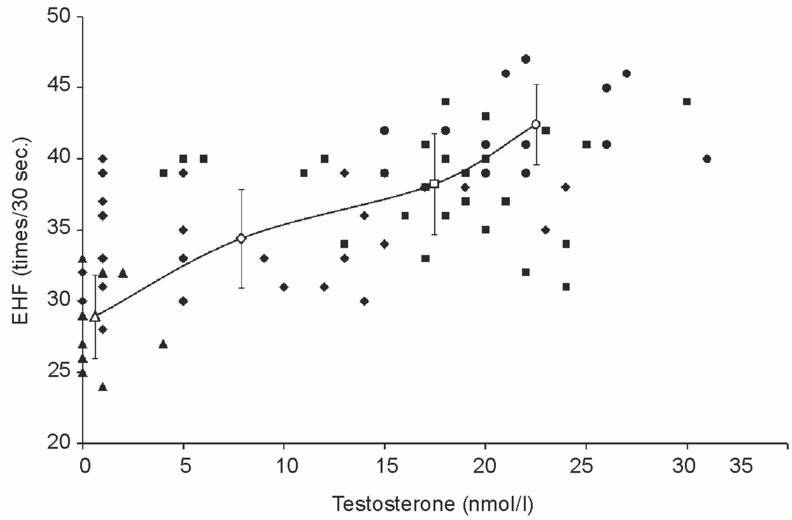

FIG. 2c. A general overview of the relationship between serum testosterone concentration and eye–hand–foot coordination (EHF) in adolescent subelite soccer players. Individual results: 10-yr.-old group (▲), 12-yr.-old group (♦), 14-yr.-old group (■), and 16-yr.-old group (●); age average and development path (–○–).

$p = .012$; 95%$CI = -.12, -.74$) groups. None of the age groups showed any significant relationships between blood testosterone concentration and peripheral awareness or between blood testosterone concentration and eye–hand–foot coordination. From 12 to 14 years of age, changes in the blood testosterone concentration were associated with relative changes in simple reaction time ($r = -.57$, $p = .039$; 95%$CI = -.06, -.85$) and in eye–hand–foot coordination ($r = .69$, $p = .006$; 95%$CI = .26, .90$). No significant relationships were found between the change in blood testosterone concentration and changes in any general perceptual motor skill variables from 10 to 12 years or from 14 to 16 years.[2]

Study 3

In the third research design, a significant main effect for soccer expertise was found in terms of simple reaction time ($F_{2,140} = 12.01$, $p = 1.5 \times 10^{-5}$; $\eta^2 = 0.14$) and peripheral awareness ($F_{2,140} = 4.66$, $p = .011$; $\eta^2 = 0.06$). In terms of simple reaction time (Fig. 3a), subelite and elite players were faster than the nonsoccer-playing group and the U-16 group was faster than the 16-year-old (subelite) players. The difference between adolescent elite

[2]Full tables of correlations for testosterone and the three perceptual and motor skills tests, as well as changes in testosterone and changes in test performances at two-year follow-up, are available as Document APD2010-005. Remit $10.00 for photocopy to the Archive for Psychological Data, P.O. Box 7922, Missoula, MT 59807-7922, for recipients inside the USA. Contact APD for shipping rates outside the USA.

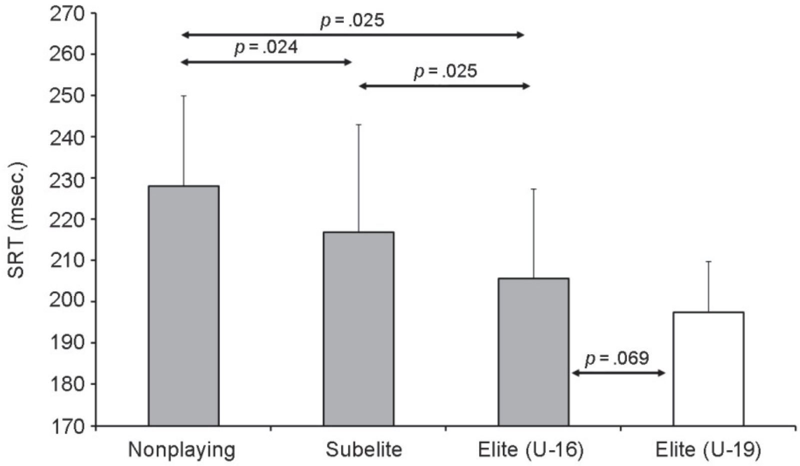

FIG. 3a. Reaction time (msec.) in simple reaction time test (SRT) for the nonsoccer-playing group, and subelite and elite soccer players at the age of 16 years with reference to young adult elite players at the age of 19 years

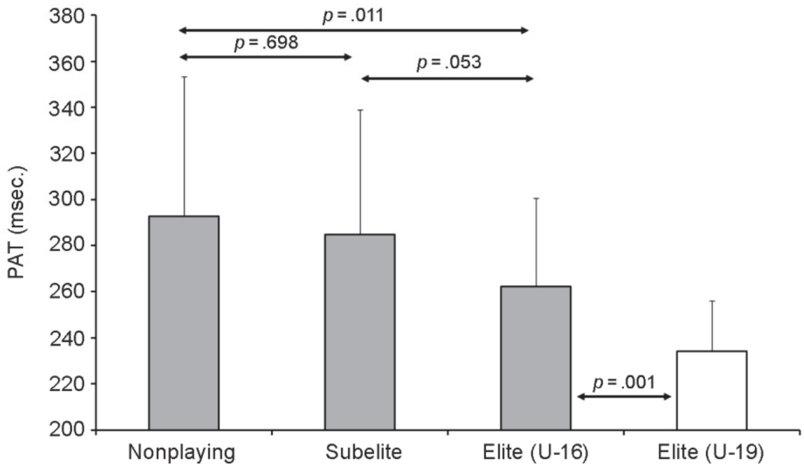

FIG. 3b. Average reaction time (msec.) in peripheral awareness test (PAT) for the nonsoccer-playing group, and subelite and elite soccer players at the age of 16 years with reference to young adult elite players at the age of 19 years.

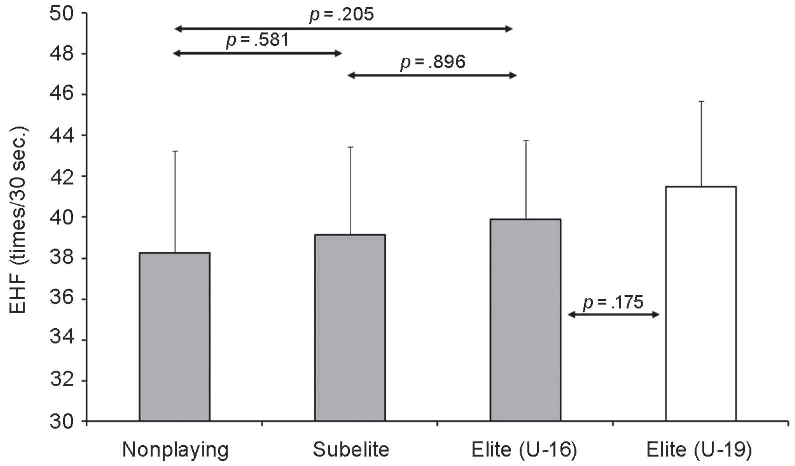

FIG. 3c. Number of extinguished lights in 30 sec. (times/30 sec.) in eye–hand–foot coordination test (EHF) for nonsoccer-playing group, and subelite and elite soccer players at the age of 16 years with reference to young adult elite players at the age of 19 years (ns = nonsignificant).

players (U-16 candidates) and young adult elite players (U-19 national team) was not significant ($p = .07$). In terms of peripheral awareness (Fig. 3b), there was a significant difference between elite players and the nonsoccer-playing group, while the difference between 16-year-old subelite players and U-16 players was not significant ($p = .053$). The mean reaction time of the U-19 group on the peripheral awareness test was shorter than that of the U-16 group ($t_{55} = 3.410$, $p = .001$, $d = 0.80$). No significant differences were found between any groups in the eye–hand–foot coordination test (Fig. 3c).

Discussion

According to the research literature, progression in reaction time tasks during growth approximates the process of neural maturation (Fulton & Hubbard, 1975; Thomas, Gallagher, & Purvis, 1981), with the effect of age being more marked for complex reaction tasks (Luchies, Schiffman, Richards, Thompson, Bazuin, & DeYoung, 2002; Der & Deary, 2006). The results of the present study showed a similar pattern. All three measured general perceptual and motor skills improved in older children, from 10 to 16 years, with the relative improvement being greatest in the most demanding tasks. Comparing 10-year-old and 16-year-old groups, simple reaction time in the older group was 10.2% faster, peripheral awareness 22.3% higher, and eye–hand–foot coordination 37.5% better. The peripheral awareness test and, in particular, the eye–hand–foot coordination test,

TABLE 2

Means and Standard Deviations of Simple Reaction Time (SRT), Peripheral Awareness (PAT), and Eye–Hand–Foot (EHF) Coordination Tests For U-16 And U-19 Expert Soccer Players, With Comparison Statistics

Test and Group	Nonsoccer players		Subelite		U-16		U-19	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
SRT, msec.	228	22	217	21	206	20	198	12
PAT, msec.	293	61	285	43	262	39	234	22
EHF, *n*/30 sec.	38.3	5.0	39.1	4.3	39.9	3.9	41.5	4.2
Group comparisons	Nonsoccer vs subelite		Nonsoccer vs U-16		Subelite vs U-16		U-16 vs U-19	
SRT, msec.	$p = .024$		$p = 8 \times 10^{-6}$		$p = .025$		$t_{55} = 1.864$ $p = .069$ $d = .45$	
PAT, msec.	$p = .698$		$p = .011$		$p = .053$		$t_{55} = 3.410$ $p = .001$ $d = .80$	
EHF, *n*/30 sec.	$p = .581$		$p = .205$		$p = .896$		$t_{55} = 1.374$ $p = .175$ $d = .41$	

require more information processing than a simple reaction time test. Because of this, age-related development in general perceptual and motor skills is probably a consequence of brain maturational processes, which are known to continue well through adolescence (Paus, 2005; Steinberg, 2005), as well as learning and experience, which affect many brain structures and functions (Durston & Casey, 2006). Maturational brain processes may also explain why there was a plateau in all three tests of general perceptual and motor skills between 12 and 14 years. One reason for this growth-related disturbance in motor control, also known as "adolescent awkwardness" (Lambert, Rothschild, Altland, & Green, 1972; Tanner, 1989), is temporal neural inefficiency, which has been shown to occur around the onset of puberty. Neural inefficiency is believed to be caused by the shift between proliferation and pruning in the brain (McGivern, Andersen, Byrd, Mutter, & Reilly, 2002).

Puberty in males is characterised by remarkable hormonal changes, including increased testosterone secretion (Malina, Bouchard, & Bar-Or, 2004). Testosterone is known to promote the functional and anatomical development of the nerves and brain (Sakai & Woody, 1988; Stocker, Guttinger, & Herth, 1994; Tan, 1996; Steinberg, 2005). Despite decades of research, the relationship between testosterone and cognitive function remains unclear (Beauchet, 2006). Studies that have examined the relationship between blood testosterone concentration and cognitive ability in adults have found both linear (Christiansen & Knussmann, 1987; Silverman, Kastuk, Choi, & Phillips, 1999) and nonlinear (Gouchie & Kimura, 1991; Moffat & Hampson, 1996) relationships between these two variables. The present study found some evidence that testosterone, or physical variables related to maturation and thus paralleling testosterone levels, could be related to improved general perceptual and motor skills during puberty. When 10- to 16-year-old adolescent subelite soccer players were treated as a single group, a significant relationship was found between all measured general perceptual and motor skills and blood testosterone concentration. Within age groups there was a significant relationship between blood testosterone concentration and simple reaction time in the 12- and 14-year-old groups but not in the 16-year-old group. In 12- and 14-year-old groups for simple reaction time and eye–hand–foot coordination, improvement was related to the blood testosterone concentration. However, no relationship between blood testosterone concentration and development of general perceptual and motor skills was found when comparing the 14- to 16-year-old groups. These findings suggest that biological age has to be considered when assessing the development of general perceptual and motor skills during early puberty. This is also the case in other physical fitness variables (Jones, Hitchen, & Stratton, 2000).

Earlier research has found that athletes have better visual skills that the general population and that physically fit individuals perform better on reaction time tasks than physically unfit individuals (Welford, 1980; Christenson & Winkelstein, 1988; Sillero Quintana, *et al.*, 2007; Stephenson, 2007). In the present study, adolescent subelite soccer players performed better than nonsoccer-playing age mates in all three tests of general perceptual and motor skills. More detailed analysis within the age groups revealed significant differences in the 14- and 16-year-old groups but not in the 10- and 12-year-old groups. The difference in general perceptual and motor skills between subelite soccer players and the nonsoccer-playing groups appeared to increase with age, although this may be a cohort bias.[3] Soccer training involves many exercises, such as small-sided games, where general perceptual and motor skills are constantly pressured (Reilly, 2005). It is possible, therefore, that subelite soccer players' engagement in fast-action sport explains why the difference between nonsoccer-playing groups and subelite players seemed to increase with age. Silverman (2006) has proposed that the increased engagement of girls in fast-action sports is one reason for decreased differences between the sexes in simple visual reaction time across time. It is also worth noting that motivational variables cannot be ignored when competitive individuals are compared to noncompetitive individuals because they are particularly relevant to alertness (Sanders, 1998). Other methodological issues that are known to be unique both in terms of developmental research (for example, that children and adolescents are inherently more variable in performance; see Thomas, 1984) and in reaction time tests (such as mood, time of day, etc.; see Sanders, 1998) may have affected the results of the present study.

When soccer expertise was further examined by comparing the general perceptual and motor skills of the 16-year-old nonsoccer-playing group with subelite and elite soccer players, a significant main effect for soccer expertise was found on simple reaction time and peripheral awareness tests. A more detailed analysis revealed that elite players had significantly faster simple reaction time than subelite players, and although the difference between elite and subelite players in terms of peripheral awareness was not significant, the effect size indicates that further research is warranted. The peripheral awareness test, particularly used to measure visual skills, was also the only test in which the young adult elite players (U-19 national team) performed better than the adolescent elite players (U-16 candidates). No differences were found in the eye–hand–foot coordination test, which addressed information processing, so it can be con-

[3]It is well known that activity levels among nonathlete youth decline during adolescence, although this is more pronounced for girls (e.g., Kimm, Glynn, & Kriska, 2002).

cluded that elite players have better visual skills (signal detection) and/or they can execute faster motor responses than subelite players or nonplaying age mates. It is also important to note that the differences in general perceptual motor skill tests between nonplaying groups, subelite players, and elite players were negligible. This justifies the earlier suggestion that athletes do not perform outstandingly in general measures of motor ability (Schmidt & Lee, 2005).

Practical Considerations for Soccer

The requirements of soccer are known to be multifactorial (Reilly, *et al.*, 2000), so it is possible that any of several abilities could make the crucial difference to the final outcome in a real game situation. The results of the present study suggest that there is a connection between soccer expertise and general perceptual and motor skills, and soccer training often involves features that enhance these abilities. However, it is important to emphasise that such basic perceptual and motor skills are rarely the limiting factor for an individual who is progressing toward the elite level. It is more likely that general perceptual motor ability can set potential limits on performance in sport, but once those limits are exceeded, task-specific skills differentiate experts from nonexperts (Ferreira, 2003). For example, the differences in general perceptual and motor skills in the present study between subelite and elite players were in the range of hundredths of a second, as compared to differences of tenths of a second that have been found in studies focused on game-reading skills, such as anticipation time (Savelsbergh, Williams, Van der Kamp, & Ward, 2002; Vaeyens, *et al.*, 2007). Previous research suggests that more significant differences between adolescent subelite and elite players can be found, for example, in agility, speed, endurance, and soccer skills (Reilly, *et al.*, 2000; Vaeyens, Malina, Janssens, Van Renterghem, Bourgois, Vrijens, *et al.*, 2006). Therefore, it can be concluded that the minor differences found in general perceptual and motor skills between groups with different soccer expertise are not meaningful enough for soccer practitioners to test these abilities on a large scale as part of their talent-identification processes. General measures of motor ability can be recommended when individual deficits are suspected, but further research should focus on developing valid tests of perceptual and motor skills that measure the abilities specifically used in soccer.

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III

CHANGES IN BODY COMPOSITION, HORMONAL STATUS, AND PHYSICAL FITNESS IN 11-, 13-, AND 15-YEAR-OLD FINNISH REGIONAL YOUTH SOCCER PLAYERS DURING A TWO-YEAR FOLLOW-UP

by

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Changes in Body Composition, Hormonal Status, and Physical Fitness in 11-, 13-, and 15-Year-Old Finnish Regional Youth Soccer Players During a Two-Year Follow-Up

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Abstract

Vänttinen, T, Blomqvist, M, Nyman, K, and Häkkinen, K. Changes in body composition, hormonal status, and physical fitness in 11-, 13-, and 15-year-old Finnish regional youth soccer players during a two-year follow-up. *J Strength Cond Res* 25(12): 3342–3351, 2011—The purpose of this study was to examine the changes in body composition, hormonal status, and physical fitness in 10.8 ± 0.3-year-old ($n = 13$), 12.7 ± 0.2-year-old ($n = 14$), and 14.7 ± 0.3-year-old ($n = 12$) Finnish regional youth soccer players during a 2-year monitoring period and to compare physical fitness characteristics of soccer players with those of age-matched controls (10.7 ± 0.3 years, $n = 13$; 14.7 ± 0.3 years, $n = 10$) not participating in soccer. Body composition was measured in terms of height, weight, muscle mass, percentage of body fat, and lean body weight of trunk, legs, and arms. Hormonal status was monitored by concentrations of serum testosterone and cortisol. Physical fitness was measured in terms of sprinting speed, agility, isometric maximal strength (leg extensors, abdominal, back, grip), explosive strength, and endurance. Age-related development was detected in all other measured variables except in the percentage of body fat. The results showed that the physical fitness of regional soccer players was better than that of the control groups in all age groups, especially in cardiovascular endurance ($p < 0.01–0.001$) and in agility ($p < 0.01–0.001$). In conclusion, playing in a regional level soccer team seems to provide training adaptation, which is beyond normal development and which in all likelihood leads to positive health effects over a prolonged period of time.

Key Words boys, performance, body composition, soccer, hormones

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Introduction

The most important variables for measuring performance in soccer are physical fitness and technical and tactical performance (33). The physical fitness of soccer players is usually measured in terms of endurance, speed, power, and strength (15). It is relatively easy to test the physical fitness of young players, but it is a more challenging task to differentiate between the effects of soccer training and growth-mediated development. In other words, changes in body size, functional capacities, and motor proficiency are highly individual during puberty, and the current performance capacity of a certain player is often closely related to their maturity status (24,31).

The composition of the bodies of young people undergoes rapid changes during the growth spurt, which occurs in boys at the age of around 14 years (22). During this growth spurt, the height increases by approximately 10 $cm \cdot y^{-1}$ and weight by 10 $kg \cdot y^{-1}$ in an average male adolescents (37). The height and weight development of young soccer players during puberty is shown to be similar to that of the general population. The only difference usually found in body composition is that soccer players tend to be leaner than are the average young people (4,13). Research evidence on how the body composition of young players contributes to their possibility of success in soccer is not fully consistent, but some evidence exists that players who are more advanced in terms of morphological growth have an advantage in the selection processes (9,30). It is also widely recognized that players born shortly after cut-off dates are more likely to be identified as more talented than their "age mates," who may have actually be born almost a year later (e.g., [3,14]).

Previous research has suggested that different physical performance characteristics become apparent in different age groups. Sprinting ability is likely to be more important in soccer during early puberty than later when growth-related differences are equalized. Gravina et al. (10) found that sprint speed was the most important physiological factor associated with players between the ages of 10 and 14 years being selected for first teams. Vaeyens et al. (39) also found that

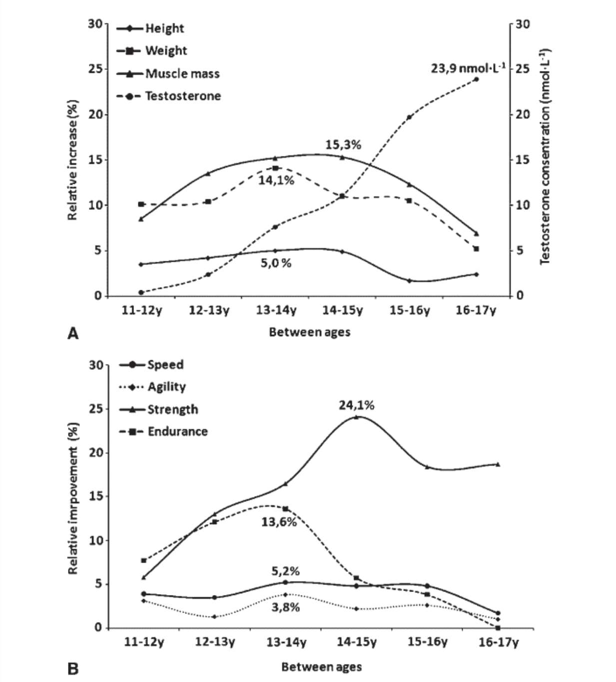

Figure 1. A) Descriptive data of soccer players' mean annual relative development in height, weight, muscle mass, and serum testosterone concentration. The greatest relative increase (value is shown in the figure) in height and in weight occurred between 13 and 14 years of age and in muscle mass between 14 and 15 years of age. Serum testosterone concentration increased from almost zero to a level equivalent to that of adults. (Please note the relative scale in other variables except for the absolute concentration of serum testosterone.) (B) Descriptive data of soccer players' mean annual relative development in speed (30-m sprint), agility (8-run), strength (isometric leg press), and endurance performance (YoYo shuttle run). The greatest relative improvement (value is shown in figure) in endurance performance, in speed, and in agility occurred between 13 and 14 years of age and in strength between 14 and 15 years of age. (Please note the relative scale).

speed was one of the factors that discriminated between elite and subelite players at the ages of 13 and 14 years, whereas aerobic endurance was more important in discriminating between players in the 15- and 16-year age groups. The development of the strength of soccer players during puberty is less studied than is speed or endurance, but observations suggest that soccer players possess a higher average strength when compared with that of the average population during puberty (4,8).

Most of the studies concerning the body composition and physical fitness profiles of soccer players have been carried out on youth teams in professional soccer clubs. However, youth soccer in Finland is mainly a recreational activity, and since 1999, the entire competition system has been based on the "All Sports" philosophy. This philosophy emphasizes that every child on a team has the right to participate and guarantees equal opportunities for each player regardless of their abilities. Because the players in this study are the first generation of players to have played their whole career under the "All Sports" philosophy, the aim of this study was to monitor how body composition, hormonal status, and physical fitness of these players developed between 11 and 17 years of age while playing regional level soccer in Finland.

Methods

Experimental Approach to the Problem

The experimental design for this study combined longitudinal and cross-sectional approach. Three age groups (11, 13, and 15 years) in the regional club team were monitored for 2 years to measure the changes in their body composition, hormonal status, and physical capacity. Two control groups consisting of school boys (11 and 15 years) were measured with the same tests as for soccer players to examine how the physical characteristics of soccer players differ from those of youths not engaged in soccer in the different age groups. Previous research literature was used to estimate how regional level players under the "All sports" philosophy develop compared with youth players in professional soccer clubs playing and training in competitive environments. The tests were selected to measure physical abilities needed in sports, and the selection was based on their regular use in field testing and in previous studies.

Subjects

The players of the club team representing an area of around 160,000 habitants participated in the present follow-up study on a voluntarily basis. At the start of the follow-up, the mean ages, from the youngest to the oldest age group, were

Table 1. Means (*SDs*) for height, weight, percentage of body fat, Testo, and Cor in the Soc. and Cont. groups by age.*

		Height (m)		Weight (kg)		Fat (%)		Testo ($nmol\cdot L^{-1}$)		Cor ($nmol\cdot L^{-1}$)	
	Age (y)	Soc.	Cont.	Soc.	Cont.	Soc.	Cont.	Soc.	Cont.	Soc.	Cont.
Group 1	11	1.42 (0.07)	1.47 (0.04)	33.0 (4.0)	39.0 (5.8)†	9.2 (3.4)	16.8 (6.6)†	0.36 (0.50)	0.33 (0.47)	547 (129)	397 (117)†
	12	1.47 (0.07)		36.5 (5.1)		11.1 (3.5)		2.36 (4.55)		586 (100)	
	13	1.53 (0.09)	1.57 (0.07)	40.2 (5.9)	47.4 (5.9)‡	10.1 (4.1)	16.7 (6.9)†	5.76 (8.21)	5.26 (7.67)	526 (94)	364 (103)§
	13	1.52 (0.1)		42.6 (7.5)		10.7 (4.2)		9.31 (7.15)		552 (121)	
Group 2	14	1.60 (0.10)		48.7 (9.1)		10.7 (4.3)		11.09 (7.13)		536 (90)	
	15	1.68 (0.10)		53.9 (9.5)		8.8 (2.9)		16.84 (6.76)		418 (94)	
	15	1.65 (0.08)	1.76 (0.06)‡	57.2 (11.2)	65.9 (8.7)†	9.9 (6.6)	13.0 (6.2)‡	18.06 (5.40)	18.36 (3.28)	598 (146)	331 (79)†
Group 3	16	1.71 (0.06)		62.8 (10.4)		9.0 (5.0)		19.69 (4.27)		529 (117)	
	17	1.75 (0.04)	1.80 (0.07)	65.9 (10.2)	69.5 (7.4)	8.5 (6.0)	12.2 (5.1)‡	22.48 (4.39)	23.90 (5.28)	538 (107)	466 (121)

*Soc. = soccer; Cont. = control; Testo = testosterone; Cor = cortisol.
†$p < 0.01$ difference in Tukey's post hoc test between soccer players (Soc.) and control group (Cont.) in the same age group.
‡$p < 0.05$, difference in Tukey's post hoc test between soccer players (Soc.) and control group (Cont.) in the same age group.
§$p < 0.001$ difference in Tukey's post hoc test between soccer players (Soc.) and control group (Cont.) in the same age group.

10.8 ± 0.3 years (group 1, $n = 13$), 12.7 ± 0.2 years (group 2, $n = 14$), and 14.7 ± 0.3 years (group 3, $n = 12$). On average, the players of group 1 participated 4.3 ± 0.8 times·per week, group 2 4.8 ± 0.9 times per week, and group 3 5.1 ± 0.9 times·per week in organized sports. The players of groups 1–3 had started to play soccer at the age of 5.9 ± 0.9, 5.8 ± 1.1, and 5.6 ± 0.9 years, respectively. Two control groups not participating in soccer, consisting of school boys with mean ages of 10.7 ± 0.3 years ($n = 13$, participated in organized sports 1.2 ± 1.1 times·per week) and 14.7 ± 0.3 years ($n = 10$, participated in organized sports 0.4 ± 0.8 times·per week), were measured at the start and the end of the follow-up period, with the same tests used on the soccer players. Training diaries documented by the team coaches were collected after the monitoring period. The protocol was approved by the Ethical Committee of the

Table 2. Means (*SDs*) for total muscle mass and LBW of trunk, legs, and arms in the soccer and control groups by age.*

		Muscle (kg)		Trunk LBW (kg)		Leg LBW (kg)		Arm LBW (kg)	
	Age (y)	Soc.	Cont.	Soc.	Cont.	Soc.	Cont.	Soc.	Cont.
Group 1	11	15.8 (1.9)	17.3 (1.7)†	13.6 (1.4)	14.7 (1.3)†	9.0 (1.3)	9.8 (1.1)	2.3 (0.4)	2.8 (0.4)
	12	17.2 (2.5)		14.6 (1.8)		9.8 (1.6)		2.6 (0.5)	
	13	20.2 (3.9)	21.6 (2.5)	15.7 (2.5)	17.5 (1.9)	10.9 (2.5)	11.7 (1.9)†	3.2 (0.8)	3.8 (0.6)
	13	20.2 (3.9)		17.1 (3.2)		12.1 (2.7)		3.8 (0.6)	
Group 2	14	24.0 (5.3)		19.3 (3.8)		14.0 (3.2)		4.1 (1.2)	
	15	28.1 (5.0)		21.3 (3.9)		15.6 (3.4)		5.0 (1.3)	
	15	28.1 (5.0)	32.3 (3.2)†	22.9 (3.2)	25.5 (2.2)‡	16.8 (2.6)	18.8 (1.9)†	5.2 (1.1)	5.9 (0.8)†
Group 3	16	32.2 (4.2)		24.9 (2.7)		18.6 (2.4)		6.0 (1.1)	
	17	34.2 (3.2)	34.6 (4.1)	26.0 (2.4)	26.6 (2.9)	19.3 (2.0)	19.6 (2.3)	6.5 (0.9)	6.7 (1.1)

*Soc. = soccer; Cont. = control; LBW = lean body weight.
†$p < 0.05$ difference in Tukey's post hoc test between soccer players (Soc.) and control group (Cont.) in the same age group.
‡$p < 0.01$ difference in Tukey's post hoc test between soccer players (Soc.) and control group (Cont.) in the same age group.

TABLE 3. Means (*SD*s) for 10- and 30-m sprint, agility, CMJ, 5-stride-jump, $\dot{V}O_2$, and YoYo shuttle run in the soccer and control groups by age.*

		10 m (s)		30 m (s)		Agility (s)		CMJ (cm)		5-Stride (m)		$\dot{V}O_2$ ($ml \cdot min^{-1} \cdot kg^{-1}$)		YoYo (m)	
	Age (y)	Soc.	Cont.	Soc.	Cont.	Soc.	Cont.	Soc.	Cont.	Soc.	Cont.	Soc.	Cont.	Soc.	Cont.
Group 1	11	2.08 (0.07)	2.21 (0.14)†	5.30 (0.21)	5.74 (0.52)‡	7.58 (0.20)	8.30 (0.54)§	28.0 (4.7)	24.1 (4.5)†	8.93 (0.62)	8.02 (0.79)‡	52.3 (3.1)	46.9 (3.9)‡	1,768 (169)	1,002 (289)§
	12	2.0 (0.08)		5.09 (0.20)		7.35 (0.19)		28.8 (3.6)		9.53 (0.70)		53.8 (3.9)		1,906 (253)	
	13	1.96 (0.10)	2.11 (0.12)‡	4.91 (0.25)	5.43 (0.41)§	7.25 (0.24)	7.95 (0.41)§	31.7 (4.7)	27.9 (4.7)	10.20 (0.94)	8.77 (0.60)§	53.7 (3.5)	47.7 (3.2)§	2,134 (284)	1,246 (287)§
	13	2.02 (0.05)		5.05 (0.16)		7.47 (0.24)		28.1 (3.1)		9.58 (0.88)		53.1 (3.0)		1,811 (348)	
Group 2	14	1.93 (0.09)		4.80 (0.28)		7.18 (0.15)		30.2 (3.4)		10.27 (0.85)		53.6 (4.2)		2,033 (327)	
	15	1.86 (0.09)		4.56 (0.23)		7.03 (0.21)		34.1 (3.9)		10.96 (1.12)		55.9 (3.4)		2,121 (285)	
	15	1.91 (0.10)	1.97 (0.16)‡	4.64 (0.23)	5.00 (0.44)†	7.22 (0.21)	7.84 (0.51)§	35.1 (5.1)	27.0 (3.6)§	10.93 (0.66)	10.14 (0.90)†	54.4 (4.9)	48.3 (4.4)§	2,297 (321)	1,146 (391)§
Group 3	16	1.83 (0.10)		4.42 (0.23)		7.03 (0.21)		37.5 (4.7)		11.80 (0.71)		55.0 (3.9)		2,358 (283)	
	17	1.80 (0.12)	1.84 (0.09)	4.34 (0.25)	4.62 (0.26)†	6.96 (0.19)	7.37 (0.39)‡	39.5 (5.5)	37.3 (5.1)	12.30 (0.83)	11.28 (1.07)†	54.8 (5.3)	48.4 (4.3)‡	2,348 (366)	1,551 (391)§

*Soc. = soccer; Cont. = control; LBW = lean body weight; CMJ = countermovement jump; $\dot{V}O_2max$ = maximal oxygen uptake.
†$p < 0.05$, difference in Tukey's post hoc test between soccer players (Soc.) and control group (Cont.) in the same age group.
‡$p < 0.01$, difference in Tukey's post hoc test between soccer players (Soc.) and control group (Cont.) in the same age group.
§$p < 0.001$ difference in Tukey's post hoc test between soccer players (Soc.) and control group (Cont.) in the same age group.

TABLE 4. Means (*SDs*) for isometric leg, abdominal, back, and grip strength and for RFD of legs in the soccer and control group by age.*

		Leg strength (N)		RFD (N·s^{-1})		Abdominal strength (N)		Back strength (N)		Grip strength (N)	
	Age (y)	Soc.	Cont.	Soc.	Cont.	Soc.	Cont.	Soc.	Cont.	Soc.	Cont.
Group 1	11	1,287 (355)	1,179 (304)	7,370 (1,969)	7,857 (2,541)	329 (68)	339 (67)	482 (75)	486 (80)	211 (42)	221 (34)
	12	1,305 (270)		8,460 (1,784)		362 (60)		527 (97)		224 (48)	
	13	1,480 (419)	1,570 (231)	10,116 (1,688)	9,082 (1,713)	377 (84)	388 (56)	600 (118)	624 (83)	242 (63)	271 (51)
	13	1,382 (255)		8,059 (2,009)		376 (84)		579 (122)		271 (79)	
Group 2	14	1,606 (334)		10,641 (2,200)		441 (77)		665 (192)		319 (101)	
	15	1,984 (619)		12,243 (3,620)		497 (143)		758 (179)		372 (102)	
	15	2,232 (508)	2,094 (415)	13,467 (3,330)	11,831 (2,515)	513 (77)	470 (51)	777 (125)	731 (80)	410 (66)	418 (48)
Group 3	16	2,663 (743)		16,696 (2,895)		641 (96)		908 (145)		446 (69)	
	17	3,140 (939)	2,285 (512)†	19,124 (3,734)	12,516 (2,539)§	663 (136)	483 (72)†	983 (181)	847 (117)†	493 (53)	491 (77)

*Soc. = soccer; Cont. = control; RFD = rate of force development.
†$p < 0.05$ difference in Tukey's post hoc test between soccer players (Soc.) and control group (Cont.) in the same age group.
§$p < 0.001$ difference in Tukey's post hoc test between soccer players (Soc.) and control group (Cont.) in the same age group.

TABLE 5. *F* values of the main effect of age and group and their interaction with effect size estimation (η^2) comparing the effect of age and the differences between soccer and control groups.*

	Age			Group			Age × group		
	F	*p*<	η^2	*F*	*p*<	η^2	*F*	*p*<	η^2
Height	103.51	0.001	0.71	8.64	0.01	0.02	0.74	NS	0.01
Weight	87.28	0.001	0.66	18.61	0.001	0.05	0.87	NS	0.01
Fat	2.01	NS	0.04	24.77	0.001	0.17	0.82	NS	0.02
Muscle	133.52	0.001	0.76	7.55	0.01	0.01	1.36	NS	0.01
Trunk LBW	119.3	0.001	0.73	9.61	0.01	0.02	1.64	NS	0.01
Legs LBW	109.62	0.001	0.72	5.05	0.05	0.01	1.83	NS	0.01
Arms LBW	119.29	0.001	0.74	10.36	0.01	0.02	0.55	NS	<0.01
Testosterone	84.76	0.001	0.68	<0.01	NS	<0.01	0.66	NS	0.01
Cortisol	3.10	0.05	0.06	27.36	0.001	0.18	1.95	NS	0.04
10 m	43.04	0.001	0.49	17.95	0.001	0.07	0.74	NS	0.01
30 m	49.35	0.001	0.50	31.17	0.001	0.11	0.30	NS	<0.01
Agility	21.13	0.001	0.27	52.77	0.001	0.22	1.00	NS	0.01
CMJ	28.56	0.001	0.38	22.08	0.001	0.10	0.69	NS	0.01
5-Step	67.65	0.001	0.57	35.43	0.001	0.10	0.05	NS	<0.01
$\dot{V}O_2max$	3.55	0.05	0.06	38.43	0.05	0.23	0.72	NS	0.01
YoYo shuttle run	12.84	0.001	0.14	116.6	0.001	0.43	0.65	NS	0.01
Leg strength	47.55	0.001	0.50	13.35	0.001	0.05	3.73	0.05	0.04
RFD	49.78	0.001	0.47	29.16	0.001	0.09	7.88	0.001	0.07
Abdominal strength	40.24	0.001	0.44	14.99	0.001	0.06	6.83	0.001	0.08
Back strength	61.59	0.001	0.59	6.66	0.05	0.02	2.33	NS	0.02
Grip strength	100.72	0.001	0.71	0.04	NS	<0.01	2.03	NS	0.01

*LBW = lean body weight; CMJ = countermovement jump; RFD = rate of force development in isometric leg press; NS = nonsignificant difference.

Table 6. Paired samples *t*-test with effect size estimation (Cohen's *d*) comparing changes between consecutive years during follow-up within soccer groups.*

	Group 1						Group 2						Group 3					
	11–12 y			12–13 y			13–14 y			14–15 y			15–16 y			16–17 y		
	$t_{(12)}$	$p<$	d	$t_{(12)}$	$p<$	d	$t_{(13)}$	$p<$	d	$t_{(13)}$	$p<$	d	$t_{(11)}$	$p<$	d	$t_{(11)}$	$p<$	d
Height	11.63	0.001	0.70	10.71	0.001	0.74	9.04	0.001	0.70	10.67	0.001	0.73	3.67	0.01	0.77	5.49	0.001	0.73
Weight	8.78	0.001	0.71	6.68	0.001	0.66	9.89	0.001	0.67	7.31	0.001	0.53	3.96	0.01	0.52	2.39	0.05	0.30
Fat%	3.61	0.01	0.55	−1.63	NS	0.28	0.07	NS	0.01	−3.10	0.01	0.51	−0.92	NS	0.15	−0.40	NS	0.07
Muscle mass	7.17	0.001	0.61	5.49	0.001	0.74	7.01	0.001	0.62	8.72	0.001	0.61	7.49	0.001	0.74	3.51	0.01	0.54
Trunk LBW	6.68	0.001	0.60	3.57	0.01	0.49	6.68	0.001	0.60	6.59	0.001	0.50	5.11	0.001	0.66	3.39	0.01	0.44
Legs LBW	6.54	0.001	0.53	3.20	0.01	0.52	7.15	0.001	0.61	5.53	0.001	0.44	6.90	0.001	0.69	3.67	0.01	0.32
Arms LBW	6.34	0.001	0.66	5.46	0.001	0.91	6.63	0.001	0.63	6.09	0.001	0.74	7.02	0.001	0.76	1.83	NS	0.46
Testosterone	1.75	NS	0.60	2.39	0.05	0.50	1.70	NS	0.25	3.91	0.01	0.75	0.98	NS	0.34	2.10	NS	0.63
Cortisol	1.33	NS	0.34	−2.18	NS	0.60	−0.40	NS	0.14	−4.49	0.01	1.09	−1.59	NS	0.51	0.23	NS	0.07
10 m	−7.03	0.001	0.98	−2.33	0.05	0.43	−5.11	0.001	1.14	−3.78	0.01	0.74	−5.93	0.001	0.75	−1.72	NS	0.29
30 m	−9.99	0.001	0.91	−4.76	0.001	0.73	−5.16	0.001	1.08	−6.26	0.001	0.88	−7.84	0.001	0.88	−2.72	0.05	0.32
Agility	−4.83	0.001	1.06	−3.09	0.01	0.53	−5.27	0.001	1.16	−3.80	0.01	0.90	−4.09	0.01	0.85	−1.71	NS	0.35
CMJ	0.96	NS	0.19	−3.41	0.01	0.66	3.10	0.01	0.60	4.98	0.001	0.93	2.55	0.05	0.48	2.22	0.05	0.38
5-Stride-jump	5.85	0.001	0.84	5.46	0.001	0.77	6.37	0.001	0.74	5.70	0.001	0.67	6.80	0.001	1.08	3.47	0.01	0.62
$\dot{V}O_2max$	2.39	0.05	0.42	−0.18	NS	0.03	0.87	NS	0.15	3.50	0.01	0.58	0.99	NS	0.14	−0.19	NS	0.04
YoYo	3.14	0.01	0.62	7.91	0.001	0.79	3.35	0.01	0.63	1.46	NS	0.29	0.78	NS	0.21	−0.14	NS	0.03
Leg strength	0.24	NS	0.06	2.26	0.05	0.49	4.52	0.01	0.70	2.84	0.05	0.53	5.36	0.001	0.65	3.18	0.01	0.55
RFD	3.14	0.01	0.57	3.45	0.01	0.87	4.84	0.001	1.07	1.67	NS	0.51	5.00	0.001	0.93	3.50	0.01	0.69
Abdominal	3.56	0.01	0.51	1.15	NS	0.21	5.13	0.001	0.75	2.16	0.05	0.47	6.10	0.001	1.19	1.06	NS	0.19
Back	2.78	0.05	0.51	5.12	0.001	0.65	2.95	0.05	0.51	3.95	0.01	0.48	6.03	0.001	0.89	3.73	0.01	0.46
Grip	1.78	NS	0.28	2.71	0.05	0.34	4.09	0.01	0.51	6.81	0.001	0.50	3.10	0.05	0.53	4.14	0.01	0.72

*LBW = lean body weight; CMJ = countermovement jump; RFD = rate of force development in isometric leg press; NS = nonsignificant difference.

University of Jyvaskyla. A written approval from parents was also requested before underaged participants were allowed to participate in the measurements.

Procedures

The height of the participants was measured using the standard stadiometer technique. Weight; total muscle mass; percentage of body fat; and lean body weight of trunk, arms, and legs were analyzed with a body composition analyzer (Inbody 720, Biospace Co., Seoul, Korea). Serum testosterone and cortisol concentration were analyzed from a venous blood sample taken between 7.30 and 8.30 AM after 12 hours of fasting (Immulite 1000, DPC Diagnostics Corporation, Los Angles, CA, USA) (Figure 1).

The physical capacity of the participants was measured in terms of isometric maximal strength, explosive strength, sprinting speed, agility, and endurance. Maximal bilateral isometric strength and the rate of force development (RFD) of leg extensor muscles were measured on an electromechanical leg press dynamometer with the subjects in a sitting position, with a knee angle of 107° (12). The force signal was recorded and analyzed with a Codas™ computer system (Codas v 1.0, Dataq Instruments Inc., Akron, OH, USA). Maximal isometric strength of trunk extension (back muscles) and flexion (abdominal muscles) was measured in a dynamometer in which the participant stood in an upright position, fixed at the height of their pelvis and chest, and pushed as much as possible either backwards or forwards against the plate with the force transducer. Explosive strength of the leg extensors was measured with a countermovement jump (CMJ) on an Ergo jump™ contact mat (Boscosystem srl, Cittaducale, Italy) and with a 5-stride jump into a long jump pit measured with measuring tape. Agility and running speed were measured with photocells (Digitest 2000, Digitest Oy, Muurame, Finland). An 8-figure test track, recommended by the national football association, was used in the agility test (40). All-out running speed over 10 and 30 m from a stationary start was measured on a track. The players started 0.70 m behind the photocells (heel on the line) that triggered the start of the time signal. Aerobic endurance capacity was determined with maximal oxygen uptake ($\dot{V}O_2max$) measured on a treadmill (Vmax series, Sensormedics Co., Yorba Linda, CA, USA). The treadmill was set at a constant 1° incline, and speed was increased by 1 $km\cdot h^{-1}\cdot min^{-1}$ (starting from 6 $km\cdot h^{-1}$) until voluntary exhaustion. Endurance performance was measured using the YoYo Endurance Test Level 1–shuttle run test (2) commonly used in soccer. The best of 3 trials was selected for further analyses in all physical capacity tests, except the 1-trial endurance tests. The measurements were repeated annually at the same time of the calendar year at the end of the season. Tests were carried out at the same time of the day in each year and, no vigorous exercise was allowed the day before the tests.

Statistical Analyses

When the effects of age was examined and soccer players were compared with the control groups, the measured variables were analyzed in a 4 × 2 (Age × Group) analysis of variance with Tukey's post hoc test. Eta-squared was used to estimate the effect size in analysis of variance. In a longitudinal approach, a paired samples *t*-test was conducted to compare the effect of age on the measured variables within each soccer group during the 2-year monitoring period. Cohen's *d* was used to estimate the effect size in paired samples *T*-test. To observe the differences between soccer groups that were sample-specific and not related to age, an independent samples *t*-test was conducted to compare the measured variables of 2 different groups of soccer players with the same ages (13 and 15 years). Significance was set at $p \leq 0.05$ for all tests.

Results

The results of the body composition and hormonal measurements from 11 to 17 years are presented in Tables 1 and 2, and the physical fitness variables in Tables 3 and 4. When the soccer and control groups were included in the analysis, it was found that Age had a significant effect on every other measured variables except for the percentage of body fat and that Group had a significant effect on all measured variables except for circulating testosterone and grip strength. The Age × Group effect was found for leg strength, RFD, and abdominal strength (Table 5). The Tukey post hoc comparisons between soccer players and the control group within each age group are presented in Tables 1–4 and the paired samples *t*-test analyses within soccer groups in Table 6.

According to the independent samples *t*-test, a significant difference between different soccer groups at 13 years of age was found in the 10-m sprint ($t_{25} = -2.17$, $p < 0.05$, $d = 0.78$), CMJ ($t_{25} = 2.34$, $p < 0.05$, $d = 0.83$), agility ($t_{25} = -2.68$, $p < 0.05$, $d = 0.92$), YoYo shuttle run ($t_{25} = 2.62$, $p < 0.05$, $d = 0.91$), and RFD ($t_{25} = 2.87$, $p < 0.01$, $d = 0.98$). Correspondingly, at 15 years of age, significant differences were found in serum cortisol concentration ($t_{24} = 3.84$, $p < 0.01$, $d = 1.20$) and agility ($t_{24} = -2.62$, $p < 0.05$, $d = 0.92$).

Discussion

Unlike most other countries, soccer is not a fully professional game in Finland. This is one reason why youth soccer in Finland is mainly seen as a recreational activity. In addition, for the last 10 years, the competition system in Finnish soccer for age groups of ≤15 years has been based on the "All sports" philosophy. The "All sports" philosophy emphasizes the right of every child to participate in sport, in contrast to a more competitive approach used during the previous decades. In this study, the performance abilities of players ranged from what could be described as recreational to one national youth team member who had played in several international tournaments. Therefore, the results of this study are not directly comparable with those reported from youth organizations in professional soccer clubs that only include talented players. However, training in Finnish soccer clubs has the same universal goal as everywhere else: to maximize the performance level of each individual player–regardless of their predictable potential in the future.

The players in this study were just above the median reference line for height and weight, according to Finnish growth charts, but were shorter and lighter when compared with age-matched control groups taken from a regular school class. It is likely that Finnish growth charts, which are based on follow-up data from children born in 1959–1971, underestimate the growth of those born afterward, because the average height of Finnish men has increased by around 1 cm per decade because of environmental factors (35). Nevertheless, the height and weight of soccer players fitted well into the normal ranges, which is in line with the findings of previous research performed on elite youth soccer players across Europe (21,22,25,39).

As expected from previous studies carried out among European youth players (31), the peak height (5.0%) and weight (14.1%) spurt occurred in the years when players turned 14 years of age. An interesting nuance in the body composition analysis was found, because it was revealed that peak muscle mass spurt occurred a year later than peak weight spurt did. This was possible because fat mass was reduced because of rapid growth and increased testosterone secretion at the same time as muscle mass was increasing. Testosterone is known to decrease triglyceride synthesis (1). In proportion to total body weight, muscle mass increased from 47.8% at 11 years to 51.9% at 17 years, which is in line with the findings in general population (23). According to a bioelectrical impedance analysis, a nonsignificant tendency was also found that, in proportion to total body weight, the lean body weight of arms and legs increased and the lean weight of the trunk decreased.

Percentage of body fat is a standard measurement in soccer because better players tend to be leaner than lower level players, even in the younger age groups (10,17,39). This was not seen in the results of this study, because Finnish regional soccer players were as lean as elite players were (10,39) and even leaner than were the age-matched French elite juniors attending the highly respected National Institute for Football (21). However, the difference observed between the French elite juniors and the Finnish regional juniors was likely related to a different measurement procedure. Bujko et al. (7) have shown that, when compared with the standard reference of underwater weighing, the amount of body fat is underestimated by bioelectrical impedance analyses and overestimated by skinfold measurements. The percentage of body fat of regional soccer players was lower than that of the control groups or average values seen in age-matched general populations in textbooks (23). Thus, it can be concluded that the body compositions of Finnish regional soccer players were identical to those of European elite players and that the soccer juniors were leaner than was the general age-matched population.

When the hormonal status of regional soccer players was examined, it was found that there were no differences in the levels of circulating testosterone between the present soccer players and control groups, but significant differences were found in serum cortisol levels in all age groups except for the oldest group of 17-year-olds. The higher cortisol concentration seen in soccer players was likely an adaptation to exercise induced stress. Cortisol promotes the use of fatty acids for energy (11) which was, as already mentioned, reflected in the differences in body fat between the soccer players and the control groups. With regard to the results of the present hormonal data, it is important to point out that in a single sample analysis the interpretations based on the concentration of hormones in the blood needs to be done with great caution.

According to Philippaerts et al. (31) speed of limb movement, trunk strength, upper-body muscular endurance, explosive strength, running speed, agility, cardiorespiratory endurance, and anaerobic capacity all showed peak development at peak height and weight spurt, which occurred at the age of 13.8 years in Flemish male youth soccer players. General data for adolescent boys suggest a slightly different pattern, such that speed attains maximal development before peak height spurt, maximal aerobic power is attained at the same time as peak height spurt, followed by strength and power afterward (5,23). Although peak height and weight spurt were not monitored in detail in this study, the results suggested that peak development in terms of endurance performance (13.6%), speed (5.2%), and agility (3.8%) occurred at the same time as peak height and weight spurt between 13 and 14 years of age. Leg strength (24.1%) attained peak development a year later, at the same time as peak muscle mass spurt, followed by trunk strength (21.9%) 2 years later, between 15 and 16 years of age. It is likely that the development of endurance performance, speed, and agility was related to the development of the nervous system, mediated by hormonal changes, because testosterone promotes neural growth, myelination, axonal conduction velocity, and the production of red blood cells (27,34,36). In addition to the changes mediated by testosterone, the development of strength in the second stage was most likely related to increased muscle mass and the increased amount of strength training reported in the team's training diary.

Although the physical fitness of soccer players was better than in the control groups under almost all circumstances, except for strength, before 17 years of age, a tendency was seen for the differences between the soccer players and age-matched school control groups to decrease with age in speed-related tasks, to remain the same in endurance performance and to increase in strength tests. It also seemed that the greatest difference was found in agility and in endurance performance when the results were considered in their entirety. These findings can be explained by the nature of the game and by the teams' training diaries. It was logical that the strength of the soccer players did not differ significantly from that of the control groups until late puberty, because muscle size during growth is mainly determined by the hormonal environment (26), and without specific strength training, the development of strength is closely related to chronological age (6). According to the teams' training diaries, the players in this study started controlled strength training at the age of 15 years from the same level as the control group. As a consequence, they were 37.4% stronger than the control group was at the age of 17 years. The difference observed in agility and in endurance performance was also to be expected, because these abilities are constantly stressed in soccer and the players also receive constant practice in these abilities (19,32).

It is obviously somewhat difficult to compare the development of Finnish regional players with that of elite players because the measurement protocols in various research projects have varied greatly, and even with the same tests the methodological issues are known to be unique in developmental research (38). It is also important to take into account that a difference was found in the performance profiles of the different soccer groups with players of the same age, even though the training culture in the present soccer club was relatively stable. This was especially evident at the age of 13 years, when the younger age class (at the end of their monitoring period) performed significantly better than did the previous one (at the beginning of their monitoring period) in almost half of the performance tests. Because no differences were found in body composition or serum hormonal levels, the results suggest that the younger age class was more talented than was the previous one. In other words, any generalizations made from the results of this study should be treated with caution because only a limited number of subjects from one soccer club were measured.

However, it is quiet safe to conclude that, on average, the Finnish regional soccer players demonstrated lower maximal oxygen uptake values, compared with the values of around 60 $ml{\cdot}min^{-1}{\cdot}kg^{-1}$ presented for elite youth and adult players in a number of studies (18,28,32). However, an improvement of >30% was observed in the YoYo shuttle run test between 11 and 16 years, which is similar to the magnitude found in endurance performance tests among elite players (16,18,21,28). In speed-related tasks, both the absolute level of performance and the yearly development rate of around 5% were compatible with that of European elite youth players (21,39). It is practically impossible to compare the strength of Finnish players against their elite counterparts because the methodology of strength measurements varies too much in different countries. However, Mero et al. (29) have studied Finnish athletes from 11 to 15 years of age competing in individual sports, specifically tennis players, track and field athletes, and weight lifters, with the same 107° isometric leg press procedure as that used in this study. A comparison between the studies demonstrates that the absolute level of strength and the longitudinal development of strength over 11–13 years of age among our regional soccer players were about the same but somewhat less over 14–15 years of age compared with that for athletes competing in other sports.

The present results suggest that although biological factors have a significant impact on various performance characteristics in youth athletes during growth spurt, playing in a regional level soccer team in a less competitive environment seems to provide training adaptation, which is beyond normal development and pretty well comparable with elite youth soccer players and to some extent also in athletes in other sports. Therefore, it can be argued that the "All Sports" system is able to develop the necessary physical abilities required in elite soccer, but further research is needed, particularly to examine how other aspects, such as technical and game skills, develop in the "All Sports" environment.

Practical Applications

The results of this study showed that the physical fitness of Finnish regional youth soccer players was clearly better than their age-matched counterparts not engaged in soccer. For example, because the endurance performance of 11-year-old soccer players was better than that of 17-year-old general youths, it is evident that participation in youth soccer greatly improves the working capacity of players, which can be assumed to lead to long-term health benefits (20). On the other hand, a tendency was seen for the differences between the soccer players and control groups to decrease with age in speed-related tasks, to remain the same in endurance performance and to increase in strength (because of the strength training program carried out by the soccer team). These results emphasize the need for long-term training programs with proper periodization for strength, speed, and endurance training to maximize players' potentiality. Special attention is recommended to be placed on speed training because it seems that normal soccer training does not give adequate stimulus for optimal speed development. Nevertheless, although training under "All sports" philosophy is not fully optimized, playing in a regional soccer team seems to provide sufficient training stimulus for the players to gain physical fitness levels that is not a limiting factor to reach the level needed in elite soccer.

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IV

DRIBBLING AND PASSING SKILL DEVELOPMENT OF MALE AND FEMALE SOCCER PLAYERS AGED 9 TO 17 YEARS IN FINLAND

by

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ABSTRACT
The aim of this study was to examine how young soccer players` technical skills have developed between 2000 and 2011 in Finland; to examine the rate of skill development between the ages of 9 and 17; and to examine the differences in soccer skills between genders. Players` (n=15835) skills were measured using the dribbling and passing test of the FA of Finland. The data was collected at youth regional competitions and youth national championships. A significant main effect between the years of 2000 and 2011 was found for Gender ($F_{1,8831}=4214.32$, $p<0.001$), Year ($F_{11,8831}=42.27$, $p<0.001$) and Gender x Year interaction ($F_{11,8831}=5.67$, $p<0.001$). A significant main effect by age was found for boys in the dribbling ($F_{7,20824}=1803.58$, $p<0.001$) and passing test ($F_{7,20824}=2027.73$, $p<0.001$) as well as for girls (dribbling: $F_{7,10500}=993.60$, $p<0.001$; passing: $F_{7,\ 10500}=1112.69$, $p<0.001$). A significant difference between genders was found in each age group ($p<0.001$). Finnish young soccer players` skills have improved with time between 2000 and 2011, soccer skills improved with age in both genders with small adolescent acceleration noticed in the passing test, and boys' soccer skills were better than girls in each age group indicating that special attention should be placed on skill training among females.

Keywords: Adolescent, Football, Testing, Technique, Boys, Girls

INTRODUCTION

Technical skills are one of the most important factors to measure when monitoring young players' development and evaluating their future potentiality (Huijgen, Elferink-Gemser, Post, & Visscher, 2009; Malina et al., 2005; Rosch et al., 2000). The fundamental technical skills required in soccer are ball control, dribbling, passing and shooting (Ali, 2011). Unfortunately, there is no generally accepted standard test to measure these skills, as tests measuring technical skills seem to be either developed specifically for research purposes (Ali, Foskett, & Gant, 2008; Russell, Benton, & Kingsley, 2010) or tied to the traditions of a specific club or region (Huijgen, Elferink-Gemser, Post, & Visscher, 2010; Malina et al., 2005). Nevertheless, the origin of the tests measuring technical skills arises from coaching practices, and they are suggested to be valid and reliable indicators of soccer skills (McGregor, Hulse, Strudwick, & William, 1999; Russell, Benton, & Kingsley, 2010).

In general, the results of technical skill tests improve with age among young soccer players, but the development is not as straightforward as found when monitoring, for example, physical fitness. When talented Dutch players were followed over 7 years from 12 to 19 years old,(Huijgen, Elferink-Gemser, Post, & Visscher, 2010) found that dribbling speed improved rapidly from 12 to 14, hardly at all between 14 and 16 and appeared to improve again after the age of 16. A study among 13-15 year-old Portuguese male soccer players showed that age, experience, body size and stage of puberty were able to explain only relatively little of the variation in technical skill tests (Malina et al., 2005). Therefore, technical skill tests should not be used so much as a tool for selecting players based on short-term outcomes, but these tests can be used for monitoring players' long-term development and responsiveness to training programmes (Meylan, Cronin, Oliver, & Hughes, 2010). From the selection point of view, it must also be pointed out that some tests, especially those including dribbling, seem to be more sensitive than others to detecting differences between elite and sub-elite players already during puberty (Huijgen, Elferink-Gemser, Post, & Visscher, 2009; Vaeyens et al., 2006).

Although there are more than 25 million female soccer players in the world (FIFA., 2007), there are very few published studies concerning the technical skill development of female players during childhood and adolescence. Based on general motor development charts (speed, agility, jumping, etc.) presented in pediatric textbooks (Malina, Bouchard, & Bar-Or, 2004), it could be expected that girls` performance in skill tests should be at almost the same level as that of boys up until the age of 13 to 14 years, after which males should be 10-15% better than females. Also taking into consideration that the maximum rate of growth (also known as peak height velocity) in western societies occurs at the age of around 12 years in girls and around 14 years in boys (Malina, Bouchard, & Bar-Or, 2004), the difference between the genders could be expected to be smallest at the age of 12 to 13 years when the difference in maturity status is at its largest. That is, it could be expected that girls` growth-related advantage in physical performance factors also temporarily equalises gender difference in skill tests.

A large database of technical soccer test results from Finland, which is based on a long tradition of youth soccer skill competitions, gives an opportunity to examine the development of technical skills in young soccer players across time in different age groups in both genders. This database was utilised in the present study in order to: (1) examine how young soccer players` technical skills have developed across a decade (between 2000 and 2011); (2) examine changes in the rate of development in technical skills between the ages of 9 to 17 years in both genders; and (3) examine the differences in technical skills between the genders.

METHODS

Participants

The participants of the present study were Finnish soccer players between 9 - 17 years of age. Players` dribbling and passing tests were recorded during the youth regional soccer skill competitions (n= 28993) and in the youth national soccer skill championships (n=2166) held between 2000 and 2011 in Finland. During these competitions, players` soccer skills were measured, depending on the age group, with 5-6 different tests (dribbling, passing, juggling, crossing, heading, scoring) in eight age categories from 9 to 17 years. Players aged 16 and 17 years competed in the same category. Only the dribbling and passing tests were selected for further analysis, because these tests were performed in every age category. In addition to the regional competitions (12 regions; participation on voluntary basis) and national championships (the most skilful players), three age groups from a regional club team were followed for two years using the same skill tests in order to examine skill development with a carefully controlled testing procedure in a group of male players (n=45) without the effects of competitive pressure. The total number of performances analysed in both tests was 31953, of which 21313 were recorded from boys and 10640 from girls. The number of players analysed was 15835 which meant that players participated in the skill tests on average around twice during the monitored period. The study was approved by the University of Jyväskylä Ethical Committee.

Dribbling test

The official dribbling test used in youth soccer skill competitions in Finland organised by the national Football Association is presented in Figure 1a. In the dribbling test, players took the ball and ran straight to a pole (with at least 3 touches before the pole) which was set to 20m from the starting line. Then players dribbled back to the starting line between the poles, which were placed 4m-2m-2m-4m-2m-2m-4m apart from each other. The same straight run - dribbling action was repeated from the other side to complete the test. The best out of two trials was selected for analysis unless the player failed to perform the test in under 50 seconds, in which case 50 seconds was registered as the performance time. In the club team, one successful performance was required in the dribbling test. A successful trial was always achieved by the fourth attempt. All tests were measured on artificial turf in indoor soccer hall. The reliability of the dribbling test was tested with a one month interval test-retest (29.6±3.2s vs. 30.0±3.1s) which showed a correlation coefficient of $r=0.82$ ($p<0.001$) among a group of 87 young soccer players (12.0±1.4y).

Passing test

The official passing test used in youth soccer skill competitions in Finland organised by the national Football Association is presented in Figure 1b. The passing test layout includes two cones 6m apart from each other, and 2m wide passing walls placed 7m away from the cones. Performance time starts when the player kicks the first pass against the wall. Then the player repeats the cycle: pass - receive rebound - dribble between cones - pass to the other wall. The performance ends when the 10th pass hits the passing wall. Five of the passes must be passed with the right foot and five with the left foot. The best out of two trials was selected for analysis unless the player failed to perform the test in under 60 seconds, in which case 60 seconds was registered as the performance time. In the club team, one successful performance was required in the passing test. A successful trial was always achieved by the fifth attempt. A one month interval test-retest (45.0±6.7s vs. 45.4±6.7s) gave a correlation coefficient for the passing test of $r=0.81$ ($p<0.001$) among a group of 87 young soccer players (12.0±1.4y).

Fifure 1a-b near here.

Statistical analyses

When skill development between the years 2000-2011 was described, the data was treated in order to give a general overview of skill development across the decade. The data treatment procedure included four steps: 1) Only the most representative 10 to 14 year-old categories, in terms of number of measured players, were selected for analysis; 2) As passing and dribbling test times correlated significantly in all age groups, these tests were combined to describe skill per se and to simplify the analysis; 3) Only the better half of the combined results in each age group were annually accepted for further analysis in order to ensure that only successful trials were included; 4) One group consisting of the same number of players from every age group (based on the age group with the smallest sample size) was formed separately for each year in both genders. This was undertaken in order to eliminate bias arising from unequal sample sizes in different age groups.

When changes in soccer skills between the years 2000 and 2011 were examined, a combined skill variable was analysed in a 2 x 12 (Gender x Year) analysis of variance. The effect of age in both genders was examined in a one-way analysis of variance using Tukey`s post hoc test. Eta-squared was used as the estimation of the effect size in the analyses of variance. Gender differences within age groups were analysed using the independent samples t-test. Cohen`s d was used as the estimation of the effect size in the independent samples t-test. Significance was set at the $p<0.05$ level.

RESULTS

The univariate analysis of variance showed a significant main effect in the combined skill between 2000 and 2011 for Gender ($F_{1,8831}=4214.32$, $p<0.001$, $\eta^2=0.31$), Year ($F_{11,8831}=42.27$, $p<0.001$, $\eta^2=0.03$) and Gender x Year interaction ($F_{11,8831}=5.67$, $p<0.001$, $\eta^2=0.01$). As presented in Figure 2, the relative difference between boys and girls varied from 12.3% (2011) to 17.9% (2001) during a research period of 12 years. The average time taken to perform the combined skill decreased from 65.7±4.8s in 2000 to 62.4±4.9s in 2011 in boys, and from 75.9±6.7s in 2000 to 70.1±6.1s in 2011 in girls. The equation of the linear trend line model for the years 2000-2011 was $y = -0.3x+66.2$ in boys and $y = -0.6x+77.6$ in girls.

Figure 2 near here.

In boys, a significant main effect was found for age in the dribbling test ($F_{7,20816} = 1820.17$, $p<0.001$, $\eta^2=0.38$) and in the passing test ($F_{7,20816} = 2027.66$, $p<0.001$, $\eta^2=0.41$). Furthermore, Tukey`s post hoc analysis revealed that the difference was significant between all age groups in the passing test and between all age groups except 15y and 17y in the dribbling test. The differences were at the $p<0.001$ level between all other ages except between the 15y and 17y groups in the passing test ($p<0.05$).

A significant main effect with regard to age was also found for girls in the dribbling test ($F_{7,10362} = 988.13$, $p<0.001$, $\eta^2=0.40$) and in the passing test ($F_{7,10362} = 854.54$, $p<0.001$, $\eta^2=0.37$). The difference between the age groups in girls also reached the level of significance in the dribbling test except between the 15y and 17y groups. The level of significance was at $p<0.001$ between all other ages, except between the 15y and 17y groups, in the passing test ($p<0.01$).

The results of the dribbling and passing tests by age and gender are presented in Tables 1 and 2 and the annual relative development for both genders in Figures 3a-3d. The relative development curves presented in Figures 3a-3d were calculated for the national championships and regional competitions from the average results of the age groups (cross-sectional approach), and for the club teams from the actual percentage of development of individual players (mixed longitudinal and cross-sectional approach). According to the independent samples t-test, the difference between genders was at the $p<0.001$ level (Cohen`s d 0.87-1.31; Table 1) in every age group.

Table 1-2 and Figures 3a-d near here

DISCUSSION

The results of the present study showed that technical skills in young Finnish soccer players improved over the 11-year study period between 2000 and 2011. In order to improve performance in soccer, it is important to receive specialised coaching and training (Ericsson & Lehmann, 1996) and to have access to appropriate training facilities (Cote, Macdonald, Baker, & Abernethy, 2006). These fundamental factors have improved in Finland during the last ten years. The Finnish coach education programme fulfilled the UEFA`s Pro licence requirements in 2002 and the number of indoor soccer halls and artificial turf pitches has more than doubled during the current century (LIPAS, 2010). It is also important to remember that the evolution of the game itself is an on-going process. The tempo of contemporary soccer has increased compared to previous decades, which means that players` performance abilities need to improve constantly in order to respond to the growing demands of the game (Huijgen, Elferink-Gemser, Post, & Visscher, 2009; Reilly, 2005).

The dribbling and passing test times improved with age, around 30% from 9 to 17 years, in both genders which is in agreement with previous research findings (Huijgen, Elferink-Gemser, Post, & Visscher, 2010; Rosch et al., 2000; Vaeyens et al., 2006). The improvement was fastest in the pre-pubertal ages between 9 to 11 years in all groups, but after that a different pattern in the rate of development was detected depending on the group (national vs. regional vs. club), test (dribbling vs. passing) and/or gender. In the boys' groups, acceleration between ages 13 to 14 could be noticed in the relative improvement in the passing test. In other words, the improvement occurred simultaneously with their expected peak height velocity, which has been shown to occur at around 14 years of age for boys in Finland and also in other western societies (Malina, Bouchard, & Bar-Or, 2004; Välimäki, Sane, & Dunkel, 2009). Therefore, it is likely that a significant part of this improvement was related to players` improved physical performance abilities, such as power, speed and agility, which are considered to peak during peak height velocity among young soccer players (Philippaerts et al., 2006). Although it is also worth to note that longitudinal data for general boys indicate a spurt in speed of movement before peak height velocity and spurt in explosive power after peak height velocity (Beunen & Malina, 1988; Malina, Bouchard, & Bar-Or, 2004) .

The development path of the dribbling test was rather similar to that of the passing test among club players, but less so in the results obtained from the national championships and regional competitions. In particular, the acceleration found in the results of the passing test between ages 13 to 14 was almost unnoticeable in the dribbling test. As such, it was not surprising that few differences were found in the effect of age between different skill tests, because studies have shown that the effect of age and maturity varies depending on the test used (Malina et al., 2005; Meylan, Cronin, Oliver, & Hughes, 2010; Valente-Dos-Santos et al., 2012). For example, Malina et al., 2005 found that the age and stage of maturity explained 21% of the variation in the "Dribbling with a pass" test in a group of 13-15 year-old Portuguese soccer players, but no explanatory model was found for the same group in the "Dribbling Speed" test. The different development pattern in the present dribbling and passing tests are likely to have arisen for two reasons. Firstly, the dribbling test itself, with a short distance between the poles (2m) favoured short and agile players, shifting the improvement towards younger age groups. Secondly, the passing test was more difficult than the dribbling test, which was highlighted by the higher percentage of failure in this test, especially in the younger age groups. It is likely that the dribbling test was easier (earlier) to learn than the passing test because the perceptual and cognitive demands of the dribbling test were much lower than those of the passing test.

In both skill tests, the most skilful male players competing in the national championships showed a lower relative annual improvement compared to players competing in the regional competitions, who in turn improved less than the club team players. It was obvious that the most skilful players were already at a high level at the age of 12 years, so that any further progression was inevitably slow. Actually, at 12 years old, the national championship players were at the same level as the 17-year-old regional competition players, and they were at least 2 years ahead of club players in both tests. These results are consistent with previous suggestions that skill tests including dribbling, such as both tests used in the present study, seem to be sensitive to detecting differences between elite and sub-elite players during puberty (Huijgen, Elferink-Gemser, Post, & Visscher, 2009; Vaeyens et al., 2006). It is also worth noting that the 2-year follow-up data from the club team showed that the newer generation performed better in both skill tests than the previous generation at the same age, or even 1-2 years older. This indicates that training procedures have improved with time, because it is justified to predict that the number of skilful players remains somewhat constant across time in the same club. Therefore, it can be concluded that even though skill influenced by many physiological and psychological factors is more difficult to measure than physiological indicators, it is certain that high quality practice is needed in order to become a skilful player (Malina et al., 2005).

There are more than 25 million female players in the world (FIFA., 2007) but female soccer players, especially youth players, are studied scarcely and much less than male players. Therefore, it is not surprising that more research has been warranted specifically for female players (Ali, Foskett, & Gant, 2008). In the present study, the improvement over the 11-year study period was around 0.5% per year for boys and 0.8% per year for girls. As girls improved slightly more than boys, the difference in soccer skills between the genders decreased on average from 16.7% (±1.2) in 2000-2002 to 13.7% (±1.5) in 2009-2011. A similar development pattern with age to that of the boys was observed in the regional competitions and national championships in girls in both skill tests. A small acceleration in the skill test results was detected just after the predicted peak height velocity between 12 and 13 years of age. Girls were 9% to 20% slower than boys in the dribbling and passing test in different age groups, with a weak tendency showing the difference to decrease with age.

From a practical point of view, an important observation was noticed when the results of the national championships for boys and girls were compared. The results revealed that 11-year-old boys were faster than 17-year-old girls in the dribbling test and almost as fast as 17-year-old girls in the passing test. Previous research has shown that 17-year-old female players` physical performance capacity is better than that of 11-year-old male players (Mendez-Villanueva et al., 2010; Vanttinen, Blomqvist, Nyman, & Hakkinen, 2011; Vescovi, Rupf, Brown, & Marques, 2011) which suggests that the observed difference between genders in the present study arose from actual ball-handling skills. The most logical explanation for this gender difference is that girls practise less than boys as it has been shown that girls in Finland engage in soccer later and they spend less time both in team sessions and practicing alone compared to boys (Konttinen & Aarresola, 2012). Nevertheless, based on the results of the present study, it can be recommended that special attention should be placed on skill training during childhood among female soccer players, especially because training is known to be the most important factor for the development of soccer skills (Helsen, Hodges, Van Winckel, & Starkes, 2000) .

In a real game, skilful performance can be simplified into three parts: identification (perceptual skills), decision-making (cognitive skills) and response (motor execution) (Welford, 1968; Whiting, 1969). Technical skill tests have been criticised for measuring only players' patterns of movement (motor execution) which, even if performed perfectly, becomes useless in a real game if the selection and timing of the action is wrong (Knapp, 1977). Both skill tests used in the present study measured mainly technical skills. The dribbling test was almost purely a measure of motor execution and the only unpredictable part of the passing test was when players needed to anticipate the speed and location of the ball after it had rebounded from the passing wall. Regardless of these limitations, technical skills should be included when young players' development is monitored and their future potential is evaluated, because technical skills are considered to be critical to performance in soccer (Huijgen, Elferink-Gemser, Post, & Visscher, 2009; Meylan, Cronin, Oliver, & Hughes, 2010). In fact, using technical tests instead of measuring "open skills" in a changing environment before puberty can be justified in a number of ways. Firstly, a certain level of technical skill is needed before a player is able to direct his or her gaze from the ball into the environment without losing ball control. Secondly, it has been suggested that at the age of 12 years, children are able to select the relevant information from various sources in the environment (Kail, 1991). It has also been suggested that reaction time to soccer-specific stimulus develops better during puberty than in pre-puberty (Vanttinen, Blomqvist, & Hakkinen, 2010). Thirdly, adolescence is a time of rapid cognitive development (Smith S.R., 2006). During and after puberty, the human brain is reorganised towards more efficient decision-making (Paus, 2005; Steinberg, 2005). Therefore, technical skill tests can be recommended before puberty in order to monitor responsiveness to training, whereas perceptual and decision-making skills should be included in the testing protocol at the latest in the beginning of puberty. However, further research is needed in order to develop skill tests that also include perceptual and decision-making skills and to examine open skills in different age and maturity groups in the changing environment. In further research, a detailed analysis of players training background is also warranted (years of experience, training frequency, amount of deliberate practise, other sport played, etc.).

CONCLUSIONS

Even though "skill" *per se* is proposed to be too difficult to measure at this moment in time (Ali, 2011), measuring "technique" is easy and, if monitored over a prolonged period of time, can provide valuable information for soccer practitioners (Huijgen, Elferink-Gemser, Post, & Visscher, 2009; Meylan, Cronin, Oliver, & Hughes, 2010). The present large cohort study, which examined technical skill tests between 2000 and 2011 in Finland, showed that young soccer players` technical skills improved with time. Soccer skills improved with age and acceleration mediated by improved physical performance abilities was detected around predicted peak height velocity in both genders. Boys were better than girls at ball-handling skills, and that is why special attention should be placed on girls` skill training. From a methodological point of view, a consistent nationwide testing protocol can be recommended for practitioners working in different countries. A nationwide database provides an excellent opportunity to, for example, create classification categories for different skill tests, to examine regional differences in "skill culture" and, over a longer period of time, to examine how different tests can predict players' success in their later soccer career. On a final note, more effort is required from researchers, practitioners and football federations to standardise testing protocols that are used to assess young soccer players' soccer skills in order to simplify the international comparability of the data and thereby facilitate worldwide soccer skill research.

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Table and figure legends

Table 1. Mean±SD of the dribbling test results by age and gender, percentage of unsuccessful performances and statistics comparing gender differences in each age group.

Table 2. Mean±SD of the passing test results by age and gender, percentage of unsuccessful performances and statistics comparing gender differences in each age group.

Figure 1a. Diagram of the dribbling test used in youth soccer skill competitions in Finland.

Figure 1b. Diagram of the passing test used in youth soccer skill competitions in Finland.

Figure 2. Mean (±SD) of the combined skill time (dribbling + passing) by year and gender between 2000 and 2010 in addition to a linear trend line and the relative difference between genders in each year*.

Figure 3a. Relative development of the dribbling test results by age in boys.

Figure 3b. Relative development of the dribbling test results by age in girls.

Figure 3c. Relative development of the passing test results by age in boys.

Figure 3d. Relative development of the passing test results by age in girls.

Table 1. Mean±SD of the dribbling test results by age and gender, percentage of unsuccessful performances and statistics comparing gender differences in each age group.

		9y	10y	11y	12y	13y	14y	15y	17y
Boys	n	2627	3429	3807	3812	3580	2224	983	363
	Avg	**33.9±4.3s**	**30.9±3.6s**	**29.2±3.1s**	**27.9±2.9s**	**26.9±2.4s**	**26.3±2.8s**	**25.8±2.9s**	**25.5±3.0s**
	Nat	-	27.3±1.9s	25.8±1.6s	25.4±2.7s	24.9±1.4s	24.4±1.3s	24.3±1.4s	24.2±1.6s
	Reg	33.9±4.3s	31.2±3.6s	29.3±3.1s	28.1±2.8s	27.1±2.4s	26.2±2.8s	26.0±3.0s	25.9±3.2s
	Club10y	-	29.3±2.0s	27.1±1.6s	26.4±1.6s	-	-	-	-
	Club12y	-	-	-	28.8±1.8s	27.3±1.8s	25.8±1.7s	-	-
	Club14y	-	-	-	-	-	26.6±1.3s	25.4±1.2s	25.3±1.7s
	Failure	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%
Girls	n	779	1545	1771	1945	1924	1427	783	327
	Avg	**40.2±5.8s**	**36.0±5.0s**	**33.2±4.2s**	**31.3±3.7s**	**30.3±3.6s**	**29.3±3.0s**	**28.5±2.6s**	**27.8±2.8s**
	Nat	-	31.3±2.7s	29.0±2.6s	28.3±2.6s	27.3±2.3s	26.7±1.8s	26.6±2.0s	26.2±1.8s
	Reg	40.2±5.8s	36.5±4.9s	33.6±4.1s	31.8±3.5s	30.4±3.5s	29.5±2.9s	28.7±2.6s	28.3±2.8s
	Failure	1.7%	<1%	<1%	<1%	<1%	<1%	<1%	<1%
Dif	♂ vs. ♀	18.6%	16.5%	13.7%	12.2%	12.6%	11.4%	10.5%	9.0%
t-test*	t	$t_{(1635)}$=-27.96	$t_{(2283)}$=-35.67	$t_{(2726)}$=-36.63	$t_{(3174)}$=-35.70	$t_{(2881)}$=-36.96	$t_{(2881)}$=-30.99	$t_{(1731)}$=-20.44	$t_{(688)}$=10.62
Sig	p<	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Cohen's	d	1.14	1.09	1.05	0.99	1.05	1.05	0.98	0.81

(* = independent samples t-test between boys and girls with-in age group; Dif = difference between boys and girls; Avg = average; Nat = national championships; Reg = regional competitions; club = club team + age at the beginning of follow-up; Failure = percentage of players who failed to perform the dribbling test in two attempts in regional competitions and in national championships)

Table 2. Mean±SD of the passing test results by age and gender, percentage of unsuccessful performances and statistics comparing gender differences in each age group.

		9y	10y	11y	12y	13y	14y	15y	17y
Boys	n	2627	3429	3807	3812	3580	2224	983	363
	Avg	**52.6±5.8s**	**47.8±6.3s**	**44.5±6.2s**	**41.9±5.9s**	**40.1±5.8s**	**37.8±4.6s**	**36.8±4.7s**	**35.7±4.6s**
	Nat	-	41.0±4.7s	37.0±3.6s	36.0±3.8s	35.3±4.6s	34.1±2.9s	33.6±3.5s	33.0±2.7s
	Reg	52.6±5.8s	48.2±6.1s	44.8±6.0s	42.3±5.8s	40.4±5.7s	38.1±4.6s	37.3±4.7s	36.5±4.9s
	Club10y	-	42.4±3.7s	39.4±2.1s	37.1±2.1s		-	-	-
	Club12y	-	-	-	40.3±3.7s	38.1±3.7s	35.5±2.7s	-	-
	Club14y	-	-	-	-	-	36.9±2.5s	35.0±1.9s	34.0±2.2s
	Failure	22.5%	9.1%	4.7%	3.4%	3.5%	5.2%	4.4%	3.9%
Girls	n	779	1545	1771	1945	1924	1427	783	327
	Avg	**58.1±3.5s**	**54.5±5.7s**	**50.9±6.4s**	**47.9±6.4s**	**45.5±6.3s**	**42.9±4.8s**	**41.5±5.0s**	**40.0±5.4s**
	Nat	-	47.4±5.4s	42.8±5.0s	40.9±4.6s	39.0±4.1s	37.5±4.2s	37.5±3.7s	36.8±4.4s
	Reg	58.1±3.5s	55.4±5.1s	51.5±6.1s	49.1±6.1s	46.1±6.1s	44.4±4.5s	43.0±5.0s	41.9±5.3s
	Failure	67.7%	34.1%	15.8%	8.7%	6.0%	12.3%	9.4%	7.6%
Dif.	♂ vs. ♀	10.5%	14.0%	14.4%	14.3%	13.5%	13.5%	12.8%	12.0%
t-test*	t	$t_{(2120)}$=-32.12	$t_{(4972)}$=-35.92	$t_{(3323)}$=-34.69	$t_{(3683)}$=-34.78	$t_{(3643)}$=-31.42	$t_{(2957)}$=-32.15	$t_{(1609)}$=-20.08	$t_{(637)}$=-11.35
Sig	p<	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Cohen's	d	1.31	1.10	1.00	0.97	0.89	1.09	0.96	0.87

(* = independent samples t-test between boys and girls with-in age group; Dif = difference between boys and girls; Avg = average; Nat = national championships; Reg = regional competitions; club = club team + age at the beginning of follow-up; Failure = percentage of players who failed to perform the passing test in two attempts in regional competitions and in national championships)

Figure 1a. Diagram of the dribbling test used in youth soccer skill competitions in Finland.

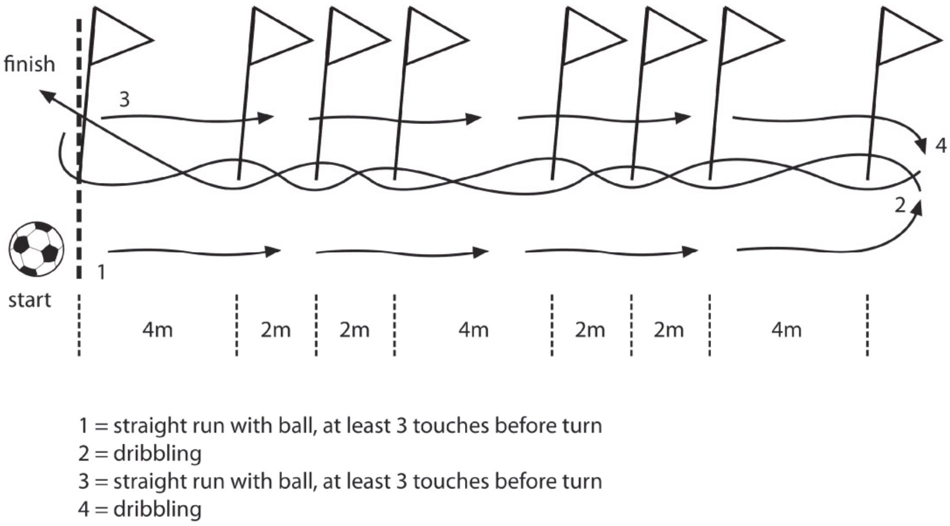


Figure 1b. Diagram of the passing test used in youth soccer skill competitions in Finland.

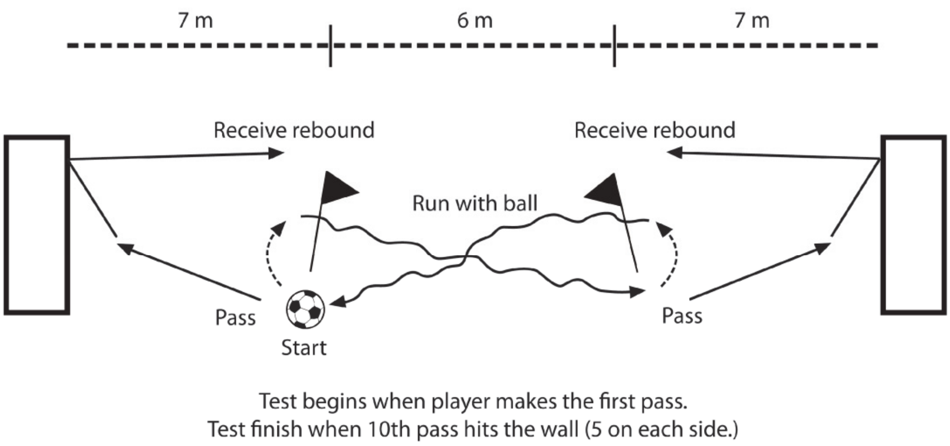
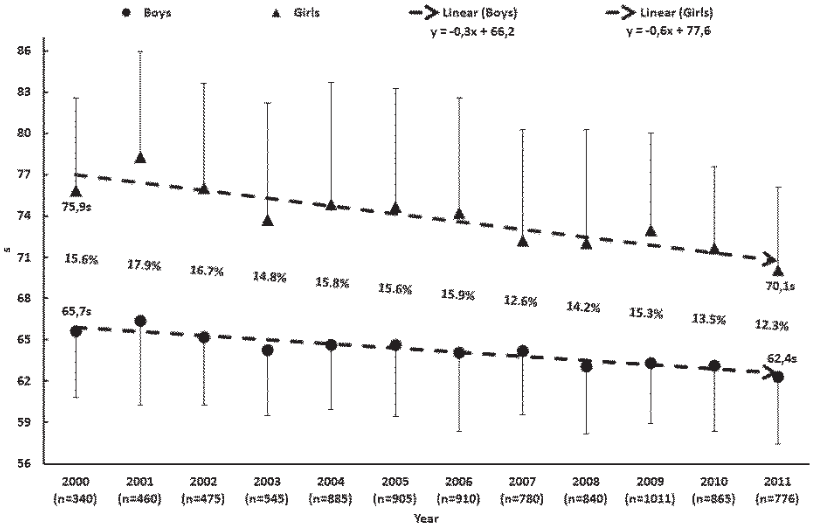
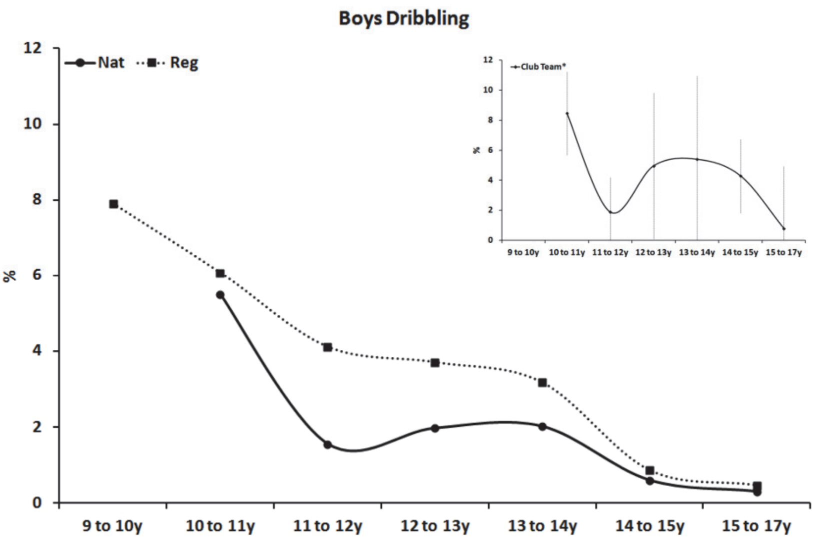


Figure 2. Mean (±SD) of the combined skill time (dribbling + passing) by year and gender between 2000 and 2011 in addition to a linear trend line and the relative difference between genders in each year*.



(*= data processed in order to increase the reliability of the analysis and to focus the analysis on talented players. For a detailed description please refer Methods section)

Figure 3a. Relative development of the dribbling test results by age in boys.



(Nat = national championships; Reg = Regional competitions; * = calculated longitudinally from players' real percentage of development)

Figure 3b. Relative development of the dribbling test results by age in girls.

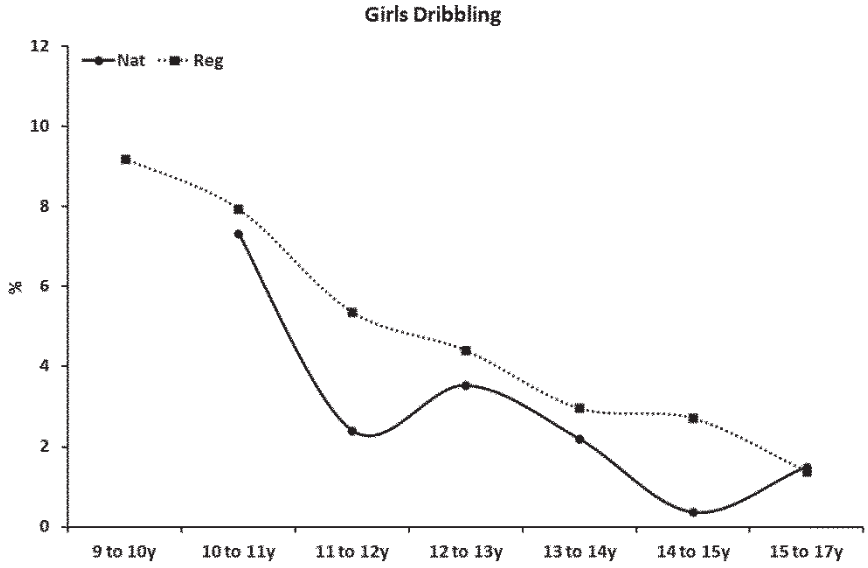
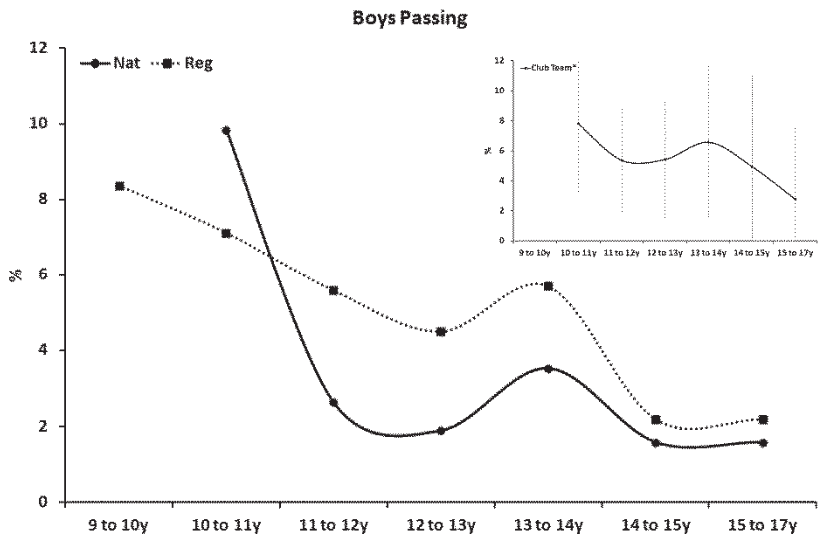
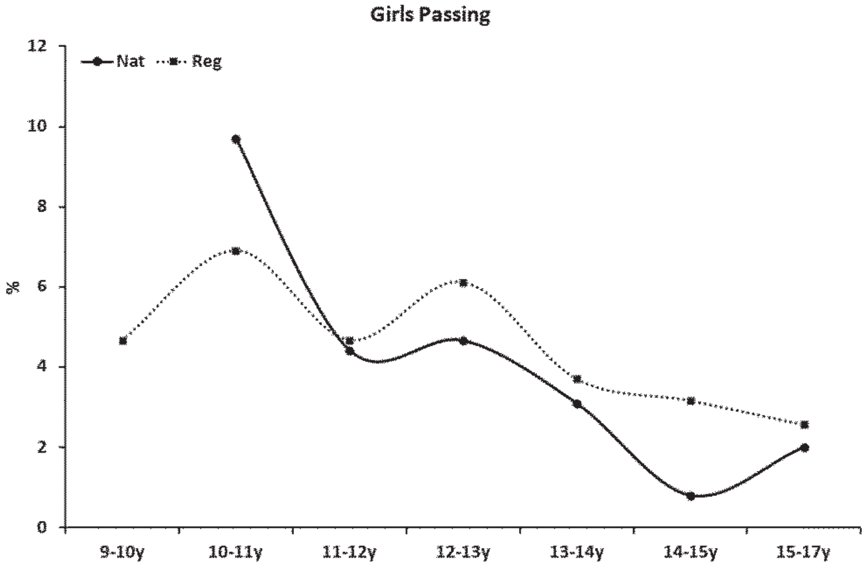


Figure 3c. Relative development of the passing test results by age in boys.



(Nat = national championships; Reg = Regional competitions; * = calculated longitudinally from players' real percentage of development)

Figure 3d. Relative development of the passing test results by age in girls.



V

DEVELOPMENT OF GENERAL AND SOCCER-SPECIFIC PERCEPTUAL-MOTOR SKILLS DURING A TWO-YEAR FOLLOW-UP IN THREE DIFFERENT AGE GROUPS IN A REGIONAL SOCCER TEAM

by

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Abstract

The aim of this study was to examine how young soccer players' general and soccer-specific perceptual-motor skills develop with age. Three age groups of the regional club team (10.8 ± 0.3y, n=14; 12.7 ± 0.2y, n=14; 14.7 ± 0.3y, n=12) were tested twice over a 2-year interval with general (peripheral awareness and eye-hand-foot coordination) and soccer-specific perceptual-motor skill tests (traditional passing skill test and soccer-specific laboratory test). When players were grouped based on their age (cross-sectional approach), a significant ($p<0.05$) main effect of age was found for general and soccer-specific perceptual-motor skills. When players development during a follow-up was analyzed within group (longitudinal approach), both general and soccer-specific perceptual-motor skills improved significantly ($p<0.05$) in all experimental groups. The Pearson correlation coefficient analyses showed that general perceptual-motor skills were related to skilled soccer performance in the younger age groups and soccer-specific perceptual-motor skills in the older age groups. To conclude, general and soccer-specific perceptual-motor skills improved with age but soccer-specific skills became increasingly important with age which is why these skills can be expected to discriminate post-pubertal players better than pre-pubertal players.

Key words: adolescent, decision making, anticipation, peripheral awareness, coordination

Introduction

Perceptual and decision-making skills are essential factors in soccer performance (Vaeyens et al. 2007) . It has even been argued that in the top level where differences in physical performance characteristics are small, it is cognitive skills that play a crucial role in the final outcome (Roca et al. 2012). This is obviously an exaggerated way to express that the requirements for soccer play are multifactorial and, therefore, all of the factors should be taking into consideration in soccer research as well as when young soccer players development is monitored in practice (Reilly et al. 2000) .

There has been a presumption that athletes need a high level of visual functions in order to meet the demands of their sport (Gardner & Sherman 1995). In supporting to this statement sport optometric research has demonstrated that athletes possess better visual skills than average people (Sillero Quintana et al. 2007, Stephenson 2007, Stine et al. 1982, West & Bressan 1996). Furthermore, optometric researchers have suggested that sport vision can be enhanced with general vision training (Clark et al. 2012, Sherman 1980). Some evidence also exists that young soccer players possess above-average general perceptual-motor skills. Montes-Mico et al. 2000 found that soccer players eye-hand and eye-foot visual reaction time was faster than in non-soccer playing children at the age of 8-13 years. In addition, Loran & Griffiths (1998, 1999) found that soccer and visual skills were related to each other in the group of young elite players and that all players rejected by a professional club team at the age of 14 years showed deficiencies in visual skills.

On the other hand, a number of researchers working in cognitive sport psychology have emphasized that athletes do not need superior general perceptual-motor skills (Ericsson & Lehmann 1996, Helsen & Starkes 1999, Starkes & Deakin 1984). This standpoint arises from expert-novice comparisons which have indicated that perceptual-motor skills are task-specific. That is to say, the level of expertise attained by extensive task-specific practice is considered to be more important than the age itself in the development of task-specific perceptual-motor skills. (Helsen & Starkes 1999, Henry 1958, Thomas 1999). Especially the ability to recognize advanced cues and extract meaningful information from those cues is a characteristic of elite athlete (Abernethy 1988, Gabbett et al. 2008). This ability has been suggested to appear already at the pre-pubertal age groups in soccer (Ward & Williams 2003). Vanttinen et al. (2010) have also suggested that with age general perceptual-motor skills become less important and soccer-specific perceptual-motor skills more important part of the successful soccer performance. To summarize, the best consensus so far is that the visual (dys)functions may set the limit to sport performance but in athletes with normal visual systems, it is more likely that sport-specific perceptual-motor skills distinguish experts from novices (Ferreira 2003).

Only few studies have examined the general and sport-specific perceptual-motor skills during childhood and adolescent and especially longitudinal studies are scarce. Therefore, the main purpose of the present study was to examine how young soccer players' general and soccer-specific perceptual-motor skills develop with age (cross-sectional approach) and during a two-year follow-up in three age groups (longitudinal approach). The second purpose was to examine what are the relationships between general and soccer-specific perceptual-motor skills especially in relation to soccer skills during childhood and puberty. The third purpose was to examine the differences between young players' performance in the traditional passing skill test (predictable=low uncertainty) and in the soccer-specific laboratory test (selections required=moderate uncertainty).

Methods

The experimental design for this study combined both longitudinal and cross-sectional approaches. Three age groups of the regional club team were measured with general perceptual-motor skill tests, with the traditional passing skill test (low uncertainty) and with soccer-specific laboratory test (moderate uncertainty). The same tests were repeated for the players two years later. At the start of the follow-up, the mean ages, from the youngest to the oldest age group, were: 10.8 ± 0.3y (U11, n=14), 12.7 ± 0.2y (U13, n=14) and 14.7 ± 0.3y (U15, n=12). Thus, respectively at the end of the follow-up: 12.8 ± 0.3y (U13, n=14), 14.7 ± 0.2y (U15, n=14) and 16.7 ± 0.3y (U17, n=12). The height of the players was measured using the standard stadiometer technique. Weight and percentage of body fat were recorded by the eight-polar bioimpedance method using multifrequency current (Inbody 720, Biospace Co., Seoul, Korea).

Players` general perceptual-motor skills were measured with two tests: peripheral awareness and eye-hand-foot coordination. Peripheral awareness was measured using the Wayne Peripheral Awareness Trainer (Figure 1), in which participants stood 60 cm away from the central cylinder, with eight peripheral lights mounted on 50 cm long rods in the cardinal and ordinal directions. Participants were asked to concentrate on the central light in the middle of the cylinder and respond using a joystick as quickly as possible to eight peripheral lights that were illuminated in random order. An average time of the eight directions was calculated, with the best out of three trials being selected. In the eye-hand-foot coordination test, the players extinguished as many randomly illuminated lights in the Wayne Saccadic Fixator board (Figure 1) as possible in 30 seconds in a predetermined manner using their hands (29 lights) and feet (four lights). The number of extinguished lights was counted and the best out of three trials was selected. In addition, a simple reaction time was measured in order to ensure that the term "Anticipation time" was justified to be used when reaction time to soccer-specific stimulus was analyzed. In the simple reaction time test, the players were instructed to extinguish a signal light switched into the same position on the Wayne Saccadic Fixator board (Wayne Engineering, USA) as quickly as possible with the index finger of their dominant hand (Figure 1). A total of five trials were recorded and the average of three responses, excluding the best and the worst, was calculated as a final score.

The passing test (Figure 2) used in youth soccer skill competitions in Finland organized by the national Football Association was used as a traditional skill test (FA of Finland 2010). The passing test layout includes two cones 6m apart from each other and 2m wide passing walls placed 7m apart from the cones. Performance time starts when a player kicks the first pass against the wall. Then player repeats the cycle: pass - receive rebound - dribble between cones - pass to other wall. The performance ends when the 10th pass hit the passing wall. Five of the passes must be passed with the right foot and five with the left foot. One successful performance was required from each player. A successful performance was always achieved by the fifth attempt.

A soccer-specific laboratory test (Vanttinen et al. 2010) was used to measure players` soccer-specific perceptual-motor skills (Figure 3). The test included a chain of typical soccer actions: anticipation, receiving, dribbling, feinting and passing. Firstly, the player watched a near life-size video sequence (1) of a soccer player receiving the ball and passing to the right or left. The player correspondingly took the ball (2) located on his left or right hand side. Secondly, the player dribbled the ball between two cones (3) and through the photocell-gate (4) which triggered a light (5) on a pole placed 5m in front of the photo-cell gate. This signal light determined which side of the pole the pass (6) should be given. Thirdly, the player was instructed to direct a pass between two switched lights in a running light track (7) proceeding at the speed of 4.17 m/s. The test included 4 familiarization and 16 actual test trials (8 on each side in a random order) with a resting period of 45 seconds between each trial. The trials were recorded with three 50 Hz camcorders and analyzed with the APAS motion analysis software (Ariel Dynamics Inc., USA). The analyzed variables were Anticipation time (= the moment of the pass on the video sequence to the player`s first movement towards the ball), Selection time (=time from illumination of the direction stimulus triggered by photocell-gate to the moment when the gaze moved away from the stimulus light), Feint-target time (= time from illumination of the direction stimulus triggered by photocell-gate to the moment when player gave a pass) and Performance time (= time from the pass impact on the screen to moment when the ball entered the line of the running light track).

A one-way ANOVA was conducted to examine the effect of age on measured variables. With-in the groups, a paired samples t-test was performed to examine the changes in the measured variables during a follow-up. An independent samples t-test was used to detect differences between the two different groups at the same age. Eta-squared and Cohen`s d were calculated as the measures of effect size. Pearson product-moment correlation coefficient was conducted to examine the relationships between perceptual-motor skills and soccer skills and between the relative improvements of these variables during follow-up. The level of significance was set at $p<0.05$.

Results

Players' height, weight and the percentage of total body fat is presented in table 1. According to paired samples t-test a significant increase in height and weight was found within all experimental groups ($p<0.01$-0.001). The percentage of body fat decreased significantly only in the U13 group during the follow-up ($p<0.05$). No differences were detected in any of the variables between the experimental groups at the same age.

A significant main effect of age was found for performance time in the traditional passing test ($F_{(3,76)}=27.04$, $p<0.001$, $\eta^2=0.52$) and in the soccer-specific laboratory test ($F_{(3,76)}=18.42$, $p<0.001$, $\eta^2=0.42$). A significant relationship between the tests were found in the U13 ($r=0.54$, $p<0.01$) and U15 ($r=0.59$, $p<0.01$) group. Calculated from the cross-sectional data the improvement from the youngest to the oldest age group was 21.4% in the passing test and 19.7% in the soccer-specific laboratory test. All three age groups improved ($p<0.001$) their performance in both skill test during the follow-up (table 2). In the soccer-specific laboratory test, a significant main effect of age was found for anticipation time ($F_{(3,76)}=41.14$, $p<0.001$, $\eta^2=0.62$), selection time ($F_{(3,76)}=18.39$, $p<0.001$, $\eta^2=0.42$) and feint-target time ($F_{(3,76)}=5.43$, $p<0.01$, $\eta^2=0.18$). Anticipation time improved 74.3%, selection time 33.3% and feint-target time 16.6% from U11 to U17. The improvement of these variables within groups during the follow-up reached the level of significance in every other case except in the selection time in the oldest U15 group (Table 3).

In the general perceptual-motor skills, a significant main effect of age was found for peripheral awareness ($F_{(3,76)}=4.58$, $p<0.01$, $\eta^2=0.15$) and for eye-hand-foot coordination ($F_{(3,76)}=40.60$, $p<0.001$, $\eta^2=0.62$). Calculated from cross-sectional data the improvement from U11 to U17 was 23.1% in peripheral awareness and 45.7% in eye-hand-foot coordination. As presented in table 4, both general perceptual-motor skill tests improved in every group during the follow-up. The effect sizes (table 4) and the relative improvements (figure 4) were greater in the eye-hand-foot coordination test compared to the peripheral awareness test within every group during the follow-up. During the two-year follow-up simple reaction time improved from 236 ± 35ms to 222 ± 18ms in the youngest age class ($p<0.01$), from 216 ± 19ms to 206 ± 20ms in the middle age class ($p<0.05$) and from 203 ± 23ms to 189 ± 21 in the oldest age class ($p<0.05$). Pearson product-moment correlation coefficients between the variables are presented in tables 5 and 6.

Discussion

The results of the present study indicated that both general and soccer-specific perceptual-motor skills improved with age but soccer-specific improved more than general. Reaction time to general peripheral stimulus improved, depending on the age group, from 9.0% to 14.3% during a two year follow-up whereas at the same time soccer-specific anticipation time improved from 14.6% to as much as 57.6%. It was also worth to note that not only soccer-specific anticipation time improved with age but the rate of improvement seemed to accelerate as players grew from pre-puberty towards adulthood. As a consequence, the importance of efficient decision making was observed particularly well in the oldest 16-17 years-old age group in which anticipation time explained over 40% of the variation in performance time at the soccer-specific laboratory test. In practice this means that at this age it was almost impossible to compensate inefficient decision making with skilful motor performance which was still possible in the pre-pubertal age groups. The findings were also in line with previous research suggesting that sport-specific perceptual-motor skills develop through extensive task-specific training and at a certain point of development these skills become a discriminating factor between elite and sub-elite athletes (Helsen & Starkes 1999, Tenenbaum et al. 2000, Vaeyens et al. 2007).

Significant associations between general peripheral reaction time and soccer-specific perceptual-motor skills were found only under the 13 year-old groups which indicated that general and soccer-specific perceptual-motor skills may have a common physiological foundation. It was thus possible that undeveloped visual skills were one of the factors that limited players` performance in general and soccer-specific perceptual-motor skill tests in the younger age groups. According to general paediatric research the central nervous system develops markedly up to around the age of 12 years at which point 95% of the adult level is reached (Malina et al. 2004), and moreover, the visual system develops throughout childhood to reach the adult functional level by the age of 15 years (Crognale 2002, Fukushima et al. 2000, Ishigaki & Miyao 1994). At the same age, children are also able to select the relevant information from various sources in the environment and their ability to process information becomes more efficient (Kail 1991, Ross 1976). Nevertheless, as associations between general and soccer-specific perceptual-motor skills showed a tendency to disappear as players grew older, it was still another proof that “nurture” was more important than “nature” on the way to soccer expertise.

In the present study, players’ ball-handling skills were measured with two soccer-specific skill tests. The traditional passing test was performed in a constant track whereas in the soccer-specific laboratory test selection was required in three occasions. Adding selections into the skill test did not affect very much into overall development which was around 20% in both tests from U11 to U17. During the follow-up only a small difference was observed in the oldest age group in which the test with selections improved 3% more than in the predictable test. When the relationships between these two skill tests were examined, it was found that the performance times of the tests correlated in those age groups (U13-U15) in which the maximum rate of growth occurs (Malina et al. 2004). Accordingly, general eye-hand-foot coordination was also related to soccer skills in the same age groups. These findings suggest that at the period of rapid growth the same players succeeded in tasks requiring motor coordination no matter whether the task was general or soccer action. Because motor coordination seemed to be particularly important, it is worth to note that there are two factors which have an opposite influence on motor coordination during the period of rapid growth. A period of rapid growth is suggested to produce temporal clumsiness to certain individuals, a phenomenon also known as adolescent awkwardness, due to the differential timing of growth spurts of the lower limbs and muscle mass (Beunen et al. 1989). On the other hand, a number of different physical abilities, such as power, speed and agility, are suggested to show the fastest improvement at peak height velocity (Philippaerts et al. 2006). Not to forget that monitoring skill development during puberty is an extremely complex phenomenon as a whole because it is influenced by many physiological, biomechanical and psychological factors as well as chronological age, maturity status and tests used (Malina et al. 2005).

The “Feint-target” phase of the soccer-specific laboratory test was examined in order to see how ball-handling interfere players’ ability to observe the surrounding environment. This analysis revealed that selection time during dribbling was about the same as general peripheral reaction time but it was different players that responded quickly in the general peripheral reaction test compared to those who made a quick selection during dribbling. This underlines that a certain level of technical skill is needed before a player is able to direct his attention from the ball to the surrounding environment, i.e. game itself. Therefore, it is not a surprise that it has been suggested to focus on ball-handling and game skills in soccer training programs for children (Lindquist & Bangsbo 1991, Wein 2007).

From the practical point of view the results of the present study suggested that there is no urgent need to emphasize decision making skills too much in soccer training before puberty. This standpoint is supported by the fact that the development of soccer-specific decision making was rather modest in the pre-pubertal age groups and related more to general development than later on. Therefore, it can be argued that a relatively low cognitive load can be used at the beginning of supervised perceptual and decision making training in order to ensure that the amount of information and interactions that needs to be processed meet children working memory capacity i.e. cognitive overload does not occur (Paas et al. 2004). On the other hand, a safe way to improve children's soccer-specific cognitive skills is to practice these skills unconsciously through games. Especially small-sided games, in which cognitive skills are constantly stressed, have been recommended for young soccer players (Reilly 2005, Unnithan et al. 2012). Unconscious learning is useful in a sense that it does not load working memory. It has also been suggested that skill acquisition through unconscious learning leads to performance that is more robust and does not break down under psychological pressure (Hardy et al. 1996, Masters 1992).

There is no doubt that anticipation and decision making skills are particularly important at the elite level because these skills are more likely to discriminate players than e.g. physiological abilities in which the differences are minimal at the top level soccer (Reilly et al. 2000, Roca et al. 2012). Therefore, decision making skills should be emphasized very much in soccer training at the beginning of puberty and thereafter. Timing of more demanding supervised decision making training around puberty can be physiologically rationalized by the fact that the brain is re-organized for better decision making during puberty and early adulthood (Steinberg 2005, Paus 2005). This was probably one reason why soccer-specific anticipation time improved almost four times more in the oldest age group (from U15 to U17) compared to the youngest group (from U11 to U13) during the follow-up of the present study. The importance of the efficient decision making skills can be further emphasized by arguing that in a real game a player with advanced anticipation skills will receive the ball and the player with poor ones ends up defending regardless of players` physical condition or technical skills.

To conclude, the results of the present study demonstrated that both general and soccer-specific perceptual-motor skills, as well as technical skills, improved with age in soccer. General perceptual-motor skills seemed to be related to skilled soccer performance during pre-puberty but after that it was the soccer-specific perceptual-motor skills which improved more markedly and became an increasingly important part of the successful soccer performance. Players' performance in skill tests with and without selection improved similarly during puberty. However, these tests were related to each other only at the age of around peak height velocity when motor coordination seemed to play an important role both in general and in soccer actions. On a final note, limitations of the present study including small sample-sizes, a heterogeneous group of players and players young ages (inherently more variable in performance and methodological issues; (Thomas 1984) may have influenced the results of this study and, therefore, more research is needed before proposed generalizations can be validated.

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Table 1. Mean ± SD and statistics for height, weight and percentage of body fat during a two-year follow-up.

	Height (m)			Weight (kg)			Fat (%)		
	Start	End	t-value	Start	End	t-value	Start	End	t-value
U11	1.44±0.06	1.53±0.09	-15.05***	33.2±4.0	40.2±5.9	-10.76***	9.4±3.5	10.1±4.1	ns.
U13	1.57±0.11	1.68±0.10	-12.62***	42.3±8.4	53.9±9.5	-10.63***	9.7±3.8	8.8±2.9	2.77*
U15	1.68±0.08	1.75±0.04	-4.72**	54.0±7.8	63.6±6.8	-9.89***	7.8±3.5	8.5±2.5	ns.

(* = p<0.05; ** = p<0.01; *** = p<0.001)

Table 2. Mean ± SD and statistics for passing test and soccer-specific laboratory test during a two-year follow-up.

Soccer Skills								
	Passing Test without Selection (s)				Soccer-Specific Laboratory Test with Selections (s)			
	Start	End	t	d	Start	End	t	d
U11	42.9±3.5	37.2±2.3	7.55***	1.92	5.57±0.33	4.89±0.27	8.72***	2.26
U13	39.5±2.9	35.2±2.8	12.86***	1.51	5.29±0.34	4.77±0.35	10.39***	1.51
U15	37.0±2.6	33.7±2.0	7.59***	1.42	5.10±0.37	4.52±0.32	6.32***	1.68

(*** = p<0.001)

Table 3. Mean ± SD and statistics for anticipation time, selection time and Feint-target time during a two-year follow-up.

Soccer-Specific Perceptual-motor Skills												
	Anticipation Time (ms)				Selection Time (ms)				Feint-Target Time (ms)			
	Start	End	t	d	Start	End	t	d	Start	End	t	d
U11	179±43	149±32	2.87*	0.79	351±47	324±26	1.65	0.71	1783±179	1545±114	4.70***	1.59
U13	161±36	99±20	6.42**	2.13	328±53	267±21	4.58**	1.51	1710±163	1563±151	3.01*	0.94
U15	91±37	46±42	4.71**	1.14	278±57	243±29	2.17	0.77	1772±254	1497±124	3.96**	1.38

(* = p<0.05; ** = p<0.01; *** = p<0.001)

Table 4. Mean ± SD and statistics for peripheral awareness test and eye-hand-foot coordination test during a two-year follow-up.

General Perceptual-motor Skills								
	Peripheral Awareness (ms)				Eye-Hand-Foot Coordination (n/30s)			
	Start	End	t	d	Start	End	t	d
U11	363±46	326±46	3.43*	0.68	29.1±3.0	35.6±3.8	-6.37***	1.90
U13	330±58	307±59	2.77*	0.39	33.8±2.7	39.7±3.1	-11.87***	2.03
U15	306±49	279±30	2.75*	0.66	37.5±3.0	42.4±2.8	-5.20***	1.69

(* = p<0.05; *** = p<0.001)

Table 5. Correlation matrix for soccer skills and perceptual-motor skills.

Soccer Skills vs Perceptual-motor Skills								
	U11 (n=14)		U13 (n=28)		U15 (n=26)		U17 (n=12)	
	Passing test	Soc-Lab test	Passing test	Soc-Lab test	Passing test	Soc-Lab test	Passing test	Soc-Lab test
PAT	0.13	0.71**	0.16	0.21	0.02	0.07	-0.28	0.25
EHF	0.24	0.25	-0.18	-0.29	-0.41*	-0.50*	0.01	0.22
Anticipation time	0.21	0.01	0.34	0.37	0.50*	0.44*	0.42	0.67*

(* = p<0.05; ** = p<0.01; Soc-Lab test = soccer-specific laboratory test; PAT = peripheral awareness test; EHF=eye-hand-foot coordination test)

Table 6. Correlation matrix for general and soccer-specific perceptual-motor skills.

General vs Soccer-Specific Perceptual-motor Skills								
	U11 (n=14)		U13 (n=28)		U15 (n=26)		U17 (n=12)	
	PAT	EHF	PAT	EHF	PAT	EHF	PAT	EHF
Anticipation Time	0.26	-0.34	0.48**	-0.13	0.11	0.06	0.22	0.03
Selection Time	-0.14	0.15	-0.06	0.13	0.12	-0.31	-0.19	0.79**
Feint-Target Time	0.70**	0.39	0.27	-0.41*	0.34	-0.40*	0.19	0.54

(* = p<0.05; ** = p<0.01; PAT = peripheral awareness test; EHF=eye-hand-foot coordination test)

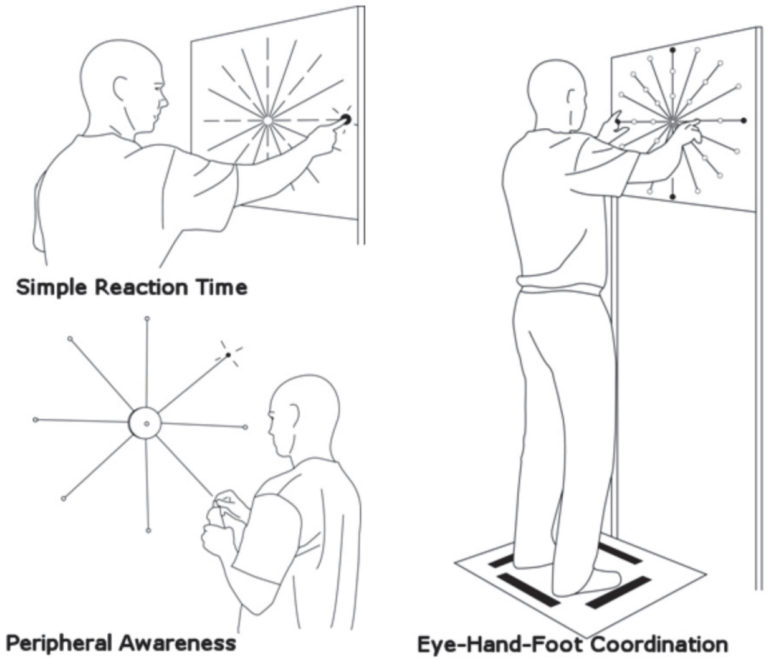

Figure 1. Schematic illustration of the simple reaction time test (upper left), peripheral awareness test (lower left) and eye-hand-foot coordination test (right).

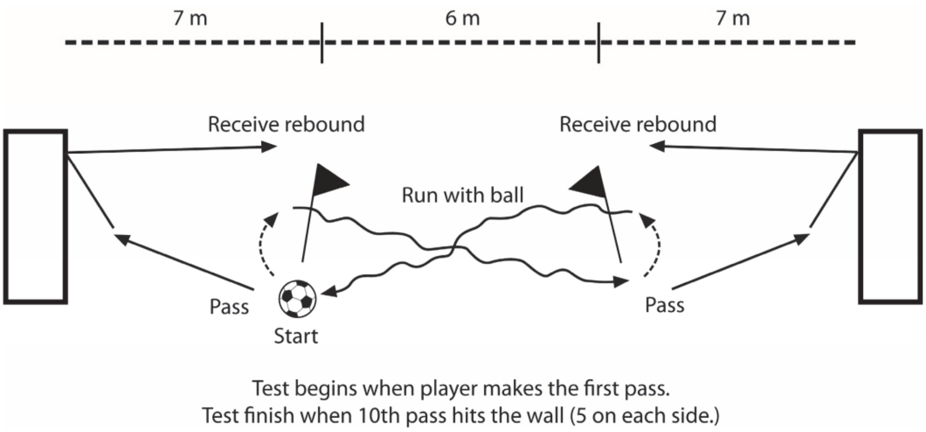

Figure 2. Schematic illustration of the passing test.

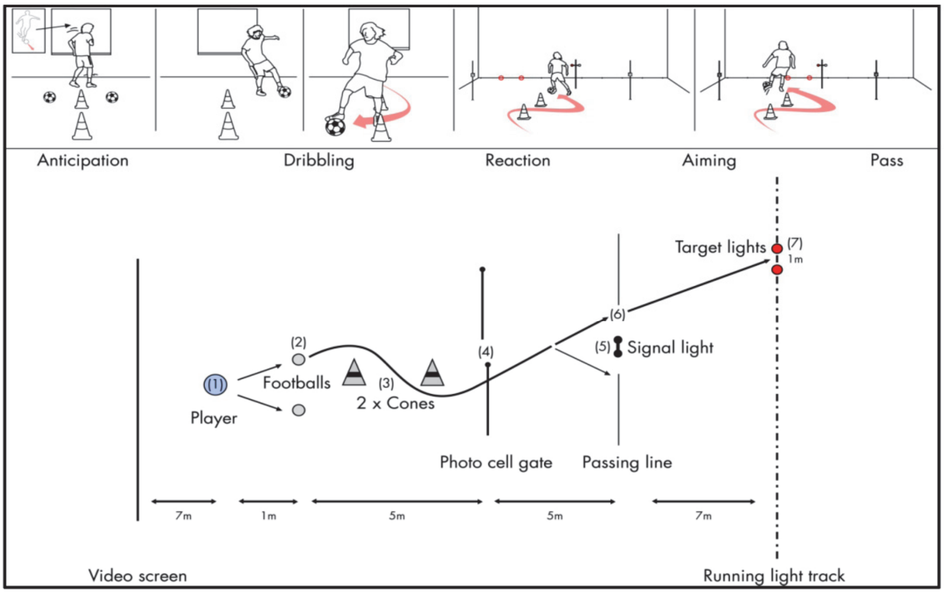

Figure 3 Schematic illustration of the soccer-specific laboratory test.

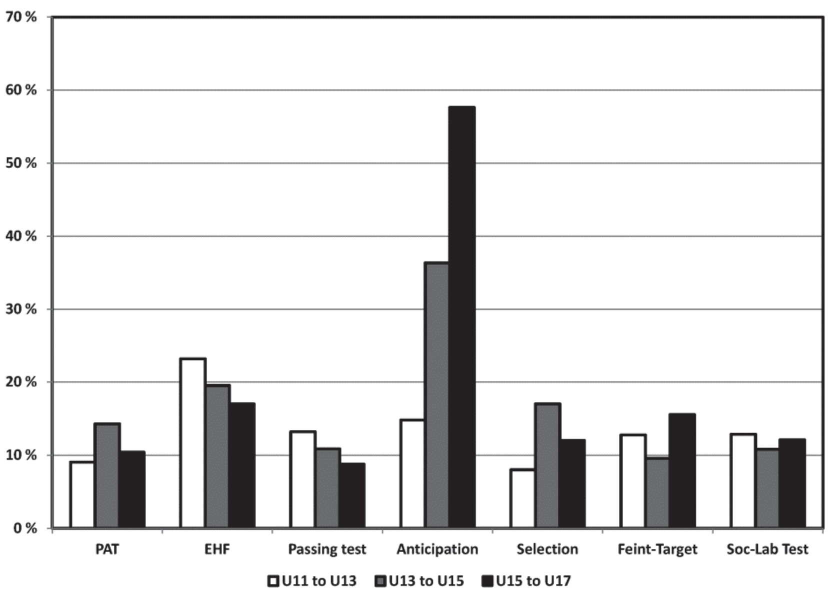

Figure 4 Relative developments of the measured variables in three different age groups during a two-year follow up.