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MILVI VISNAPUU

Relationships of anthropometrical characteristics with basic and specific motor abilities in young handball players

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1. INTRODUCTION

Short bursts of high intensity power production are typical of team sports and ball games like handball, basketball, tennis, ice hockey, soccer where players are often engaged in short bursts of high intensity physical activity separated by varying intervals of low and moderate intensity (Pauole et al. 2000, Bencke et al. 2002, Ratel et al. 2002).

In handball like in basketball successful performance is dependent on several physical components which must be performed repeatedly with maximal intensity (Gabbett 2005, Ronglan et al. 2006). The ability to run faster, to jump higher, to demonstrate greater agility and throwing velocity with great accuracy are the skills needed for successful play at all levels and all ages (Greene et al. 1998, Lidor et al. 2005). All these actions of physical activity, which play a fundamental role in handball, are anaerobic in nature (Wallace & Cardinale 1997, Hoffmann et al. 2000, Rannou et al. 2001).

In some sport activities, such as handball, hands are used as tools (Quaine et al. 2003, Leyk et al. 2006) because many external forces affect the fingers (Hore et al. 2001, Hughes et al. 2004), and sports equipment or performance requires maximal grip strength or optimal grip span. Grip strength is measured in several sports disciplines (Margonato et al. 1994, Pugh et al. 2003) and it is important for success in handball (Leyk et al. 2006), where the ball is handled with one hand most of the time. Handgrip strength is markedly associated with the level of physical activity and different types of work (Chau et al. 1997, Josty et al. 1997, Ruiz-Ruiz et al. 2002) as well as with general health and hand injuries (Fraser et al. 1999, Rauch et al. 2002).

Different sports require different motor abilities; in addition there are specific requirements on body composition and proportions (McKenzie Gillam 1985, Bencke et al. 2002, Gabbett et al. 2006). Constitutional factors are important for the children's choice of sport (Pienaar et al. 1998, Damsgaard et al. 2001, Gabbett et al. 2006). The physique of players and anthropometrical characteristics may be the essential factors that guarantee success in sports games (van der Tillaar & Ettema 2004, Ostojic et al. 2006).

Various anthropometrical, body composition and anaerobic performance variables have been tested in sports to evaluate the effects of training and to provide information to coaches to select young players, to distinguish the demands of different competition levels and of different sports (Ugarkovic et al. 2002, Lidor et al. 2005). In studies with pre-pubertal children researchers (Baxter-Jones et al. 1995, Damsgaard et al. 2000) did not determine an effect of training on body composition, anthropometrical parameters or pubertal development, confirming that children in competitive sports are selected due to constitutional factors. On the other side in literature it has been confirmed that body composition and some anthropometrical characteristics provide an advantage in certain sports (van den Tillaar & Ettema 2004, Gabbett et al. 2006). Within a sport, such as basketball, tallness is an advantage (Carter et al. 2005), and taller and more powerfully built players have an advantage in handball

(Gorostiaga et al. 2005, Granados et al. 2007). At the same time training at competitive level is influenced by motor abilities of children and adolescents (Maffulli et al. 1994, Gorostiaga et al. 1999).

Several studies have investigated the relationships between basic anthropometrical parameters and anaerobic performance (speed, vertical jump, explosive power of upper and lower limbs, agility, speed of change of direction, throwing speed) in children (Pienaar et al. 1998, Bencke et al. 2002) and adolescents (Ugarkovic et al. 2002, Gabbett et al. 2006). The relationships between constitutional factors and anaerobic performance in certain sport activities (Gorostiaga et al. 1999, Mohamed et al. 2009) or in certain age groups (Greene et al. 1998, Gurd & Klentrous 2003) were studied. Some earlier studies investigated the relationships between age, body composition and anaerobic performance in sedentary children, adolescents and young adults not participating in competitive sports and demonstrated the positive effect of body mass and the negative effect of fat mass (skinfold thicknesses) on the anaerobic performance (Inbar 1996, Armstrong et al. 2001, Dore et al. 2005). The physical and physiological requirements for participation in senior elite handball have been studied earlier (Ronglan et al. 2006, Chaouachi et al. 2008, Granados et al. 2008). There are no studies in youth handball to have investigated relationships between basic anthropometrical characteristics, hand anthropometry and basic and specific motor abilities in young handball players at 10–17 years of age.

2. REVIEW OF THE LITERATURE

2.1. Anaerobic power in children and adolescents

The need for anaerobic power and short burst muscle strength plays a major role in sports games (Bencke et al. 2002, Lidor et al. 2005, Mohamed et al. 2009). Success in sports games is more dependent on the players' anaerobic power (Parsons & Jones 1998, Granados et al. 2008) rather than on aerobic power and capacity (Hoffmann et al. 1996, Rannou et al. 2001, Ostojic et al. 2006).

Depending on the intensity and duration of the effort, different energy systems will predominate in anaerobic performance. The very short, high intensity efforts (lasting less than 2 s) mostly involve the adenosine-tri-phosphate (ATP) depots in the muscles, and the performance will depend on the cross-sectional area of muscle fibres, the type of muscle fibres, and the central nervous ability to excite the motor units at a high rate. The high intensity activities lasting up to 5–6 s also depend on the ATP depots in the muscles, but additionally also on the ability to utilize the phosphocreatine (CrP) depots. The longer high intensity activities will depend more on the muscle fibres' ability to produce ATP through the glycolytic pathway at a high rate (Bencke et al. 2002).

Anaerobic energy production is important for the growing child because physical activity patterns of young people are characterized by short bursts, predominantly anaerobic activities (Inbar 1996, Armstrong et al. 2001). The power generated per kilogram of body weight during high intensity anaerobic exercise is lower in adolescents than in adults (Naughton et al. 2000). The lower anaerobic power in younger population is explained by:

- lower levels of phosphorfructokinase (PFK) which is a rate-limiting enzyme of the glycolytic pathway (Eriksson et al. 1973, Inbar 1996, Naughton et al. 2000, Van Praagh & Dore 2002, Yanagiya et al. 2003),
- lower sympatho-adrenal activity (Inbar 1996, Naughton et al. 2000),
- maturational differences in muscle fibre distribution (Inbar 1996, Naughton et al. 2000, Rogol et al. 2002, Yanagiya et al. 2003),
- immature anabolic hormonal responses (such as lower level of testosterone) (Inbar 1996, Naughton et al. 2000, Rogol et al. 2002).

From age 12 to 17 the peak power (PP) and mean power (MP) of boys expressed in watts (W), increased by 121% and 113% respectively (Armstrong et al. 2001). A steady increase in anaerobic power of males occurs during childhood, with an increased rate of improvement at the onset of puberty (Inbar 1996, Beunen 1997, Pearson et al. 2006). Sprint speed and jumping ability improve to a great extent during adolescence, with the highest rate of increase at the age of 14 and 15 (Malina & Bielicki 1992, Malina et al. 2004b). A steady increase in strength occurs during childhood, followed by a more dramatic improvement that peaks between 14 and 16 years of age during adolescence (Inbar et al. 1996, Malina et al. 2004a, Pearson et al. 2006).

Anaerobic performance of the growing individual is closely related to body dimensions (Delgado et al. 1993, Dore et al. 2001, Bencke et al. 2002, Malina et al. 2004a, Mastrangelo et al. 2004), body mass (Delgado et al. 1993, Armstrong et al. 2001, Van Praagh & Dore 2002, Malina et al. 2004a), especially the lean body mass (Inbar 1996, Dore et al. 2005). By stepwise multiple regression analyses Mercier et al. (1992) in an earlier study determined anthropometrical variables related to maximal anaerobic power during growth in adolescence.

The changes in muscle mass and muscle size have been largely determined by hormonal influences (Hulthen et al. 2001, Dore et al. 2005). The serum testosterone is the most active stimulator of the anabolic process in the muscles. The dramatic increase of testosterone levels in boys between mid- and late puberty, may explain gender-related (Naughton et al. 2000, Dore et al. 2001, Dore et al. 2005) and age-related (Naughton et al. 2000, Hulthen et al. 2001, Rogol et al. 2002, Pearson et al. 2006) differences in lean body mass.

In a study with young male soccer players Hansen et al. (1999) showed a significant positive relationship between development in all strength parameters and serum testosterone concentration, indicating that level of serum testosterone is important for development of muscle strength in young boys. The strong relationship between gains in muscle strength and increased level of serum testosterone in boys was confirmed by Nevill et al. (1998) too. The increase in muscle strength with age in young boys cannot be explained only by growth. It is more likely to be dependent on the interrelationship between age, stature, weight, muscle size, and maturation (Hansen et al. 1999, Armstrong et al. 2001).

Several studies (Gorostiaga et al. 1999, Hansen et al. 1999, Naughton et al. 2000, Gorostiaga et al. 2004, Ingle et al. 2006, Pearson et al. 2006) have reported training-induced improvement in anaerobic power in pre-pubertal, mid-pubertal and post-pubertal children and adolescents. According to Malina & Bielicki (1992) anaerobic power production in adolescents is strongly related to body mass; with up to 92% of variance in peak power performance (during Wingate test) explained by a combination of an athlete's anthropometrical dimensions – such as height, leg length, lean body mass, leg volume and total muscle mass. The absolute as well as the relative (to body mass) peak power output increased with age throughout the whole growth period. The absolute anaerobic power at ages 8 and 16 years is only 30–40% and 75–85% of that at the age of 18. At the same time relative (body mass independent) anaerobic power at the same ages is already 70–80% and 85–90% of that at the age of 18, indicating the important role of body mass and muscle mass in the age-associated increase in anaerobic power (Inbar, 1996).

2.2. Explosive power of lower body and anthropometrical characteristics

Special speed and jumping training are not components of normal daily practices; however sprint, acceleration and jumping movements inherent in competitive team handball are also in common use in daily practices (Cardoso Marques & Gonzales-Badillo 2006). Speed, strength qualities and explosive power are important for jumping (Young et al. 1999, 2001a).

Explosive strength defined as the ability of muscles to release maximal force in the shortest possible time, is usually assessed by the means of various jumping tests (Malina et al. 2004a). Explosive strength is a performance-related physical fitness component and is an essential component of successful athletic performance at all ages (Bencke et al. 2002).

The squat jump used as the most functional expression of explosive muscle strength requires only concentric activation (Bencke et al. 2002), the countermovement jump requires moderate eccentric activation followed by high concentric activation and requires a more complex timing and distribution of the motor units (Bencke et al. 2002). The squat jump can serve as a measure of the potential of explosive muscle strength and countermovement jump as a measure of the development of this potential (Bencke et al. 2002, Vanezis & Lees 2003). A study with trained female athletes confirmed that the countermovement jump is a measure of slow stretch-shorten cycle performance and the drop jump a measure of fast stretch-shorten cycle (Hennessy & Kilty 2001).

Lees et al. (2004) examined vertical jump performance using an arm swing. In this experiment subjects jumped higher (0.086m) with arm swing compared to the no-arm swing, and they explained that this increase was due to increased height (28%) and velocity (72%) of the centre of mass at take-off. The arm swing significantly influences total work done by all joints in vertical jump performance (Young et al. 2001b, Hara et al. 2005), which includes 34.1 % of upper limbs' joint work and 65.9 % of lower limbs' joint work (Hara et al. 2005). Better jumpers demonstrated greater joint movements, power and work at the ankle, knee and hip, and jump higher (Vanezis & Lees 2003, Hara et al. 2005). The muscle strength characteristics of the lower limbs' joints are the main determinants of vertical jump performance (Vanezis & Lees 2003).

According to a study of children participating in different sports (handball, swimming, tennis and gymnastics) by Bencke et al. (2002) the anaerobic power was highly related to body size and at the same time peak power development and vertical jump performance were weakly related. The peak power performance may depend more on the ability to use the ATP and CrP stores which to a high degree is related to muscle size (Bencke et al. 2002).

The study of growth in explosive strength during adolescence (Inbar 1996, Beunen 1997, Peeters et al. 2005) showed that vertical jump performance increases over the whole age period from 10 to 18 with clear growth spurt in performance in boys. Performance in vertical jump increases linearly with age until 13 years in boys (Beunen & Malina 1988, Malina et al. 2004), whereas maximum velocity in vertical jump coincides with maximum velocity in static strength (Philippaerts et al. 2006). The earlier literature (Inbar 1996, Beunen 1997, Peeters et al. 2005) confirmed that for males' leg explosive strength peak coincides with peak height velocity (PHV) or occurs immediately before peak height velocity. Beunen & Malina (1988) previously confirmed that muscle groups may mature differently. Earlier studies confirmed that age related changes on relative strength occur concurrently with changes in body mass (Inbar 1996, Beunen 1997, Buchanan & Vardaxis 2003). Based on a study of young soccer players by Hansen et al. (1999) the increase in muscle strength with age in young boys can be related to age, stature, weight, muscle size and maturation.

Peeters et al. (2005) observed that the stability of explosive strength during adolescence is to a great extent caused by a stable genetic influence. The muscle fibre type distribution, as a determinant of explosive strength (Mero et al. 1991) is stable and heritable and this may be a partial explanation of genetic stability in explosive strength. In a study (Peeters et al. 2005) with twins about the influence of genetic and environmental factors on explosive strength during adolescence it was determined that additive genetic factors are the main cause of the phenotypic stability in vertical jump performance during adolescence. In late adolescence, after peak height velocity the unique environmental influences increased in significance in determining vertical jump performance (Peeters et al. 2005), which may be explained by an increase in specificity of physical activities (Bencke et al. 2002, Hughes et al. 2004).

Several studies (Deheeger et al. 1997, Reilly et al. 2000a, Baquet et al. 2004, Lidor et al. 2005, Ingle et al. 2006) have confirmed training–induced improvement in explosive strength of lower and upper limbs in young subjects going in for sports. When comparing children participating in sports and sedentary children both may be similar in height, age and body mass but the active in sport children have higher body lean mass and lower percentage of body fat (Vicente-Rodriquez et al. 2004). Results of a study (Ingle et al. 2006) with pre- and early pubertal boys suggest the training-induced improvement in dynamic strength, vertical jump performance and sprinting speed as well as favourable changes in body mass, especially lean body mass; however anaerobic power does not change. Baquet et al. (2004) in a study of effects of short-term interval training on physical fitness in pre-pubertal children suggested that the improvement in explosive strength after the training program was explained by one of 3 aspects:

- neurological adaptations (i.e. muscle fibre adaptation),
- morphological adaptations (i.e. a change of muscle fibre characteristics),
- interactions of neurological and morphological factors.

The reason for the increase in explosive strength in young players year by year may be due to a greater training-induced relative increase in muscle mass in young players (Gorostiaga et al. 2005, Granados et al. 2008) and thus a larger cross-sectional area of muscles (Mero et al. 1991). Earlier studies have determined that elite players have more development in stature and lean body mass compared to amateur players or subjects not going in for sports (Leatt et al. 1987, Hansen et al. 1999). A larger lean body mass is possibly caused by muscle hypertrophy as a response to training (Hansen et al. 1999).

In a study with adult elite and amateur handball players it was found that there were no significant differences in explosive strength of lower limbs, because the vertical jump height did not differ between elite and amateur players (Gorostiaga et al.2005) and no significant improvement in vertical jump height was registered after an entire season, which suggests the lack of any significant effect of a season on explosive strength of lower limbs (Gorostiaga et al. 2006, Granados et al. 2008). Some investigations have shown negative correlation between body mass and vertical jump in adult subjects active in sport (Stuempfle et al. 2003).

Little effect of anthropometrical characteristics on explosive strength of lower limbs explains that explosive power of lower limbs is largely determined genetically (Peeters et al. 2005). General anthropometrical parameters are poor predictors of jumping performance in young sportsmen (Beunen 1997, Bencke et al. 2002, Ugarkovic et al. 2002, Peeters et al. 2005). However several studies have reported significant relationship between anthropometrical parameters, body composition and anaerobic peak power (Blimkie et al. 1988, Mercier et al. 1992, Dore et al. 2004, Mastrangelo et al. 2004) confirming that lean body mass is a highly correlated variable determining maximal anaerobic leg power. The total body mass and lean body mass were highly correlated (Mastrangelo et al. 2004) at early pubertal ages (11–13 years). However, tasks in which the body mass has to be overcome, e.g. the vertical jump, consistently demonstrated negative correlations with body mass (Malina 1994). The importance of body mass in the age-associated increase in anaerobic power was indicated by Inbar (1996).

In conclusion, it is not clear how much explosive strength of lower limbs in young sportsmen is influenced by genetic and environmental factors, how much by anthropometrical characteristics, body composition, and to what extent it derives from trainability.

2.3. Movement speed in sports games and anthropometrical characteristics

Running is common to many recreational and organized sport activities and requires moving the body mass (Mastrangelo et al. 2004). Malina et al. (2005) confirm that body mass and maturity accounted for 50% of the variance in running speed. So the relative mean power, which is highly determined by body mass, could be the most important factor in running (Mastrangelo et al. 2004). Earlier investigations with pre-pubertal (Docherty & Gaul 1991, Ball et al. 1992, Ara et al. 2004) and adolescent (Blimkie et al. 1988, Lefevre et al. 1990, Okely et al. 2004) boys show that running and other fundamental movement skills (jump, throw, catch), – which are anaerobic by nature – are significantly related to anthropometrical characteristics (body mass, body height, BMI, body shape, waist circumference).

Sprints for short distances (20–30m) are fundamental in team handball – during a fast break or while returning to defence after a ball loss (Lidor et al. 2005). Earlier studies (Cronin & Hansen 2005) emphasized that first step quickness and acceleration are important to many sports. Kotzamanidis (2006) in a study of pre-pubertal boys found that anthropometrical parameters did not correlate significantly with all running phases (0–10m, 10–20m, 20–30m, 0–30m) in a 30m dash. A study with adults Kukolj et al. (1999) confirmed that anthropometrical characteristics do not affect running speed.

According to Armstrong et al. (2001) the performance in cycling sprint tests depends on muscle power which results from the optimal combination between force and velocity. The force is mainly determined by muscle mass in children (Blimkie et al. 1988, Van Praagh & Dore 2002) and muscle contraction velocity depends on the proportion of type II muscle fibres (Armstrong et al. 2001, Vicente-Rodriquez et al. 2004) which is age dependent (Armstrong et al. 2001). From childhood to adolescence fibre size increases 4.5-fold in boys and boys achieve peak fibre diameter in young adulthood (Armstrong et al. 2001). In earlier studies the training-induced increases in muscle size and cross-sectional area in adolescent and pre-adolescent boys were determined by Häkkinen et al. (1989), Ramsay et al. (1990) and Mero et al. (1991).

In recent studies with the young population the concurrent negative effect of fat mass on the growth of peak power was observed. Research with males aged 11 to 19 years (Mercier et al. 1992) affirms that force-velocity tests closely relate to anthropometrical parameters – body height, leg length, and body mass. Ara et al. (2004) in a study of pre-pubertal boys found that lower whole body mass and percentage of body fat were observed in physically active boys compared to physically non-active boys and demonstrated relationships between running speed (30m), body height, body mass, BMI and body fat. They found that mean speed in 30m running test in combination with body height and whole body mass is predictive of the body fat mass ($R^2=0.98$, $p<0.001$) and concluded that regular participation in sport activities and competitions is associated with increased physical condition and lower fat mass in pre-pubertal boys. Lefevre et al. (1990) confirm that speed of limbs' movements is negatively related to age at peak height velocity in adolescence. Earlier studies in literature (Malina et al. 2004a, Philippaerts et al. 2006) found that the relationship between body height parameters and 30m straight sprint was significantly negative at peak height velocity and adolescent spurt in muscle mass. Nesser et al. (1996) argue the importance of quick start and rapid acceleration, strength of knee flexors and hip extensors to propel the body forward and the capacity of these muscles to rapidly contract and produce force.

Earlier studies may conclude that anthropometrical parameters are poor predictors for movement speed and game-specific speed in young sportsmen. At the same time body composition, especially lean body mass influences movement speed and game-specific speed to a great extent.

2.4. Game-specific skill, agility and anthropometrical characteristics

Many field and court sports involve some straight sprinting but more often repeated short sprinting with changes of direction (Sheppard & Young 2006). Most court sports require 180 degrees turns over a small distance (Barnes et al. 2007) and such sports to a great extent demand agility. There are two main components of agility – change of direction speed and perceptual and decision-making factors (Sheppard &Young 2006). Agility is often described as the quality of possessing the ability to change direction and start and stop quickly (Parsons & Jones 1998, Little & Williams 2005). The straight sprint and agility tests assess specific qualities which do not transfer one to the other (Young et al. 2001a, Little & Williams 2005). Young et al. (1995) indicate that strength qualities relate to starting performance and to maximum sprinting speed. The reactive strength of leg extension muscles (leg muscle power) has some importance in change-of-direction performance but other agility performance factors must also be considered (Young et al. 2002).

Young et al. (2002) presented universal components of agility:

1. perceptual and decision-making factors –
    a. visual scanning
    b. knowledge of situations
    c. pattern recognition
    d. anticipation
2. change of direction speed –
    a. technique
    b. straight sprinting speed
    c. leg muscle qualities – reactive strength, concentric speed and power and left-right muscle imbalance
    d. anthropometry

In a study with young water-polo players Falk et al. (2004) emphasized the players' ability to anticipate, respond, focus attention and make the appropriate decision as an important factor in achieving success in ball games.

Gabbett & Benton (2009) in an investigation of rugby players emphasized the importance of reactive agility and confirmed that elite players had better response accuracy, faster decision and faster movement times on the reactive agility tests and in addition they emphasized the importance of the contribution of perceptual skill to agility. Athletes must improve their sprinting ability and their knee flexor strength to allow effective neuromuscular control of the contact phase in performing change of direction tasks (Jones et al. 2009).

Some earlier studies (Mercier et al. 1992, Inbar 1996, Beunen 1997, Dore et al. 2004, Mastrangelo et al. 2004) confirm that leg muscle power relates to body composition (especially body mass and fat free mass). So it may be assumed that body composition and anthropometrical characteristics influence performance in change-of-direction tasks. In sports games, such as soccer and rugby, Reilly et al. (2000a) and Gabbett (2002) found that athletes who perform better on change-of-direction speed tests also tend to have lower body fat.

Factors that could potentially be related to change-of-direction speed performance are body height, relative limb length, and the height of the athlete's centre of gravity (Sheppard & Young 2006). Persons with a low centre of gravity could be able to apply horizontal force more quickly than a taller athlete, because they would require less time to lower their centre of gravity in preparation for a lateral direction change (Sheppard &Young 2006). Cronin et al. (2003) in a study with court-sport players suggest that limb length has a relationship with lunges typical of directional changes in badminton, squash and tennis. The lunges characterize movements in defence and breakthrough in handball and basketball as well. The investigation with adolescent soccer players (Malina et al. 2005) indicates that the contribution of body size, age, maturity status and years of experience to success in soccer-specific skill tests is relatively small (8–21%). Chronological age, body height, body mass and skeletal age in different combinations accounted for the largest percentage variation in performance at 14 and 15 years of age (Malina et al. 2004a).

Many factors other than body size and maturity status, such as neural control of movement and perceptual-cognitive skills (anticipation, visual search strategies) influence performance in sport-specific skill tests (Williams & Reilly 2000). The central components in the development of playing ability of young athletes are the coordination of sporting movements and sport-specific technical skills (Dierks & Daum 1997, Malina et al. 2005, Gabbett 2006, Ostojic et al. 2006), which are dependent upon speed, agility, explosive power of lower and upper limbs (Hoffmann et al. 2000, Gabbett et al. 2005) and which must be performed repeatedly with minimal cost in time (Dierks & Daum 1997, Hoffmann et al. 2000, Gabbett et al. 2005).

Results of a study with professional soccer players (Little & Williams 2005) suggest that acceleration, maximum speed and agility are relatively independent of each other and require high power production, which itself partly depends upon the leg explosive strength, body mass and fibre type proportion.

2.5. Strength and power of upper body and relations with anthropometrical characteristics

In earlier studies it has been confirmed that throwing velocity in handball and rugby, which is dependent on the ability to produce power, is important for success (Hoff & Almasbåkk 1995, van den Tillaar 2004, Gabbett 2005).

Muijtjens et al. (1991) noted that the combination of ball velocity and accuracy in throwing is one of the most important factors and has a decisive role in scoring. Three basic components have an effect on the efficiency of arm throwing (Jöris et al. 1985, Muijtjens et al. 1991, Gorostiaga et al. 2005): throwing technique, the timing of consecutive actions of body segments and upper and lower limbs' muscle strength and power. In handball, the players predominantly use only one arm and it could be presumed that training in different sports will induce different effects on arm strength (Bencke et al. 2002). The higher relationship between throwing tests' results with dominant hand and anthropometrical characteristics could be explained by better technical performance (Van den Tillaar & Ettema, 2004) which allows to take better advantage of body height and body composition. This enables better energy transfer through the kinematical chain during the handball throw (Skoufas et al. 2002, Gorostiaga et al. 2005). Barata (1992) found in an earlier study with adolescent handball players that technique rather than force will influence the handball throw velocity which was also confirmed by Gorostiaga et al. (2005) in a study with elite and amateur handball players.

The adolescents' spurt in arm strength begins 1.5 years before the age of peak height velocity and reaches the peak about 0.5 years after peak height velocity. The anaerobic peak power and mean power of arms during adolescence are highly correlated with lean body mass and fat-free mass among boys (Blimkie et al. 1988). The relative increase is greater in upper body strength than in lower body strength when the strength gains are expressed as a percentage of the level of strength increments (Beunen & Malina 1988). In a study with young soccer players Hansen et al. (1999) found that the increase in muscle strength may be due to a greater relative increase in the muscle mass of the young elite players and thus a larger cross-sectional area of muscles. According to Deighan et al. (2006) the mean muscle cross-sectional area of upper arm for 9–10 years old boys was 12.9±2.6 cm^2, for 16–17 years old young males it was 30.3±4.2 cm^2 and for males over 21 years it was 37.5± 7.9 cm^2. The percentage increase between the child and adult age groups was 207% for elbow extensor muscle cross-sectional area and 210% for elbow flexor muscle cross-sectional area. The development in static strength is partially related to hypertrophy of the muscles (Hansen et al. 1999).

Handball players have a greater overload of the force component in the medicine ball throw and a greater overload of the velocity component in handball throw (Gorostiaga et al. 1999, Skoufas et al. 2003, Van den Tillaar 2004). On the basis of force-velocity relationship it can be derived that slow movements are ideal for generating high mechanical force; at the same time many functional activities are performed at fast velocities which are less conducive to high force generation (Weiss et al. 2002) which partially influences the role of general anthropometrical parameters in different throwing and static strength tests. According to Delgado et al. (1993) the force-velocity relationship of upper limbs correlates highly with body height and body mass during puberty. For the same reason anthropometrical characteristics have different effect on medicine ball and handball throw for younger and older age groups, because handball players have different training and playing experience in different age groups.

Maximal strength and force production of upper extremities depend more on body mass, BMI (Gorostiaga et al. 2005) and body size (Van den Tillaar &

Ettema 2004). Higher fat free mass gives an advantage in absolute maximal strength and muscle power (Gorostiaga et al. 2005) and partially explains the difference in handball throw velocity between experienced and novice players (Van den Tillaar & Ettema 2004, Granados et al. 2007). Throwing distance relates strongly to muscle power and throwing velocity, body mass and fat free mass (Van den Tillaar & Ettema 2004). Explosive power is a crucial factor in ball throwing and throwing technique is an important contributor to its successful execution (Falk et al. 2004).

In addition to upper body strength and body dimensions the over-arm throw depends on the muscular power of lower limbs (Fleck et al. 1992, Gorostiaga et al. 2005, Hirashima et al. 2008) and whole body muscular strength (Jöris et al. 1985, Cardoso Marques & Gonzales-Badillo 2006, Marques et al. 2007). Beunen & Malina (1988) suggested that muscular strength increases linearly with chronological age from early childhood to approximately 12 or 13 years of age and that weight gain is accompanied by an increase in static strength (Malina et al. 2004a). Age at peak velocity in strength development is reached 0.5 to 1.0 year after peak height velocity (Beunen 1997) or around peak height velocity (Inbar 1996). The relationship between body mass and muscular strength is the highest at the age of 13 to 15 (Malina et al. 2004a). The increase in muscle strength with age in young boys cannot be explained only by growth as, in both pre-pubertal and pubertal boys, strength increases more rapidly than body height. The spurt in muscle mass in adolescents occurs shortly after peak height velocity (Malina et al. 2004a). Peak gain in muscle mass (Beunen & Malina 1988), and peak gain in muscle strength and power occur after peak height velocity or closer to peak weight velocity (Beunen & Malina 1988, Hulthen et al. 2001, Malina et al. 2004a).

Earlier studies with persons in pre-pubertal (Hansen et al. 1999, Ara et al. 2004), pubertal (Hansen et al. 1999, Apostolidis et al. 2004, Vicente-Rodriguez et al. 2004) and adult (Gorostiaga et al. 2005, Granados et al. 2007) age groups who are active in sports, including persons active in team handball, confirm that average body mass, fat free mass and BMI are higher among elite players than among amateur or non-elite players or non-active in sports persons. The studies with pre-pubertal and pubertal soccer players (Hansen et al. 1999) and adult handball players (Gorostiaga et al. 2006, Granados et al. 2008) confirmed that elite players were heavier and taller, but no significant differences in BMI occurred. The elite players had less subcutaneous fat which indicated a larger lean body mass likely caused by training-induced muscle hypertrophy. Peak muscle mass and peak muscle strength are achieved at a similar age (Hulthen et al. 2001).

In conclusion, the over-arm throw in handball is characterized by the effects of force, velocity and throwing technique which must be adjusted to the player's anthropometrical peculiarity. Regular participation in team handball practices and competitions can plausibly be associated with increased lean body mass and with lower whole body fat mass in young handball players.

2.6. Handgrip strength and relationships with anthropometrical parameters

Musculoskeletal development is one of the key features in childhood and adolescence. Hence, muscle action determines the functional requirements that are imposed on other organ systems (Neu et al. 2002, Rauch et al. 2002). The need to manage everyday tasks independently raises the necessity to produce sufficient grip force already in early childhood (Groslambert et al. 2002, Hager-Ross & Rösblad 2002). Hand grip strength is an important measure of general health and is regarded as one of the most reliable clinical methods for estimation of general strength (Mathiowetz et al. 1985, Fraser et al. 1999, Groslambert et al. 2002, Hager-Ross & Rösblad 2002).

Various occupational (Oh & Radwin 1993, Grant & Habes 1997, Josty et al. 1997) and sport settings (Grant et al. 2001, Pugh et al. 2003, Quaine et al. 2003, Watts et al. 2003) require a sustained level of hand prehensile force to maximize control and performance as well as to reduce the possibility of injuries (Blackwell et al. 1999). Most manual grips can be divided into precision and power grips (Fraser et al. 1999, Ehrsson et al. 2000, Pouydebat et al. 2009). During the precision grip task, the subjects apply the tips of the thumb and fingers for the manipulation of small objects. During the power grip task, subjects flex all digits in palmar opposition around an object (Flanagan et al. 1999, Ehrsson et al. 2000, Pouydebat et al. 2009). Ehrsson et al. (2000) observed that power grip was associated predominantly with contra-lateral left-sided brain activity, whereas precision grip tasks involved extensive activations in both hemispheres.

Prehensile movement of the hand has been described as cylinder, ball, ring, pliers or pincer grips – these grips are variants of either the precision or power grip (Nag et al. 2003). When handgrip strength is measured with hand dynamometer, the subjects produce force with all fingers (i.e. they perform a power grip task).

Handgrip strength measurement using hand dynamometer is a simple, economical and well-established method that gives information on muscle and other organs, as well as joint functions and disorders (Watts et al. 1993, Grant et al. 2001, Rauch et al. 2002, Ruiz-Ruiz et al. 2002, Vaz et al. 2002, Quaine et al. 2003). Grip strength reflects only one aspect of muscle function (Rauch et al. 2002) and does not provide insight into other functionally important measurements of muscle performance (Rauch et al. 2002).

The studies related to the force of the human hand and fingers are numerous (Fransson & Winkel 1991, Latash et al. 1998, Li et al. 1998a, Zatsiorsky et al. 2000) however, these studies concentrate on central neural factors. Additionally, several authors have investigated grip strength related to muscle disorders (Fraser et al. 1999, Rauch et al. 2002) and some paediatric researches have investigated grip strength in children and adolescents (Newman et al. 1984, Kromholz 1989, Häger-Ross & Rösblad 2002, Sartorio et al. 2002). Still, in these studies, hand grip strength data is mainly presented as a function of age and sex. Some also discuss differences between dominant and non-dominant hands (Mathiwetz et al. 1986, Kromholz 1989, De Smet & Vercammen 2001, Neu et al. 2002). The dimensional and anatomical features of the human hand, such as size and shape, and the texture of the object also influence the grip formation and grip strength (Fransson & Winkel 1991, Firrell & Crain 1996, Fraser et al. 1999, Ruiz-Ruiz et al. 2002, Nag et al. 2003).

The grip strength of the subjects increased year by year (Newman et al. 1984, Mathiowetz et al. 1986, Chatterjee & Chowdheeri 1991, De Smet & Vercammen 2001, Hager-Ross & Rösblad 2002, Rauch et al. 2002). Newman et al. (1984) agree that boys manifest an approximately linear increase in grip strength throughout all age groups of 5–18 years; a greater increase in maximal handgrip strength after the age of 11 was confirmed by the results of a study by Sartorio et al. (2002). Häger-Ross & Rösblad (2002) showed that the highest increase in handgrip strength appears at the age of 13 compared to 12. Rauch et al. (2002) demonstrated maximal increase in grip strength at the age of 14.1 years.

Previous studies (Chatterjee & Chowdheeri, 1991, Chau et al. 1997, Häger-Ross & Rösblad, 2002, Vaz et al. 2002) have shown that general anthropometrical characteristics such as body height and body mass significantly influenced handgrip strength in children and adults. Few studies have been found that have investigated the influence of hand dimensions and finger mobility on handgrip strength. An earlier study (Häger-Ross & Rösblad 2002) with children of different ages confirmed that hand length (distance from wrist joint to tip of middle finger) is an important parameter for handgrip strength, indicating that the contribution of age, mass and hand length in combination was significant for boys of all ages. The involvement of hand length in the handgrip strength of adults was noted in literature (Fraser et al. 1999). Previous studies confirmed that the contribution of each digit to the total grip force decreased from radial to ulnar (Kinoshita et al. 1996, Reilmann et al. 2001, Quaine et al. 2003, Olafsdottir et al. 2005). These studies investigated force production by individual digits in multi-finger tasks.

In a study of the influence of wrist position on individual finger strength during a forceful grip Li (2002) confirmed that the force-sharing percentage was 32.2 ± 3.8% for the index finger; 32.6 ± 4.3% for the middle finger; 23.5 ± 4.5% for the ring finger and 11.7 ± 4.9% for the little finger. Other earlier studies demonstrated approximately similar relative involvement of single fingers in maximal handgrip strength (Li et al. 1998a, Quaine et al. 2003, Olafsdottir et al. 2005). In a study with rock climbers (Quaine et al. 2003), a relatively higher contribution of the ring finger was found. It may be explained by the fact that different position of the thumb significantly influenced the force production of other digits except the little finger (Olafsdottir et al. 2005) and that the ring and the middle fingers are the least independent (Häger-Ross & Schieber 2000, Reilly & Hammond 2000b, Slobounov et al. 2002).

In the five-digit task, the digits shared the total force differently depending on the position of the thumb. When the thumb acted in parallel with the other digits, the index finger had the greatest force, followed by the middle finger, the thumb, the ring and the little finger. When the thumb acted in opposition to other fingers, it was the strongest (Li et al. 1998b, Olafsdottir et al. 2005), but in this position, the thumb enslaved other fingers 2.1 times more than in parallel acting. The ring finger showed 42% more enslaving than when the thumb acted in parallel with the others (Olafsdottir et al. 2005). It is important to note that the biomechanical analysis suggests that the primary line of the transmission of force is along the middle finger. Forces through the other fingers are also transmitted to the radius and with the excessive spreading of fingers the lines of the transmission of force are distorted (Nag et al. 2003). Nag et al. (2003) studied the relationship between hand length and other hand dimensions and noted that grasping an object that requires widely spread fingers is less efficient and more fatiguing than the one that confirms to neutral positions.

Earlier studies with rock climbers (Grant et al. 2001), tennis players (Maughan et al. 1986), fencers (Margonato et al. 1994) and handball players (Leyk et al. 2006) illustrate that trained subjects were able to exert greater grip strength. Nevill & Holder (2000) agree that handgrip strength was greatly associated with the level of physical activity and Josty et al. (1997) found that heavy manual workers had the strongest handgrip strength and office workers the weakest. In a study with highly trained elite female handball players and healthy young women (Leyk et al. 2006) found that hand-grip strength was linearly correlated with lean body mass and relative hand-grip parameters (Fmax/body weight and Fmax/LBM), and on the other hand it did not show any significant correlation to hand dimensions (hand length and hand width). However, the female players were significantly stronger than their untrained counterparts. In handball, the player must grip the handball (big object) predominantly with one hand and for successful holding and throwing the handball player needs strong hands and fingers. Kinnunen et al. (2001) confirmed significant correlation between basketball free throw shooting performance and handgrip strength as well as between basketball free throw shooting performance and hand width in a study with young girls.

The general anthropometrical characteristics such as body height and body mass significantly influenced handgrip strength in children and adults. The increase in the maximal isometric grip force during childhood and adolescence was affected by muscle growth during puberty and increase in grip force for muscle cross sectional area (Neu et al. 2002). Few studies have investigated the influence of hand dimensions and fingers' mobility on handgrip strength, only the importance of hand length (distance from wrist joint to tip of middle finger) has been confirmed.

2.7. Grasping, catching and throwing objects

Earlier studies confirmed that speed of movement with ball, agility in ball pass and ball manipulation ability were especially important specific abilities for successful play in handball (Katic et al. 2007). Different types of throws and passes are crucial elements of handball and basketball. Frequently, different biomechanical aspects of a throw have been studied (Jöris et al. 1985, Bideau et al. 2004, Gray et al. 2006, Sachlikidis & Salter 2007). Studies with baseball players (Gray et al. 2006) and young cricketers (Sachlikidis & Salter 2007) found that the speed-accuracy adjustment exists for the skilled hands and that unskilled players cannot throw fast because they have not developed the coordination mechanisms to effectively adjust interaction in joints.

Ball throwing is one of the most skilled multi-joint movements requiring excellent coordination between joints. The ball throwing movement requires not only high ball speed but also accuracy (Hirashima et al. 2007). Humans can throw a ball with a wide range of ball speed at the same time maintaining the hitting accuracy at the same level (Hirashima et al. 2003). Hore et al. (2001) in a study about the control of finger grip force in over-arm throws made by skilled throwers found that skilled throwers could adjust the finger grip force in proportion to the back force and keep the amplitude of finger extension relatively constant from throw to throw. The possible reason for constant amplitude of finger opening is to ensure the ball accuracy in throw (Hore et al. 2001, Hirashima et al. 2007). The variability in ball speed is due to variability in arm speed for skilled throwers (Jegede et al. 2005), but unskilled throwers could not control the finger grip force precisely (Timmann et al. 2001). As the lengths of the forearm and upper arm are longer than that of the hand, the angular velocity of the elbow and shoulder ensure the increase of ball speed, and the role of the wrist is to simplify the control of the finger grip force to ensure an accurate ball release (Hirashima et al. 2003).

However, the speed and accuracy of the throw or shot depend on different anthropometrical parameters of the player as well. Generally, taller players have some advantages compared to shorter players (Sidhu et al. 1975, Housh et al. 1984). More specifically, the arms' span and height with outstretched hands are probably the most important in ball throw. The longer arms' span enables effective manipulation of the ball (Skoufas et al. 2003, Katic et al. 2007). In a recent study with pubertal handball players Zapartidis et al. (2009) established that young elite players have bigger hands' spread, wider arms' span and are taller, than young sub-elite players; taking into consideration also the playing position the relationship was statistically significant for back-court players. However, there is lack of data about the influence of basic anthropometrical parameters on the results of different throwing techniques in young handball and basketball players.

Measurement of the hand and its segments is often included in large-scale anthropometrical studies (Staszkiewicz et al. 2002, Ruiz-Ruiz et al. 2002, Nag et al. 2003, Jürimäe et al. 2009). The hand functions include activities such as pushing, adjusting objects, striking blows, and supporting the body in space. The hand may be used as a fist, or forces may be transmitted through the fingers extended in close-packed positions. In college students, Nicolay & Walker (2005) concluded that longer fingers do not necessarily indicate greater strength, and may reduce mechanical efficiency. On the other hand, the longer the fingers, the better the accuracy of different shots or throws among children. All shots and throws are finished with the wrist and fingers which requires finger strength for holding the ball and for finishing the throw efficiently and accurately (Hore et al. 2001, Hirashima et al. 2003). This may be done more efficiently when fingers' and hand surface parameters are longer. Results of a recent study (Hung et al. 2008), where a multi-joint throwing task was carried out, indicated that throwing accuracy had an inverse relationship with the actual variability of end-point path. These findings support the theory that skill acquisition consists of two learning processes – intrinsic pattern of end-point path is acquired early during practice, while dynamic control (joint coordination) occurs at a much slower rate. The throwing velocity of experienced handball players was approximately 85% of the maximal velocity when practicing throwing accuracy (van den Tillaar & Ettema 2003). However, no trade-off has been found between speed and accuracy among novice handball players (van den Tillaar & Ettema 2006). The results of a study with rugby players by Trewartha et al. (2008) confirmed that players demonstrated greater accuracy at shorter throwing distances than during throws over longer distances.

The grasping of an object (handball, basketball, medicine ball) is the outcome of simultaneous movements of several joints – transporting the hand to the object, pre-shaping the fingers into an appropriate grip and orienting the wrist. All these movements may differ widely but they all attend the same final purpose: to achieve a stable grasp for holding and manipulating the object (Paulignan et al. 1997). The objects may be grasped in several ways due to their physical properties, the context surrounding the object or the goal of the grasping (Ansuini et al. 2008). The results of a study on grasping kinematics in case of different goals of grasping showed that the nature of the task to be performed after grasping affects the positioning of the fingers during the reaching phase (Ansuini et al. 2008). The maximum grip aperture during prehension is linearly related to the size of the object being grasped (Säfström & Edin 2008). If the object was larger than expected, the moment of contact occurred earlier, and conversely if the object decreased in size, the moment of contact occurred later. Mazyn et al. (2007) confirmed that the successful catch depends on the forward displacement of the hand and on the dynamics of the hand closure.

The literature related to the human hand is numerous and connected to structural issues (Hager-Ross & Schieber 2000), problems of mobility and forms of grasping (Blackwell et al. 1999). The role of the different finger lengths which produce different force is not well defined (Reilly & Hammond 2000b). The hand must be able to grasp the ball while energy is transmitted to it, and accurately control its release for efficient throwing. This requires a fingertip grip. The thumb and the two first fingers play a major role in the throwing grip (Young 2003). The thumb must be long enough and sufficiently mobile to position its fingertip pad to the ball on one side while the fingers oppose their distal pads to the opposite side (Young 2003).

No standard methodology exists for the measurement of hand anthropometry among children. For adults, Nicolay and Walker (2005) used six parameters and Nag et al. (2003) even 51 hand dimensions that include different length, breadth, circumference, depth, spread and clearance parameters of the hand and fingers. The hand perimeters are essential for handball players because they grasp and catch the ball with two hands and then handle (pass and throw) it predominantly with one hand which requires optimal hand surface and good technique.

2.8. Summary

In conclusion, high level of handball-specific and basic motor abilities is a precondition for high technical-tactical preparation. Most physical performance indexes reach a peak around the time of maximal growth in height and the performance continues to improve after peak height velocity due to the time differential in growth in muscle mass and regular training-induced influences (Philippaerts et al. 2006). Most of physical performance tests' results have a relationship with anthropometrical characteristics, especially with body height and lean body mass. Lean body mass to a great extent depends on activity in sports. Hand grip strength and hand dimensions are essential anthropometrical parameters for holding, throwing and catching an object which characterises the playing performance in handball.

Knowledge of the proven mechanisms in the morphological and functional changes and the specificities of the physical capabilities of boys and adolescents facilitate directing the youth's sporting activities, choosing the talented and compiling sport-specific and the youth's developmental phase specific training programs. Boys and adolescents active in sports may improve their anaerobic power through mechanisms that occur due to changes in their anthropometry and body composition, hormonal changes or relatively high level of daily physical activity (Naughton et al. 2000).

Players who outperform their peers in terms of basic and specific physical abilities, which are partially due to their advantages in anthropometrical dimensions, proceed to the next level teams earlier. Even though in handball the early mature adolescents are often more successful, a handball player fully matures only at the age of 26 (Roattino & Lacour 1994).

Despite the studies about pubertal changes and the effect of regular training on the development of the organism of a youth, the distinction between and identification of the extent of the effect of training and the extent of changes due to the natural development of the body is difficult. However, it is crucial to identify sport-specific requirements for the player from beginner's level to professional in order to choose and guide the preparation.

3. AIMS OF THE INVESTIGATIONS

Different aspects of the physical and physiological requirements for participation in elite handball have been studied earlier focusing mostly on adults (Gorostiaga et al. 2005, Ronglan et al. 2006, Granados et al. 2008, Chaouachi et al. 2009). Lidor et al. (2005) and Mohamed et al. (2009) have studied talent identification in handball. However, there have been no complex investigations into young handball players in the age group 10 to 17 years. Our hypothesis regarding young competitive level handball players were,

1. Basic anthropometrical parameters influence at all ages general motor abilities more than specific motor abilities and are weak predictors of handball-specific motor abilities, the needed agility and technical skills.
2. Maximal handgrip strength is largely determined by specific hand anthropometrical parameters, specifically the length of the fingers.
3. Hand specific anthropometrical parameters are important for the results of different specific and non-specific throwing tests among young handball and basketball players.

The aim of the present cross-sectional study was:

1. To investigate anthropometrical characteristics and basic as well as handball-specific motor abilities of young Estonian male handball players.
2. To investigate the relationship between anthropometrical characteristics and basic and handball-specific motor abilities in young male handball players and to compare these relations in different age groups.
3. To investigate the relationships of basic body and specific hand anthropometrical parameters with handgrip strength in boys going in for handball and basketball.
4. To investigate the relationships of basic body anthropometrical parameters and specific hand anthropometrical parameters with specific and non-specific throwing tests' results among young male handball and basketball players.

4. MATERIAL AND METHODS

4.1. Approach to the problem

The pattern of highly masterful player makes certain demands which must be taken into account already in the preparation of young players. The first part of the study was designed to determine general anthropometrical characteristics which are fundamental in the development of basic and handball-specific motor abilities. The present cross-sectional study compared the relationship of general anthropometrical parameters to basic and handball-specific motor abilities and compared their differences in 10–17 year old handball players.

The second part of the study was conducted to compare the relationships of hand specific anthropometrical parameters (finger span, finger length and perimeters) to the handgrip strength in 10–17 year-old handball and basketball players with a new simple method for the measurement of hand-specific anthropometrical parameters. The relationships of basic body anthropometry (body height, body mass, BMI) on the handgrip strength were studied as well.

Thirdly, the importance of basic body and hand anthropometry in the results of different throwing tests among young handball and basketball players was investigated.

4.2. Subjects

In total, 193 Estonian handball and basketball-playing non-obese boys aged 10–17 participated in the study. The subjects were divided into different age groups based on the aims of the study. Biological age of the children was not measured because only chronological age is used for grouping in competitions. The subjects were exercising at the following frequency: 10–11-year-olds – 3 times per week, in total approximately 4.5 hours; 12–13-year-olds – 4 times per week, in total approximately 6.0 hours; 14–15-year-olds and 16–17-year-olds – 4–5 times per week, in total approximately 6.0–7.5 hours. Typical handball trainings were performed for increasing different skills, motor abilities, playing tactics, etc. No specific programs were used to develop certain basic or handball-specific motor abilities. All players belonged to the teams participating in the national championships of Estonia in their age category. In addition all players participated in compulsory physical education classes 2 times per week at school. All subjects were healthy and none of them was at that moment receiving any medicaments. All children and their parents were thoroughly informed of the purposes and content of the study and granted their consent to perform the experiments. This study was approved by the Medical Ethics Committee of the University of Tartu (Estonia).

In total 133 handball-playing non-obese Estonian boys aged 10–17 years participated in **study I.** The subjects were divided into four chronological age groups: 10–11-year-olds (n=34), 12–13-year-olds (n=39), 14–15-year-olds (n=39) and 16–17-year-olds (n=21).

In total, 193 Estonian handball- and basketball-playing non-obese boys aged 10–17 participated in **study II**. The subjects were divided into six groups: 10-year-olds (n=35), 11-year-olds (n=37), 12-year-olds (n=37), 13-year-olds (n= 24), 14–15-year-olds (n=39), and 16–17-year-olds (n=21).

The subjects of **study III** were 34 handball and 38 basketball players in the 10–11 years old age group, 39 handball and 22 basketball players in the 12–13 years old age group and 39 handball players in the 14–15 years old age group – in total 172 boys.

4.3. Measurements of anthropometrical characteristics

The body standing height, sitting height (Hansen et al. 1999, Damsgaard et al. 2001), and body height with outstretched hands (Gabbett et al. 2006) were measured (Martin metal anthropometer) to the nearest 0.1 cm. Body mass was measured (medical electronic scale; A&D Instruments Ltd, Abingdon, UK) to the nearest 0.05 kg. The body mass index (BMI $kg{\cdot}m^{-2}$) was calculated as body mass (kg) divided by height (m) squared. Arms' span (Damsgaard et al. 2001, Cook et al. 2006) was measured (Martin metal anthropometer) as the distance between the tips of the longest digits on each hand with the arms stretched out horizontally. Leg length was calculated as standing height minus sitting height (Dore et al. 2005) to the nearest 0.1 cm.

A new original method was presented for the measurement of specific anthropometrical parameters of the hand. The subjects were asked to be seated comfortably and were instructed to place the spread and stretched out dominant hand onto a paper on the table. The outline of the hand was drawn on the paper. The outlines of the dominant hand were drawn by one examiner for all subjects. The outlines were drawn with a thin marker that was placed perpendicularly onto the paper. The contour of the hand was drawn with maximal active voluntary adduction of thumb and other fingers. The outlines of the dominant hand of the subjects were used for measuring specific hand anthropometrical parameters. Three groups of parameters were measured: fingers' span, fingers' length and some circumferences of the hand. The dimensions of the hand were measured with an accuracy of 0.1 cm. The following parameters of fingers' span were measured (Figure 1): from the tip of the thumb to the tip of the index finger (finger span 1 – FS1); from the tip of the thumb to the tip of the middle finger (finger span 2 – FS2); from the tip of the thumb to the tip of the ring finger (finger span 3 – FS3); from the tip of the thumb to the tip of the little finger (finger span 4 – FS4); from the tip of the thumb to the tips of all fingers (finger span 5 – FS 5). Fingers' length was measured between the wrist ([W] proximal starting point at the hand length measurement) joint and the tip of the fingers (Figure 2): length from the wrist joint to the tip of the thumb (thumb length – TL); length from the wrist joint to the tip of the index finger (index finger length – IFL), length from the wrist joint to the tip of the middle finger (middle finger length – MFL); length from the wrist joint to the tip of the ring finger (ring finger length – RFL); length from the wrist joint to the tip of the little finger (little finger length – LFL). The following perimeters of the dominant hand were measured (Figure 3): from the wrist (W) joint to the tip of the thumb (T) to the tip of the index (I) finger and to the wrist (W) joint (WTIW – P1); from the wrist (W) joint to the tip of the thumb (T) to the tip of the middle (M) finger and to the wrist (W) joint (WTMW – P2); from the wrist (W) joint to the tip of the index (I) finger to the tip of the middle (M) finger and to the wrist (W) joint (WIMW – P3); from the wrist (W) joint to the tip of the middle (M) finger to the tip of the ring (R) finger to the tip of the little (L) finger and to the wrist (W) joint (WMRLW – P4); from the wrist (W) joint to the tips of all fingers and to the wrist (W) joint (WTIMRLW – P5).

For ten 10–11 and eleven 16–17-year-old boys, the hand anthropometry was repeated with a one-hour interval for two times to calculate the reliability of the measurement (intra-class correlations [ICCs]).

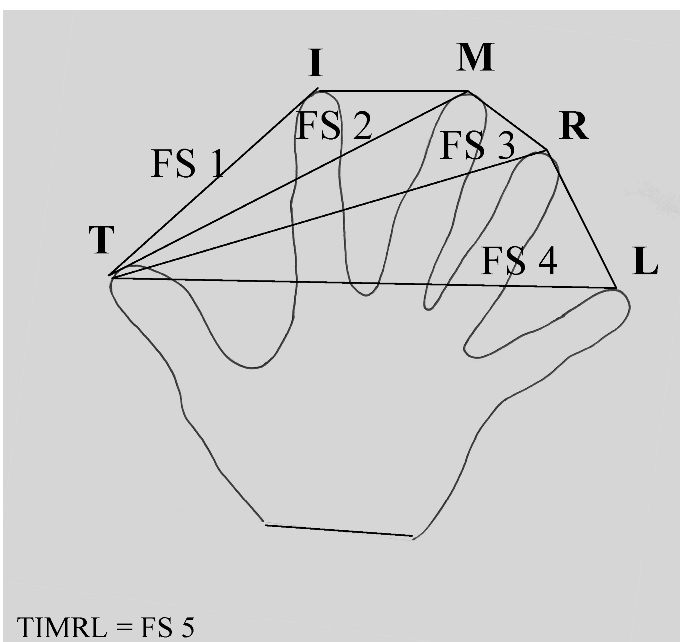

Figure 1. Measured finger spans of the dominant hand (explanations see text)

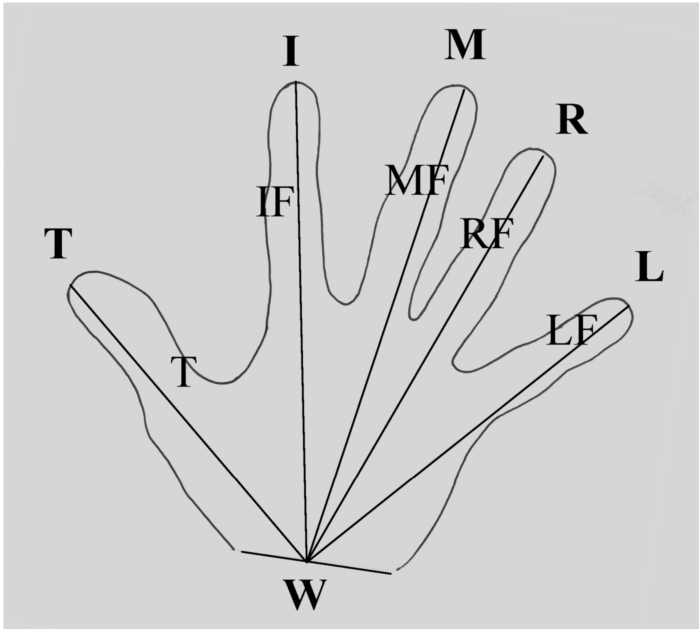

Figure 2. Measured finger lengths of the dominant hand (explanations see text)

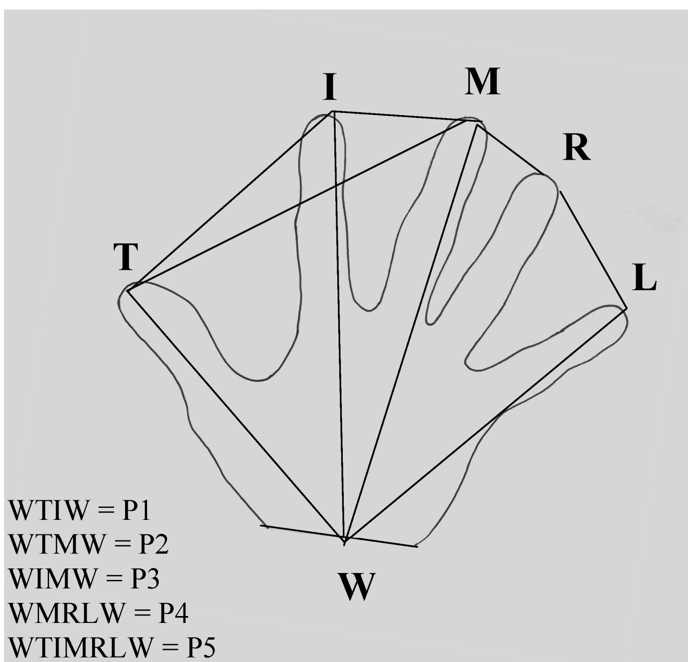

Figure 3. Measured finger perimeters of the dominant hand (explanations see text)

4.4. Measurement of handgrip strength

The maximal handgrip strength of the dominant hand was measured with a hand dynamometer (Lafayette Instrument, Lafayette IN, USA). Hand dominance was determined by asking for the hand used to hold a pencil and throw a ball (Ager et al. 1984). Two settings of the dynamometer were used: the first setting was for 10–12-year-old boys (5.0 cm) and the second setting (6.0 cm) was for boys 13 years of age and older. The subjects were standing comfortably with the shoulders adducted. The dynamometer was held freely without support; it was not touching the subject's trunk. The position of the hand remained constant in a downward direction. The palm did not flex at the wrist joint. The subjects were required to exert maximal strength on the dynamometer (maximal voluntary contraction). All subjects performed three trials with the dominant hand, and the best performance was used. The scale of the dynamometer indicated handgrip strength in kilograms. Maximal grip strength in Newtons was calculated by multiplying the dynamometer index by 9.81.

4.5. Measurement of basic motor abilities

For the measurement of basic motor abilities the following tests were used (Lidor et al. 2005, Kotzamanidis 2006):

The 30 m run (Wicente-Rodriguez et al. 2004) from standing position in an indoor handball field. Sprint times were recorded with 0.01 s accuracy with an electronic chronometer (IVAR, ESTONIA), with photocells at the start line and at the finish line. The subjects decided themselves when to start from a static position 1.0 m behind the photocell. The time was recorded when the subjects intercepted the photocell beam and stopped when the subjects intercepted the photocell beam at the finish line. Each subject performed two trials and the best time was used in further analyses. Recovery time between trials was 2 minutes.

Vertical jump on contact platform (Newtest OY, Finland)

- with hands on hip (Squat jump – SJ) (Hara et al. 2005, Vicente-Rodriquez et al. 2004). From a standing position, legs in semi-squat position, arms placed on the hips subjects performed three jumps with recovery time between each jump. The participants were informed to try to jump as high as possible. The jumps were recorded in centimetres and the highest was used in data analyses.
- with arms' swing (counter-movement jump – CMJ) (Corostiaga et al. 2004, Vicente-Rodriguez et al. 2004). Hara et al. (2005) found that total work done by all the joints increased significantly with arms' swing: 34% of this increase came from upper extremity joints and 66% from the lower extremity joints. The players were asked to perform a maximal jump on the contact platform from the upright position with a preparatory movement into the semi-squat position followed by an immediate attempt to jump as high as possible with an arm swing.

Medicine ball (1 kg) over-arm throws with dominant hand from sitting position. Medicine ball (1 kg) throw was used to assess explosive power of the upper limbs. Different medicine ball throw tests have been used to assess the dynamic strength and muscular power of the upper extremities of handball players (Spiezny & Zak 1999, Lidor et al. 2005). The subjects threw a 1-kg medicine ball as far as they could. The medicine ball was thrown over-arm with dominant hand from the sitting position. Both feet were stretched out behind the throwing line and the upper body was upright to minimize the contribution from upper body and foot muscles. Throwing distance was measured to the nearest 1 cm. Each subject performed 3 trials and the best was used in further analyses.

4.6. Measurement of specific motor abilities

For the measurement of specific motor abilities the following tests were used (Lidor et al. 2005):

4x10 shuttle run to estimate agility and specific speed (Lidor et al. 2005). The distance of 10 m was marked on the floor with two white lines (width 5 cm). The subjects were required to run the distance of 10 m back and forth twice (four times in all). After each 10 m distance the participant had to cross over a white line with both feet. After the last 10-meter-run, when returning to the starting point, the time was recorded by the experimenter using a handheld stopwatch with 0.01 s accuracy. The subjects were asked to run every 10 m as fast as possible and turn around as fast as possible after every 10 m.

Slalom dribble test. Skill, agility, ball handling on dribble and changes of direction were assessed in a slalom dribble test. In some previous studies (Lidor et al. 2005) different versions of slalom dribble test were used to estimate the skill, agility and technical preparation of handball players. In this study the slalom dribble test version displayed in Figure 4 was performed. Subjects dribbled the handball around six cones and finished the test with a jump shot on the goal. Each subject dribbled the distance twice and the sum of two trials was used in further analyses. Test time was recorded with a handheld stopwatch with 0.01 s accuracy. Two minutes recovery was given between trials. On the first attempt at the starting line the subjects began dribbling with the right hand to the right side around the first (1) cone, then from the left side around the second (2) cone, then from the right side with the right hand around the third (3) cone, then with the left hand around the fourth (4) cone, then with the right hand around the fifth (5) cone and to the left side around the sixth (6) cone to finish the test with a jump shot on the goal (Figure 4). The time was stopped by handheld stopwatch at the moment when the ball left from the player's hand. On the second attempt the participants began the dribble to the left side, dribble around 1a, 2, 3a, 4, 5a cone and finished around the sixth (6) cone to the right side with a jump shot on the goal (Figure 4).

30-metre dribbles to estimate dribbling technique and speed. See the section "30 m sprint" for the description of the performance of the test.

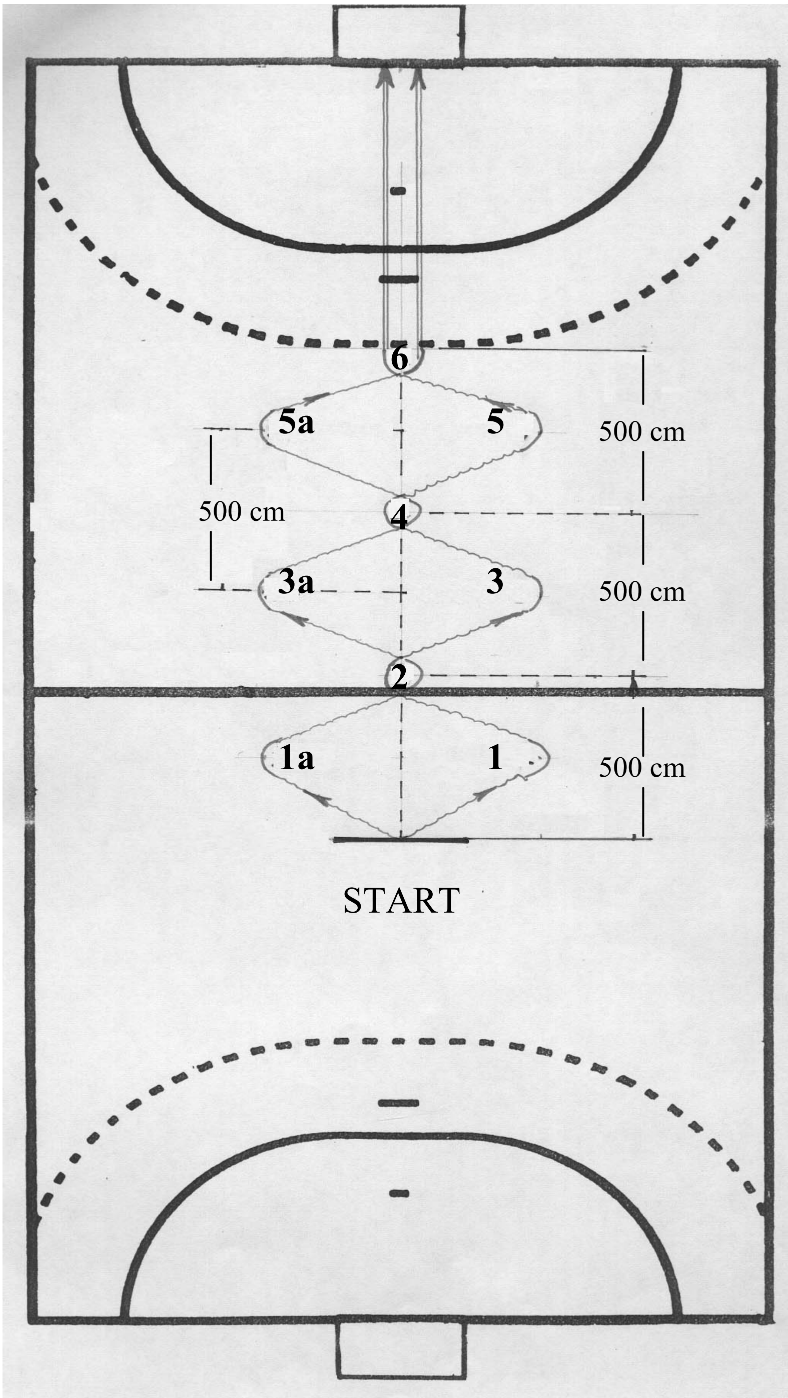

Figure 4. Slalom dribble test (explanations see text)

Handball throws with dominant hand in a sitting position to estimate throwing power. The subjects were asked to throw as far as possible. See the section "medicine ball throw test" for the description of the performance of the handball throw test.

From one step run-up vertical jump on dominant leg to assess explosive power of dominant leg (Newtest OY, Finland). Most jumps in team handball are performed from out-legged vertical jump (shots from wings, shots from fast-break, shots-in-the-distance). The subjects performed three trials and the best was used in further analyses.

Pass the ball on speed and precision. A line for making the pass was drawn on the floor 3 m from the wall (Figure 5) and a 40x40 cm square was drawn on the wall with the lower side at 180 cm from the floor. Subjects were standing behind the line for the pass in a comfortable catching-passing position and were passing on the target on the wall with maximum speed during 30 s. Handball players used the catch with two hands and the over-arm pass with the dominant hand; basketball players used the catch and pass with two hands at the chest. Handball players used handball nr. 2 and basketball players used the basketball. Two investigators recorded all passes that the subjects performed during the 30s and the passes that the subjects performed accurately on the target. All performed passes were recorded as passes on the speed and passes which were on the target were recorded as precision passes. The same investigators recorded the tests with all subjects and all tests were performed in the same place.

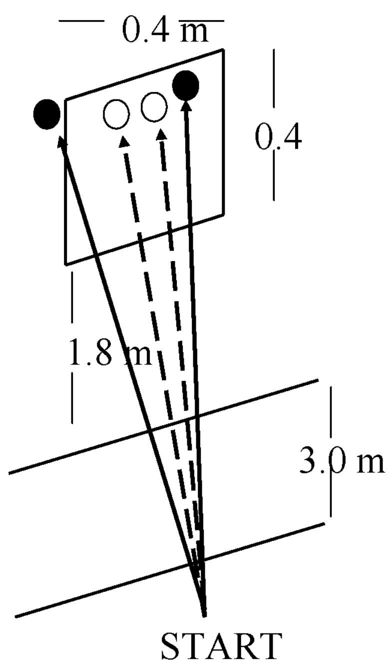

Figure 5. The passing the ball on speed and precision (explanations see text)

4.7. Statistical analysis

The analysis was conducted using the SPSS version 10.0 statistical software program (SPSS Inc., Chicago, IL). Standard statistical methods were used to calculate mean ($\overline{X}$) and standard deviation (± SD). A Fisher`s least significant differences test was used to determine the differences between age groups. Pearson correlation coefficients were used to determine the relationships between dependent variables. As handgrip strength highly correlated with body mass, the partial correlation analyses was used to calculate the relationship between handgrip strength and hand anthropometrical parameters where body mass was eliminated. The stepwise multiple regression analysis was used to determine the effect of general body and specific hand anthropometrical parameters (fingers' span, fingers' length and circumferences) on the handgrip strength. Reliability of hand anthropometrical parameters was assessed using 2-way average-measures ICCs, based on subset of ten 10–11-year-old and eleven 16–17-year-old boys. The α level of 0.05 was used for all statistical tests.

5. RESULTS

5.1. Relationships between anthropometrical characteristics and basic and specific motor abilities in young handball players (study I)

There were significant differences between each age group in body height, body mass, BMI, arms span, height with outstretched hands, sitting height and leg length ($p<0.05$, Table 1). In each older age group the results were significantly better in 30 m run, vertical jump with hands on hip (except between 14–15-yr.-olds and 16–17-yr.-olds), vertical jump with arms' swing (except between 14–15-yr.-olds and 16–17-yr.-olds), medicine ball throw from sitting position and handgrip strength. In all used specific motor ability tests, the results in the older age group were significantly better than in the younger group ($p<0.05$–0.001).

Table 1. Mean anthropometrical characteristics and general and specific motor abilities of young handball players ($\overline{X}$ ±SD).

	10–11 years (n=34)	12–13 years (n=39)	14–15 years (n=39)	16–17 years (n=21)
Anthropometry				
Body height (cm)	146.6±6.8	160.1±9.2	173.0±6.4	176.6±7.7
Body mass (kg)	37.7±6.1	47.1±8.0	60.9±9.0	68.3±10.3
BMI (kg/m^{-2})	17.3±1.7	18.2±1.6	20.4±1.7	21.9±2.0
Arms' span (cm)	147.1±9.0	160.3±10.4	175.1±8.1	181.1±9.2
Height with out-stretched hands (cm)	185.4±9.7	202.8±12.5	220.5±9.8	227.3±8.9
Sitting height (cm)	75.0±3.0	80.8±4.7	88.0±3.6	89.6±4.8
Leg length (cm)	71.6±5.3	79.3±5.1	84.8±4.9	87.0±4.3
Basic motor ability tests				
30 m run from standing position (s)	5.48±0.32	5.06±0.29	4.61±0.28	4.47±0.28
Vertical jump with arms' on hip (cm)	23.62±4.49	27.85±4.09	32.26±4.57	35.67±6.18
Vertical jump with arms' swing (cm)	28.74±5.00	33.79±3.95	37.85±5.13	41.62±5.43
Medicine ball (1 kg) throw with dominant hand from sitting position (m)	4.65±0.85	6.79±1.43	10.64±2.17	12.90±2.19
Handgrip strength of the dominant hand (kg)	16.32±6.10	26.90±8.10	42.26±7.96	48.05±11.00
Specific motor ability tests				
4x10 m shuttle run (s)	12.06±0.67	11.44±0.67	10.78±0.48	10.35±0. 46
Slalom dribble test (s)	21.89±2.57	18.83±2.03	16.61±1.11	16.36±1.36
30 m dribbling test (s)	6.14±0.45	5.48±0.42	5.01±0.33	4.76±0.32

	10–11 years (n=34)	12–13 years (n=39)	14–15 years (n=39)	16–17 years (n=21)
Handball throw with dominant hand from sitting position (m)	9.14±1.85	13.42±3.14	19.06±3.63	21.93±3.29
Vertical jump from dominant leg (cm)	20.09±5.51	22.97±3.14	27.85±4.90	31.81±6.08
Handball pass on speed and precision (x)-30s	12.56±3.10	16.67±3.29	19.23±2.90	19.33±4.23

* In anthropometrical characteristics there were significant differences between each age group ($p<0.05$).
* From the basic motor ability tests in each older age group the results were significantly better in 30 m run, vertical jump with arms swing (except between 14–15-yr.-olds and 16–17-yr.-olds), medicine ball throw from sitting position and handgrip strength.
* In all used specific motor ability tests the results in older age groups were significantly better than in younger ones.

The basic motor abilities were selected as dependent variables and anthropometrical parameters as independent variables for stepwise multiple regression analysis (Table 2). There were relatively few anthropometrical parameters which significantly influenced basic motor abilities. It was interesting that sitting height significantly influenced all measured basic motor ability test results in 14–15-yr.-old group (16.48–52.35%, R^2x100). Only some of the specific motor abilities were predicted by the anthropometrical parameters (Table 3). The most important was sitting height which influenced different test results by 13.41–41.59% (R^2x100).

Table 2. Stepwise multiple regressions where basic motor abilities are the dependent variable and all used anthropometrical characteristics are independent variables

Dependent variable	Age	Independent variables	R^2x100	F	P
30 m run	10–11	Body height	10.92	5.04	<0.032
	14–15	Sitting height	16.48	8.50	<0.006
Vertical jump with hands on hip	14–15	Sitting height	22.95	12.32	<0.001
Vertical jump with arms' swing	10–11	Leg length	13.82	3.65	<0.038
	14–15	Sitting height	23.17	12.46	<0.001
Medicine ball throw	10–11	Body height	36.91	20.31	<0.000
	12–13	Body mass, height with outstretched hands	61.80	31.34	<0.000
	14–15	Sitting height	37.31	23.62	<0.000
	16–17	Arms' span	54.61	25.06	<0.000
Handgrip strength	10–11	Body mass	43.80	26.72	<0.000
	12–13	Body mass	27.55	15.45	<0.000
	14–15	Sitting height	52.35	21.87	<0.000
	16–17	Body mass	43.83	16.60	<0.001

Table 3. Stepwise multiple regressions where specific motor ability test results are the dependent variable and all used anthropometrical characteristics are independent variables

Dependent variable	Age	Independent variables	R^2x100	F	P
4x10 m shuttle run	10–11	BMI Body height	12.33	3.32	<0.049
	14–15	Sitting height	13.67	7.02	<0.012
30 m dribbling	12–13	Arms' span	10.78	5.59	<0.024
Vertical jump from one leg	12–13	BMI	8.04	4.32	<0.045
	14–15	Sitting height	13.41	6.89	<0.013
Handball pass on speed and precision	12–13	Sitting height	21.56	6.22	<0.004
Handball throw from sitting position	10–11	Body height	45.19	28.21	<0.000
	12–13	Height with outstretched hands	55.05	48.69	<0.000
	14–15	Sitting height	41.59	14.53	<0.000
	16–17	Arms' span	61.17	32.50	<0.000

5.2. Handgrip strength and hand dimensions in young handball and basketball players (study II)

In Tables 4 and 5, the mean general body and specific hand anthropometrical parameters are presented. Body height and body mass had increased significantly by the age of 12 compared to similar measures in 11-year-old boys; by the age of 13, compared to similar measures in 12-year-olds; and by the age 14–15 compared to similar measures in 13-year-olds. Additionally, body mass increased significantly by the age 16–17, compared to measures in 14–15-year-olds. The increase in BMI was significant at the age of 12, compared with BMI in 11-year-olds, at the age of 14–15, compared with BMI in 13-year-olds, and at the age of 16–17 compared with BMI in 14–15-year-olds. There were only a few significant differences in fingers' span parameters year by year. FS1 increased significantly at the age of 11, compared to 10-year-olds; FS3, FS4, and FS5 increased significantly at the age of 13, compared to 12-year-olds; and FS1, FS2, and FS3 increased significantly at the age of 14–15, compared to 13-year-olds

All fingers' lengths had increased significantly at the age of 12, 13, and 14–15, compared with boys who were, respectively, 1 year younger ($p < 0.05$); the increase in IFL was statistically significant ($p < 0.05$) between ages 10 and 11 and between ages 14–15 and 16–17. Finally RFL increased significantly between ages 14–15 and 16–17. There were significant differences in all hand perimeters (P1–P5) of boys at the ages of 12, 13, and 14–15 compared with boys who were, respectively, 1 year younger and in perimeters P1 and P2 at the age of 11 compared to 10-year-olds. The reliability of the hand anthropometrical parameters (finger spans, finger length, and perimeters) in both groups of children was very high ($r > 0.92$).

Table 4. Mean basic anthropometrical parameters and handgrip strength in boys ($\overline{X}$ ± SD)

Variable	Age groups (years)					
	10 (n = 35)	11 (n = 37)	12 (n = 37)	13 (n = 24)	14–15 (n = 39)	16–17 (n = 21)
Height (cm)	146.6 ± 6.2	149.6 ± 7.6	157.7 ± 9.1 *	163.9 ± 8.0*	173.0 ± 6.4 *	176.6 ± 7.7
Body mass (kg)	37.2 ± 5.4	38.7 ± 5.6	45.5 ± 8.6 *	50.2 ± 8.6*	61.4 ± 7.9 *	68.4 ± 10.6*
BMI (kg/m^2)	17.2 ± 2.0	17.3 ± 1.6	18.1 ± 1.8*	18.5 ± 1.7	20.4 ± 1.7 *	21.8 ± 1.9*
Handgrip strength (N)	171.5 ± 49.8	194.6 ± 55.8	260.9 ± 78.3 *	285.3 ± 82.5	414.5 ± 78.1 *	471.8 ± 108.0*

* $p < 0.05$ with the younger age group

Table 5. Mean specific hand anthropometrical dimensions in centimeters ($\overline{X}$ ± SD)

Variable	Age groups (years)					
	10 (n = 35)	11 (n = 37)	12 (n = 37)	13 (n = 24)	14–15 (n = 39)	16–17 (n = 21)
FS1	9.7 ± 1.3	10.5 ± 1.8*	10.7 ± 1.5	11.1 ± 1.8	12.0 ± 1.6 *	12.2 ± 1.1
FS2	13.8 ± 1.5	14.4 ± 1.9	14.8 ± 1.7	15.4 ± 1.8	16.5 ± 1.6 *	16.4 ± 1.3
FS3	15.9 ± 1.5	16.5 ± 1.8	17.0 ± 1.7	17.9 ± 1.9 *	18.9 ± 1.5 *	18.8 ± 1.3
FS4	17.6 ± 1.4	18.0 ± 1.8	18.6 ± 1.6	19.7 ± 1.7 *	20.6 ± 1.5	20.4 ± 1.4
FS5	23.9 ± 2.3	24.4 ± 2.6	25.1 ± 2.1	26.5 ± 2.7 *	27.6 ± 1.9	27.2 ± 2.4
TL	10.7 ± 0.9	11.1 ± 1.0	11.7 ± 1.1*	12.9 ± 1.0 *	13.4 ± 1.0 *	13.9 ± 1.0
IFL	15.2 ± 0.7	15.6 ± 0.9 *	16.3 ± 1.1*	17.7 ± 1.1 *	18.5 ± 1.0*	19.1 ± 1.1 *
MFL	16.2 ± 0.8	16.3 ± 0.9	17.3 ± 1.0 *	18.6 ± 1.1 *	19.5 ± 1.0 *	20.0 ± 1.0
RFL	15.7 ± 0.8	15.8 ± 0.9	16.6 ± 0.9 *	17.7 ± 1.1 *	18.7 ± 0.9 *	19.3 ± 0.9 *
LFL	13.8 ± 0.8	13.9 ± 0.8	14.7 ± 0.9 *	15.5 ± 1.0 *	16.5 ± 1.0 *	16.9 ± 0.8
P1	35.6 ± 1.9	37.2 ± 2.8 *	38.7 ± 2.7 *	41.6 ±3.0 *	44.0 ± 2.4 *	45.2 ± 2.2
P2	40.7 ± 2.2	42.0 ± 2.9 *	43.8 ± 2.7 *	46.8 ± 3.1 *	49.4 ± 2.4 *	50.4 ± 2.3
P3	36.4 ± 1.7	37.0 ± 2.1	38.5 ± 2.2 *	41.5 ± 2.6 *	43.4 ± 2.4 *	44.2 ± 2.2
P4	39.2 ± 2.0	39.5 ± 2.2	41.4 ± 2.3 *	44.3 ± 2.8 *	46.2 ± 2.3 *	46.8 ± 2.8
P5	48.4 ± 2.7	49.4 ± 3.3	51.5 ± 3.0 *	54.9 ± 3.8 *	57.5 ± 2.8 *	58.0 ± 3.2

* $p<0.05$ compared with the younger age group. Abbreviations: see Methods

Table 4 presents the mean handgrip strength measures for the dominant hand with the advancement of age. From the total of 193 sportsmen studied, the right hand was dominant for 179 (92.7%) and left hand for 14 (7.3%) boys. There were significant differences in maximal handgrip strength at the age of 12 compared with that observed in 11-year-old boys, at the age of 14–15 compared with that observed in 13-year-old boys, and at the age of 16–17 compared with that observed in 14–15-year-old boys.

In most cases there were highly significant relationships between maximal handgrip strength of the dominant hand and general anthropometrical variables (r = 0.39–0.79) in all age groups (Table 6), but this was not the case with the specific hand dimensions. Maximal handgrip strength of the dominant hand correlated significantly with all finger span dimensions only in 14–15-year-olds (r = 0.54–0.65). However, after controlling for body mass, the relationship was significant but lower. Maximal handgrip strength was significantly related to fingers' length at the age of 12 (r = 0.34–0.54), 13 (r = 0.41–0.53) and 16–17 (r = 0.52–0.67). Interestingly, after controlling for body mass, this relationship was not significant with regard to 12- and 13-year-olds and in 14–15-year-olds in TL, IFL, and MFL. At the ages of 10, 11 and 13, the maximal handgrip strength did not correlate significantly with any finger spans or at the age of 10 with any finger length. All measured hand perimeters demonstrated a significant relationship with maximal handgrip strength at the ages of 12 (r = 0.46–0.62) and 16–17 (r = 0.54–0.65); this result was similar to that observed with the relationships between handgrip strength and finger length. After controlling for body mass in 16–17-year-olds, none of these relationships were significant any more, and in the case of the 12-year-olds, the relationship was lower but significant in P2, P3, and P5.

The results of the stepwise multiple regression analysis are presented in Table 7. From the hand anthropometrical parameters (independent parameters were all measured finger spans, finger lengths, or perimeters separately), handgrip strength was dependent on FS2 and FS3 (13.48%, R^2 x 100) and P4 (14.47%) in 10-year-olds and in 11-year-olds on IFL and P4 (9.86% and 11.69%, respectively). In 12-year-olds, handgrip strength was first of all dependent on P3 (37.19%), MFL (34.01%), and FS4 (9.19%). In 13-year-olds IFL (24.67%) was selected from the finger lengths, FS1 in combination with FS3 (20.79%) from the finger spans and P1 and P5 together (51.16%) from the perimeters. In 14–15-year-olds, from the hand anthropometry, the most important is FS2 (40.07%); the influence of P2 and P3 (36.40%) and LFL (11.15%) is lower. In the oldest age group, MFL and RFL in combination (49.29%), P5 (39.64%) and FS4 (32.13%) are important parameters influencing handgrip strength.

Table 6. Relationships between handgrip strength and basic body and hand specific anthropometrical parameters.
In the brackets partial correlations were the body mass is controlled *

Vari-able	Handgrip strength of the dominant hand					
	10 yrs (n = 35)	11 yrs (n = 37)	12 yrs (n = 37)	13 yrs (n = 24)	14–15 yrs (n = 39)	16–17 yrs (n = 21)
Body height	0.61***	0.48**	0.48**	0.72***	0.42**	0.57**
Body mass	0.54***	0.47**	0.51***	0.79***	0.67***	0.73***
BMI	0.26	0.25	0.39*	0.72***	0.68***	0.73***
FS1	0.08 (0.01)	0.13 (–0.01)	0.12 (0.12)	0.27 (0.08)	0.54* (0.50*)	0.36 (0.26)
FS2	0.12 (0.04)	0.18 (0.04)	0.21 (0.17)	0.10 (–0.02)	0.65* (0.60*)	0.43 (0.25)
FS3	0.25 (0.12)	0.26 (0.11)	0.25 (0.20)	0.03 (–0.10)	0.64* (0.55*)	0.50* (0.25)
FS4	0.23 (0.06)	0.29 (0.18)	0.34* (0.26)	0.12 (–015)	0.62* (0.46*)	0.60* (0.19)
FS5	0.25 (0.14)	0.25 (0.12)	0.33* (0.27)	0.04 (–0.20)	0.58* (0.40*)	0.57* (0.17)
TL	0.02 (–0.24)	0.29 (0.06)	0.54* (0.32)	0.49* (0.14)	0.11 (–0.40*)	0.28 (–0.31)
IFL	0.18 (–0.18)	0.35*(0.09)	0.54* (0.29)	0.53* (0.04)	0.15 (–0.41*)	0.52* (0.19)
MFL	0.25 (–0.13)	0.33*(0.06)	0.53* (0.29)	0.48* (–0.06)	0.24 (–0.34*)	0.56* (–0.17)
RFL	0.33 (–0.03)	0.31 (0.01)	0.42* (0.15)	0.41* (–0.07)	0.30 (–0.24)	0.67* (0.03)
LFL	0.31 (–0.05)	0.30 (–0.03)	0.34* (0.11)	0.38 (–0.10)	0.37* (–0.12)	0.60* (0.09)
P1	0.13 (–0.17)	0.30 (0.02)	0.52* (0.32)	0.53* (0.13)	0.47* (0.13)	0.54* (–0.05)
P2	0.18 (–0.12)	0.32*(0.17)	0.55* (0.35*)	0.40 (0.02)	0.57* (0.18)	0.62* (–0.03)
P3	0.24 (–0.07)	0.34* (0.16)	0.62* (0.43*)	0.31 (–0.12)	0.22 (–0.39*)	0.61* (–0.09)
P4	0.41* (0.08)	0.38* (0.12)	0.46* (0.24)	0.31 (–0.22)	0.30 (–0.32*)	0.59* (0.10)
P5	0.31 (0.03)	0.34* (0.12)	0.52* (0.35*)	0.26 (–0.14)	0.55* (0.11)	0.65* (–0.13)

Data: Pearson's coefficient of correlation (r). * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$
Abbreviations: See Methods

Table 7. Stepwise multiple regression where handgrip strength was dependent variable and fingers' span, length or perimeters were independent variables.

Age (years)	Independent variable	R^2 x 100	F	p
Fingers' span				
10	FS2, FS3	13.48	3.65	< 0.05
12	FS4	9.19	4.64	< 0.05
13	FS1, FS3	20.79	4.02	< 0.05
14–15	FS2	40.07	26.41	< 0.001
16–17	FS4	32.13	10.47	< 0.01
Fingers' length				
11	IFL	9.86	4.94	< 0.05
12	MFL, RFL	34.01	10.28	< 0.001
13	IFL	24.67	8.53	< 0.01
14–15	LFL	11.15	5.77	< 0.05
16–17	MFL, RFL	49.29	10.72	< 0.001
Perimeters				
10	P4	14.47	6.75	< 0.01
11	P4	11.69	5.77	< 0.05
12	P3	37.19	22.32	< 0.001
13	P1, P5	51.16	13.05	< 0.001
14–15	P2, P3	36.40	11.88	< 0.001
16–17	P5	39.64	14.13	< 0.001

Abbreviations: see Methods

5.3. Relationships of basic body and hand anthropometry with results of different throwing tests in young handball and basketball players (study III)

Mean anthropometrical parameters of the young handball and basketball players are presented in Table 8. Only in 10–11 years old age group, the body height was significantly higher and sitting height lower among basketball players compared to handball players of the same age. Hand specific anthropometrical parameters are presented in Table 9. From the perimeters of the hand, only P1 was higher in 10–11 years old age group and from finger length parameters MFL and RFL among handball players.

Table 8. Mean anthropometrical parameters and throwing tests' results of the young handball and basketball players ($\overline{X}$ ±SD).

	10–11-year-olds		12–13-year-olds		14–15-year-olds
	Handball (n=34)	Basketball (n=38)	Handball (n=39)	Basketball (n=22)	Handball (n=39)
Body height (cm)	146.6±6.9	149.9±7.0*	160.1±9.2	160.5±9.5	173.0±6.4
Body mass(kg)	37.3±4.9	38.8±6.0	47.1±8.0	48.0±10.5	61.4±7.9
BMI (kg/m^2)	17.2±1.5	17.3±2.1	18.2±1.6	18.4±2.2	20.4±1.7
Arms' span(cm)	147.1±9.0	148.4±9.2	160.3±10.4	160.9±13.4	175.1±8.1
Height with outstretched hands (cm)	185.4±9.7	188.9±9.8	202.8±12.5	201.9±13.6	220.5±9.8
Sitting height (cm)	75.0±3.0	72.8±4.5*	80.8±4.7	77.0±4.6	88.0±3.6
Throwing tests:					
Medicine ball throw (m)	4.6±0.9	4.0±0.6	6.8±1.4	5.2±1.4	10.6±2.2
Handball or basketball throw (m)	9.1±1.9	4.7±0.8	13.4±3.1	6.0±1.5	19.1±3.6
Handball or basketball pass on speed (m)	16.6±2.4	15.9±1.6	20.2±2.6	19.6±3.0	23.6±2.7
Handball or basketball passing on precision (m)	12.6±3.1	14.0±2.3	16.7±3.3	18.0±2.6	19.5±3.2

*$p<0.05$ between same age handball and basketball players

Table 9. Mean hand anthropometrical parameters of the young handball and basketball players ($\bar{X}$±SD).

	10–11-year-olds		12–13-year-olds		14–15-year-olds
	Handball (n=34)	Basketball (n=38)	Handball (n=39)	Basketball (n=22)	Handball (n=39)
FS1	10.4±1.6	9.9±1.6	11.2±1.5	10.2±1.8	12.0±1.6
FS2	14.5±1.7	13.8±1.7	15.6±1.3	13.9±2.0	16.5±1.6
FS3	16.5±1.7	16.0±1.6	18.0±1.4	16.1±1.9	18.9±1.5
FS4	18.0±1.6	17.6±1.6	19.7±1.3	18.0±1.9	20.6±1.5
FS5	24.4±2.4	23.9±2.5	26.4±2.0	24.2±2.6	27.6±1.9
TL	11.1±0.9	10.7±0.9	12.4±1.1	11.8±1.4	13.4±.1.0
IFL	15.6±1.0	15.3±0.8	17.0±1.3	16.5±1.2	18.5±1.0
MFL	16.6±1.0	16.3±0.8	18.0±1.3	17.4±1.1*	19.5±1.0
RFL	15.9±0.9	15.7±0.8	17.2±1.2	16.6±1.1*	18.7±0.9
LFL	13.9±0.8	13.9±0.8	15.2±1.0	14.7±1.0	16.5±1.0
P1	37.1±2.8	35.8±2.2*	40.6±3.1	38.5±2.9	44.0±2.4
P2	42.1±2.8	40.8±2.3	46.0±3.0	43.1±2.9	49.4±2.4
P3	37.1±2.2	36.3±1.6	40.4±2.7	38.4±2.5	43.4±2.4
P4	39.5±2.2	39.6±2.0	43.8±3.0	41.7±2.5	46.2±2.3
P5	49.5±3.3	48.5±2.8	54.0±3.4	50.9±3.4	57.5±2.8

*$p<0.05$ between same age handball and basketball players

Basic anthropometrical parameters highly influenced the results of throwing tests (Table 10). In the youngest age group (10–11-year-olds) the medicine ball throw results depended on the body height (handball players, 37.00%, R^2x100) or body mass (basketball players, 41.94%). In the 12–13 years old age group height with outstretched hands (58.33% and 72.85%, respectively) were the most influential. In the oldest age group, body mass and sitting height together (47.64%) were the most important. Handball/basketball throw results depended on the body height and arms' span in the youngest age group (41.90% and 31.70%, respectively). In the 12–13 years age group, the height with outstretched hands was highly important (56.76% and 66.88%). Span of the arms was important in the 14–15 years age group (31.92%). The results of the handball or basketball pass on speed were not dependent on the basic anthropometrical parameters among the 10–11 and 14–15-year old handball players (Table 10). Among 10–11 and 12–13 years old basketball players, the most important parameters were height together with height with outstretched hands or only height with outstretched hands (39.44% and 47.33%). Among 12–13 years old handball players, the most important factors were sitting height together with arms' span (17.70%). The results of passing the handball or basketball on precision were dependent on several anthropometrical parameters. Among handball players, only in the middle age group the body mass together with arms' span was significant (18.16%). In basketball players the most important was height with outstretched hands (30.20% and 45.09%), respectively in youngest and middle age group.

Table 10. Stepwise multiple regressions where throwing parameters were the dependent variables and basic anthropometrical parameters were independent variables.

Dependent variable	Age groups	n	Independent variable	R^2x100	F	p
Medicine ball throw	10–11 HB	34	Body height	37.00	20.38	<0.0001
	10–11 BB	38	Body mass	41.94	27.73	<0.0000
	12–13 HB	39	Height with outstretched hands	58.33	54.19	<0.0000
	12–13 BB	22	Height with outstretched hands	72.85	57.36	<0.0000
	14–15 HB	39	Body mass and sitting height	47.64	18.29	<0.0000
Handball or basket-ball throw	10–11 HB	34	Body height	41.90	24.78	<0.0000
	10–11 BB	38	Arms' span	31.70	18.17	<0.0001
	12–13 HB	39	Height with outstretched hands	56.76	50.88	<0.0000
	12–13 BB	22	Height with outstretched hands	66.88	43.42	<0.0000
	14–15 HB	39	Arms' span	31.92	18.82	<0.0001
Handball or basketball pass on speed	10–11 BB	38	Body height and height with outstretched hands	39.44	13.05	<0.0001
	12–13 HB	39	Sitting height and arms' span	17.70	5.09	<0.0114
	12–13 BB	22	Height with outstretched hands	47.33	19.87	<0.0002
Handball or basketball pass on precision	10–11 BB	38	Height with outstretched hands	30.20	17.01	<0.0002
	12–13 HB	39	Body mass and arms' span	18.16	5.22	<0.0102
	12–13 BB	22	Height with outstretched hands	45.09	17.43	<0.0005

HB – handball players
BB – basketball players

The results of medicine ball throw among handball players depended on the hand anthropometrical parameters P1 (11.76%, R^2x100), TL (47.23%) and P2 (43.78%) in the 10–11, 12–13 and 14–15 years old age groups (Table 11). In basketball players, the results were dependent on the P3 and IFL (36.16%) or IFL and P1 (61.07%) in 10–11 and 12–13 years old age groups. The results of handball or basketball throw depend on quite different hand anthropometrical parameters. Among handball players P1 (14.05%), TL (41.62%) or P2 and LFL (40.38%) and among basketball players P3 and IFL (32.88%) and IFL (51.94%) were the most significant (Table 11). Handball or basketball pass on speed was not highly dependent on hand anthropometry. Among handball players the influence was significant only among 10–11-year-olds with FS5 and P1 (14.33%), and among basketball players with MFL and P3 (26.76%) and TL (29.99%) among 12–13-year olds. The results of passing the handball or basketball on precision were moderately dependent on IFL and P3 (13.33%) parameters among the 10–11-year-old basketball players. In the 12–13 years old age group the results were dependent on FS3 (16.70%) and TL (35.10%) among handball and basketball players. In the 14–15 years old age group the results were dependent on the FS3 (8.01%).

Table 11. Stepwise multiple regressions where throwing parameters were the dependent variables and specific hand anthropometrical parameters were independent variables.

Dependent variable	Age groups	n	Independent variable	R^2x100	F	p
Medicine ball throw	10–11 HB	34	P1	11.76	5.40	<0.0267
	10–11 BB	38	P3 and IFL	36.16	11.48	<0.0002
	12–13 HB	39	TL	47.23	35.04	<0.0000
	12–13 BB	22	IFL and P1	61.07	17.47	<0.0001
	14–15 HB	39	P2	43.78	30.59	<0.0000
Handball or basketball throw	10–11 HB	34	P1	14.05	6.39	<0.0166
	10–11 BB	38	P3 and IFL	32.88	10.06	<0.0004
	12–13 HB	39	TL	41.62	28.09	<0.0000
	12–13 BB	22	IFL	51.94	23.70	<0.0001
	14–15 HB	39	P2 and LFL	40.38	13.87	<0.0000
Handball, basketball pass on speed	10–11 HB	34	FS5 and P1	14.33	3.76	<0.0345
	10–11 BB	38	MFL and P3	26.76	7.58	<0.0019
	12–13 BB	22	TL	29.99	9.99	<0.0049
Handball or basketball pass on precision	10–11 BB	38	IFL and P3	13.33	3.77	<0.0332
	12–13 HB	39	FS3	16.70	8.62	<0.0057
	12–13 BB	22	TL	35.10	12.36	<0.0021
	14–15 HB	39	FS3	8.01	4.31	<0.0450

Abbreviations: see Methods
HB – handball players
BB – basketball players

Finally, when we studied the influence of both basic and hand anthropometry together on the different throw results it appeared that basic anthropometry is more significant than hand anthropometry (Table 12). Medicine ball throw results in the 10–11 years old age group were highly dependent on the body height (37.00%, R^2x100, handball players) and body mass (45.81%, basketball players). In the 12–13 years old age group, the most important factor is TL (47.25%, handball players) or height with outstretched hands (72.85%, basketball players). Among the 14–15 years old handball players the medicine ball throw results depended on P2 and sitting height (55.05%). Quite different anthropometrical parameters appeared to influence the handball and the basketball throw results (Table 12). In the 10–11 years old age group the most important parameters were body height (41.90%, handball players) or LFL (41.96%, basketball players). In the 12–13 years old age group, the most important was height with outstretched hands and P2 (56.53%, handball players) or for basketball players only height with outstretched hands (68.71%). Among the 14–15 years old handball players LFL and sitting height were the most important (45.10%). Handball or basketball pass on speed depended on the combination of body mass and FS5 and body height with height with outstretched hands (21.98% and 39.44% respectively among 10–11 year old handball and basketball players). Sitting height in combination with arms span is the most important (17.70%) among 12–13–year-old handball players and only height with outstretched hands (61.40%) among the same age basketball players. Handball or basketball passing on precision results depended on body height and P3 (21.44%) or P1 (10.25%) among handball and basketball players in the 10–11 years old age group. In the 12–13 years old age group the results of precision passes were dependent on the combination of FS3 and body mass (27.93%) and LFL and height with outstretched hands (55.82%) among handball and basketball players respectively.

Table 12. Stepwise multiple regressions where throwing parameters were the dependent variables and all used anthropometrical parameters were independent variables.

Dependent variable	Age groups	n	Independent variable	R^2x100	F	p
Medicine ball throw	10–11 HB	34	Body height	37.00	20.38	<0.0001
	10–11 BB	38	Body mass	45.81	16.64	<0.0000
	12–13 HB	39	TL	47.25	35.04	<0.0000
	12–13 BB	22	Height with outstretched hands	72.85	57.36	<0.0000
	14–15 HB	39	P2 and sitting height	55.05	24.27	<0.0000
Handball or basketball throw	10–11 HB	34	Body height	41.90	24.78	<0.0000
	10–11 BB	38	LFL	41.96	14.37	<0.0000
	12–13 HB	39	Height with out-stretched hands and P2	56.53	26.18	<0.0000
	12–13 BB	22	Height with out-stretched hands	68.71	12.53	<0.0001
	14–15 HB	39	LFL and sitting height	45.10	16.61	<0.0000
Handball or basketball pass on speed	10–11 HB	34	Body mass and FS 5	21.98	5.65	<0.0081
	10–11 BB	38	Body height and height with outstretched hands	39.44	13.05	<0.0001
	12–13 HB	39	Sitting height and arms span	17.70	5.09	<0.0114
	12–13 BB	22	Height with outstretched hands	61.40	17.70	<0.0001
Handball or basketball pass on precision	10–11 HB	34	Body height and P3	21.44	5.50	<0.0090
	10–11 BB	38	P1	10.25	5.22	<0.0283
	12–13 HB	39	FS3 and body mass	27.93	5.91	<0.0023
	12–13 BB	22	LFL and height with outstretched hands	55.82	13.63	<0.0003

Abbreviations: see Methods. HB – handball players, BB – basketball players

6. DISCUSSION

6.1. Relations of anthropometrical characteristics with scores on basic and specific motor tasks in young handball players (study I)

The major finding of this study was that the anthropometrical characteristics are relatively poor predictors of the results of basic and handball specific motor abilities that need agility, explosive strength of lower limbs, precision, speed of movement and handball-specific skills. At the same time anthropometrical characteristics were significantly related to the results of general and handball-specific throwing tests and static strength of upper limbs in young handball players of different ages.

In the present study, the vertical jump with hands on the hips (SJ) and with arms' swing (CMJ) were used to assess the explosive power of lower limbs. The vertical jump on contra-lateral leg to dominant arm from one step run-up was used as a handball-specific test. There were relatively few significant relationships between vertical jump tests and the used anthropometrical characteristics. In 14–15-year-old players, sitting height determined the results of vertical jump with hands on the hips by 22.95% (R^2x100) or the results of vertical jump with arms' swing by 23.17% and the results of vertical jump from dominant leg by 13.41%. Kanehisa et al. (2006) with reference to Tanner confirmed a significant relationship between peak velocity of the muscle width and sitting height, which explains the results of our study. A relatively low effect of anthropometrical characteristics on explosive strength of lower limbs in this study coincides with earlier studies (Bencke et al. 2002, Ugarkovic et al. 2002). However, it is well known that legs' explosive strength peak occurs simultaneously with peak height velocity or immediately after peak height velocity (Inbar 1996, Beunen 1997, Peeters et al. 2005), which also explains the results of this study. It is important to note that in youth competitive sports' teams are based on players' chronological age (Buchanan & Vardaxis 2003) and earlier in literature it has been confirmed that typically peak height velocity occurs at 13.5±0.9 years according to Baquet et al. (2006), in young soccer players at 13.8±0.8 years according to Philippaerts et al. (2006). Peeters et al. (2005) in a study with twins confirmed peak height velocity for boys at the age 14.15±0.98 years.

In a study with twins Peeters et al. (2005) confirmed that after peak height velocity the environmental influences became more important in vertical jump performance, which coincides with the results of our study. This may be explained by the potential increase in specificity of physical activities (Bencke et al. 2002, Hughes et al. 2004). According to Vanezis & Lees (2003) the muscle strength characteristics of the lower limbs' joints are the main determinants of the vertical jump performance. The leg length had little effect on the results of the vertical jump with arms' swing at the age of 10–11 years

(13.82%, p<0.05). This relationship may be due to the increased movement amplitude, height and velocity at take-off. The reason for this is longer legs and arms' swing, which coincides with data in literature (Lees et al. 2004).

Short distance runs of 20 to 30 m are fundamental in team handball – during a fast break or while returning to defence after a ball loss (Lidor et al. 2005). Kotzamanidis (2006) found that anthropometrical characteristics did not correlate significantly with all running phases (0–10m, 10–20m, 20–30m, 0–30m) during 30m run in pre-pubertal boys. In our study, body height determined the results in 30m run by 10.92% at the age of 10–11 years, while in the 14–15-year-old age group sitting height was more important (16.48%). Differences between the results in our study and results in Kotzamanidis (2006) study are explained by the fact that subjects in this study went in for sports regularly, and Kotzamanidis (2006) investigated children who were not active in sports. Pre-pubertal boys active in sport have greater percent of lean body mass (Deheeger et al. 1997, Damsgaard et al. 2001). Handball training significantly improves pre-adolescents' lower limbs' performance (Oxyzoglou et al. 2007). The data in literature supports the results of our study. It is known that pubertal growth begins with growth in limbs (Cameron et al. 1982) and boys with longer legs may run with longer strides. These are explanations for the relationship between straight sprint running and body height in 10–11-year old handball players. The arms' span determined to a little extent (10.78%) handball-specific speed (30m dribbling) in 12–13-year old handball players. In the pre-pubertal ages and at the onset of puberty the effective learning in basic technical performance takes place which allows taking advantage of longer arms during dribbling.

The relevance of sitting height as a determinant of running speed among the 14–15-year-olds may be explained by the fact that after peak height velocity young players run with longer strides. With high probability peak height velocity appears at this age and adolescents' spurt in muscle mass coincides with peak height velocity or occurs immediately after peak height velocity (Malina et al. 2004a, Philippaerts et al. 2006). Higher sitting height entails higher muscle mass and higher strength of lower body. The data in literature (Kanehisa et al. 2006) about the relationship between muscle width and sitting height confirms this. The results of the present study coincide with the data in earlier studies (Lefevre et al. 1990) which confirmed that during adolescence the speed of limb movement is negatively related to age at peak height velocity. The training-induced effects on body composition must be taken into account as the subjects in our study went in for sports regularly. In a study with pre-pubertal boys Ara et al. (2004) confirmed that regular participation in sports activities and competitions is associated with increased physical condition and lower fat mass. Physically active boys showed better results in 30m running and vertical jump tests than physically non-active boys.

A few significant relationships between agility and handball-specific skill tests' (4x10m shuttle run, slalom dribble) results with anthropometrical characteristics in young handball players were established in this study. Body height in combination with BMI was a statistically significant determinant of the agility (4x10m) test results at the age of 10–11 years (12.33%) and sitting height at the age of 14–15 years (13.67%,). No statistically significant relationships between handball-specific skills (slalom dribble) and anthropometrical parameters in young handball players were determined in this study. An investigation with adolescent soccer players (Malina et al. 2005) indicates that the contribution of body size, age, maturity status and years of experience is relatively small in soccer-specific skill tests: (8–21%), which is also suggested by the results of our study. Gabbett (2002) and Reilly et al. (2000) in studies with rugby and soccer players found that athletes who perform better on change-of-direction speed tests also have lower body fat. According to Sheppard & Young (2006) the factors that could be determinants of change-of-direction speed performance are body height, relative limb length and the height of athlete's centre of gravity. Many factors other than body size and maturity status, such as neural control of movement and perceptual-cognitive skills (anticipation, visual search strategies) influence the performance in sport-specific skill tests (Williams & Reilly 2000a).

In handball, the players predominantly use only one arm and it could be presumed that training will induce different effects on arm strength (Bencke et al. 2002). Higher relationship between throwing tests' results with dominant hand and anthropometrical parameters could be explained by better technical performance (Van den Tillaar & Ettema 2004) which allows making better use of the advantages in body composition, especially body height dimensions.

In our study multiple regression analysis indicated that the relationship between medicine ball throw and anthropometrical parameters was highest at the age of 12–13 years. Height with outstretched hands together with body mass determined the results of the medicine ball throw by 61.80%; arms' span determined the results of the medicine ball throw by 54.61% at the age of 16–17 years. Height with outstretched hands determined the results in handball throw by 55.05% at the age of 12–13 years. It is well known that pubertal growth begins from growth in limbs and we assume that at the age of 12–13 years young handball players have biggest increase in body height parameters. Body height dimensions are essential for handball throw (Van den Tillaar & Ettema 2004, Gorostiaga et al. 2006, Granados et al. 2008, Mohamed et al. 2009). Multiple regression analyses indicated that arms' span determined the result in handball throw to the greatest extent at the age of 16–17 years (61.17%). This may be explained by better technical performance because players are experienced enough at this age. In an earlier study with adolescent handball players Barata (1992) found that technique rather than force will influence handball throw velocity, which was confirmed by Gorostiaga et al. (2005) in a study with elite and amateur handball players, too. Falk et al. (2004) in a study with young water-polo players confirmed that explosive power is a crucial factor in ball throwing and the technique of throw is an important contributor to its successful execution. The important characteristic of medicine ball and handball throw, the force-velocity relationship of upper limbs, according to

Delgado et al. (1993) correlates significantly with body height and body mass during puberty and throwing distance relates strongly to muscle power and throwing velocity, which in turn relates to body mass and fat free mass (van den Tillaar & Ettema 2004).

Multiple regression analyses indicated that body mass determined static strength of dominant hand to the greatest extent at the ages of 16–17 years and 10–11 years (accordingly 43.83% and 43.80%), at the age of 12–13 years by 27.55%. The adolescent spurt in arms strength begins 1.5 years before the age at peak height velocity and reaches a peak about 0.5 years after peak height velocity. The anaerobic peak power and mean power of arms during adolescence are highly correlated with lean body mass and fat-free mass among boys (Blimkie et al. 1988). Based on the multiple regression analyses the most important determinant of arms' static strength is body mass and body height dimensions contribute to successful performance in throwing events, especially handball throw. Earlier literature (van den Tillaar & Ettema 2004, Gorostiaga et al. 2005) has confirmed that maximal strength and force production of upper extremities depend mostly on body mass, BMI and body size. The relative increase is greater for upper body strength than for lower body strength when strength gains are expressed as a percentage of the level of strength increments (Beunen & Malina 1988). The results in our study are in accordance with this data in literature.

6.2. Relationships of basic body anthropometry and hand dimensions with handgrip strength in young handball and basketball players (study II)

A major conclusion drawn from this study is that the general body anthropometrical characteristics (body height, body mass and BMI) are more important than hand-specific anthropometrical parameters in predicting handgrip strength in young handball and basketball players. From the specific hand anthropometrical parameters, some perimeters are the most significant (in the oldest age groups). In younger age groups, the influence of specific hand anthropometrical parameters on handgrip strength is relatively low. Probably taller young players with longer fingers have an advantage in sport games. The presented new method for the measurement of hand anthropometrical parameters (fingers' span, fingers' length and perimeters) in children is highly reliable.

Häger-Ross & Rösblad (2002) showed that the highest increase in handgrip strength occurs at the age of 13 compared to age 12. However, Rauch et al. (2002) demonstrated maximal increase later – at the mean age of 14.1 years. Maximal handgrip strength in our study was higher in each successive age group. Our subjects demonstrated the highest increase at the age of 14–15, which may be associated with the rapid increase in body height and body mass at this age. Mean results in our handball and basketball players are very similar to our previous results in Estonian non-athletic boys at the age of 11; in every successive older age group, the differences between sports participants and non-participants increased (Jürimäe & Saar 2003). In addition to this, the discrepancies in maximal handgrip strength may also be due to the practice of sports activities that require hands as tools for catching and throwing the ball, especially the dominant hand.

We should mention some methodological limitations of this study. Our novel method for the measurement of hand anthropometry needs to be validated with standard equipment. However, the standard tools are mostly designed for clinical use in case of different pathologies. Typically, studies have used measuring boards, tapes and callipers (Garrett 1971), stereo-photography (Ghosh & Poirier 1987), MRI scanning (Ostergaard et al. 2001) or laser-aligned method (Highton et al. 2003). Unfortunately, no highly acceptable methods are available for the validation of hand anthropometry.

Previous studies (Häger-Ross & Schieber 2000) have shown that general anthropometrical parameters such as body height and body mass were significantly correlated with handgrip strength in children. Our results confirmed that general anthropometrical parameters are more important in the prediction of maximal handgrip strength than are specific hand anthropometrical dimensions.

Body height was the most significant general anthropometrical parameter for the youngest subjects, predicting maximal handgrip strength at the age of 10 by 35.16% (R^2 x 100) and at the age of 11 by 20.58%. At the age of 12, body mass explained the variance of maximal handgrip strength by 62.15% and at the age of 13, accounted for 60.18% of the total variance. Finally, in older age groups, BMI was a significant general anthropometrical parameter that determined 44.80% of the variance in maximal handgrip strength at the age of 14–15 and 50.45% at the age of 16–17. The increase in the maximal isometric grip force during childhood and adolescence is affected by muscle growth during puberty and an increase in grip force for muscle cross-sectional area (Newman et al. 2002).

Few studies have been found that have investigated the influence of hand dimensions on handgrip strength. An earlier study (Häger-Ross & Schieber 2000) with children of different ages confirmed that hand length (distance from wrist joint to tip of middle finger) is an important parameter for handgrip strength, indicating that the contribution of age, mass and hand length in combination was significant for boys of all ages. To the contrary, Nicolay & Walker (2005) have recently indicated that among college students, from the measured wrist and hand anthropometrical parameters, the correlation of finger length with handgrip strength was significant but low. Our hypothesis about the leading role of the hand length parameters to the handgrip strength was only partly confirmed. This relationship was highly dependent on body mass.

Previous studies have confirmed that the contribution of each digit to the total grip force decreased from radial to ulnar (Kinoshita et al. 1996, Ostergaard et al. 2001, Quaine et al. 2003, Reilly & Hammond 2000b). Force production was investigated for individual digits in multi-finger tasks. In this study, in 10-

year-olds, the finger length did not influence handgrip strength at all (Table 7). The relative involvement of index finger length in maximal handgrip strength was highest in 11-year-olds (9.86%) and 13-year-olds (24.67%). The length of the middle finger in combination with the ring finger was important in 12-year-olds (34.01%) and especially in 16–17-year-olds (49.29%); the length of the little finger had a less significant effect. In a study of the influence of wrist position on individual finger strength during a forceful grip, Li (2002) confirmed that the force-sharing percentage was 32.2 ± 3.8% for the index finger; 32.6 ± 4.3% for the middle finger; 23.5 ± 4.5% for the ring finger and 11.7 ± 4.9% for the little finger. Our study demonstrated broadly similar relative involvement of index and middle fingers in maximal handgrip strength in all age groups. In rock climbers (Quaine et al. 2003), a relatively higher contribution of the ring finger was found. It may be explained by the fact that the different position of the thumb significantly influenced the force production of other digits except the little finger (Olafsdottir et al. 2005) and that the ring and the middle fingers are the least independent (Häger-Ross & Rösblad 2002, Reilmann et al. 2001).

In the five-digit task, the digits shared the total force differently depending on the position of the thumb. In the present study, we did not determine the position of the thumb. The contribution of the more independent index finger in maximal handgrip strength was significant at the age of 13 (24.67%). This is in line with the data in earlier studies (Häger-Ross & Rösblad 2002, Reilmann et al. 2001). It is important to note that biomechanical analysis suggests that the primary line of the transmission of force is along the middle finger (Garrett, 1971, Nag et al. 2003). Forces through the other fingers are also transmitted to the radius (Nag et al. 2003). With the excessive spreading of fingers, the lines of the transmission of force are distorted (Nag et al. 2003). This explained a relatively small influence of finger spans on maximal handgrip strength in this study. However, FS2 explained 40.07% of the variance in maximal handgrip strength in the age group of 14–15 years.

In summary, the results of this study suggest that in the sport activities that use hands as tools, training has advanced handgrip strength of the dominant hand already at young ages. Basic anthropometrical characteristics were related to maximal handgrip strength to a degree that was greater than specific hand dimensions. The specific hand anthropometrical parameters that were measured, especially finger lengths and perimeters significantly correlated with the maximal handgrip strength. However the relationship depends on body mass.

6.3. The importance of basic body and hand anthropometry on the results of different throwing tests in young handball and basketball players (study III)

Our study showed that both basic anthropometry and hand anthropometry are important predictors of the different throwing test results for young handball and basketball players. The non-specific and relatively heavy medicine ball throw results depend first of all on the basic anthropometrical characteristics (body height and body mass and height with outstretched hands). The results of different investigations show that body height and body mass (especially fat free mass) are important predictors of muscle force (Bäckman et al. 1989, Van den Tillaar and Ettema 2004). Accordingly, the taller (and heavier) players have some advantages compared with shorter players.

It is interesting to note that finger spans did not influence the medicine ball throw results in any age group of the handball or basketball players that were studied (Tables 11 and 12). In an earlier study which estimated the relationship between hand length and other hand dimensions found that grasping an object that requires widely spread fingers is less efficient and more fatiguing than grasping an object with fingers in a neutral position (Nag et al. 2003), which supports the finding of our study. Even the biomechanical analysis suggests that the primary line of the transmission of force is along the middle finger. Forces through the other fingers are also transmitted to the radius and with the excessive spreading of fingers the lines of the transmission of force are distorted (Nag et al. 2003). However, the holding of a medicine ball in the over-arm position and throwing needs the application of fingers' force. By data in literature, the fingers' span influences the grip strength results (Fransson & Winkel 1991, Ruiz-Ruiz et al. 2002). On the other side, the relationship between hand grip strength and handball throw is unknown. Although, Leyk et al. (2007) in a study with elite female handball players confirmed that handball training influences strongly handgrip strength. At the same time in a study with baseball players Pugh et al. (2001) found that grip strength correlated significantly with throwing speed for the experienced players, but not for inexperienced players.

In our study, from the hand anthropometrical parameters the results of medicine ball throw were dependent on the fingers' length and hand perimeters. With high probability players with longer fingers (especially younger players) do not spread out their fingers for holding large and heavy medicine ball, which allows increasing the force of fingers acting in parallel during the throw. The combination of IFL and P1 very highly influenced the medicine ball throw results especially in 12–13-year-old basketball players (61.07%, R^2x100). This is understandable because the long flexors of the index finger have tight relation to force (Maier & Hepp-Reymond 1995). Contrarily, throwing a relatively heavy ball and throwing a light ball presumably require different neural command, because the weight of the ball affects the mechanics of the arm, and particularly, the mechanics of the finger. Yet finger control is crucial to the accuracy of over-arm throw. Finger opening in over-arm throws is controlled by the means of an internal model of the motor apparatus and the external load (Hore et al. 1999).

In the 12–13 years old age group both throw tests (medicine ball and handball throw) were highly dependent on the TL parameter among handball players (Table 11). Similarly, among the same age group basketball players both passing exercises were also highly dependent on TL. We can explain this with the well known fact that from the five fingers the thumb is the most important of the finger forces on the sustained object holding tasks (Li 2002). TL was the most important anthropometrical parameter explaining the results of medicine ball throw among the 12–13-year-old handball players when all the used anthropometrical parameters were analyzed together (Table 12). However, individual finger force production is not independent of force produced by other fingers. In particular, maximal force of each individual finger drops with an increase in the number of fingers acting in parallel (Li et al. 1998b). In both throws (medicine ball and basketball) there is a good combination of P3 and IFL, explaining more than 30% of the total variance of results among 10–11-year-old basketball players (Table 11). For 14–15-year-old handball players, P2 is the essential hand surface parameter, explaining 43.78% of the total variance of the results of medicine ball throws and in combination with the little finger length (LFL) explains 40.38% of the total variance of the results in handball throw (Table 11). In a study by Hore et al. (2001) about the control of finger grip force in over-arm throw by skilled throwers found that the force recorded by each finger is affected by the different distribution of force across the fingers due to the different diameter and different weight of the ball. With high probability, as ball weight and diameter increase, a relatively higher proportion of the total back force is applied to the index and the ring fingers, rather than to the middle finger.

To a little extent the hand anthropometrical parameters determine the results in handball throw on precision. Only FS3 (distance between the tops of the thumb and the ring finger) determines the performance in handball throw on precision at the age of 12–13 years and 14–15 years, accordingly 16.70% and 8.01%. The finger force in an over-arm throw is controlled precisely to keep the amplitude of finger extension relatively constant from throw to throw. The constant amplitude of finger opening ensures the ball accuracy in over-arm throwing (Hore et al. 2001, Hirashima et al. 2007).

Comparing both basic and hand anthropometrical parameters with different throws' results we can conclude that the basic anthropometrical parameters are more important (Table 12). In case of all throws, the most important factors were body height dimensions, especially for handball players; because they performed over-arm throws. Zapartidis et al. (2009) in study with adolescent handball players considering the different playing position, found significant differences between hand spread, arms' span and body height in elite and sub-elite back-court players confirming the importance of hand dimensions and body height dimensions for young handball players. Probably in the future more advanced anthropometry needs to be used because over-arm throwing is a skilled multi-joint movement with potentially many degrees of freedom. We can conclude that the basic anthropometrical parameters are slightly more important than hand anthropometry on different throw results.

7. CONCLUSIONS

In conclusion we suggest:

1. Anthropometrical characteristics are relatively poor predictors of the results of basic and handball-specific motor abilities that need agility, explosive strength of lower limbs, precision, speed of movement and handball-specific skills.
2. Anthropometrical characteristics are significantly related to the results of basic and handball-specific throwing tests and static strength of upper limbs in young handball players of different age groups.
3. Basic body anthropometrical parameters (body height, body mass and BMI) are more important than hand-specific anthropometrical parameters in predicting handgrip strength in young handball and basketball players.
4. Both general anthropometrical characteristics and hand anthropometrical parameters are important in determining the results of basic and specific throws in young handball and basketball players.

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SUMMARY IN ESTONIAN

Noorkäsipallurite kehaehituslike iseärasuste ja käe antropomeetria seosed üldise ja erialase motoorse võimekusega

Sissejuhatus

Viimastel aastatel on käsipalli areng toimunud eelkõige kiiruse ja võimsuse suunas, mille aluseks on mängijate morfoloogiliste-antropomeetriliste iseärasuste muutused, üha kasvav motoorne võimekus ning tehnilis-taktikaline meisterlikkus. Kuigi erinevad spordialad vajavad spetsiifilisi motoorseid võimeid, siis nende realiseerimiseks mängus on oluline ka spetsiifiline kehaehitus. Mängijate kehaehitus ja antropomeetrilised näitajad on tihti olulised faktorid, mis tagavad edu sportmängudes. Nii loovad võimsa kehaehitusega pikad mängijad eelise käsipallis. Ka noormängijate esmasel valikul ning hilisemal spetsialiseerumisel kindlale mängupositsioonile on aluseks mängija kehaehituslikud iseärasused ja antropomeetrilised tunnused. Tippmängijale esitatavaid nõudmisi kehaehituslike iseärasuste osas, eriti seoses visketehnika ja -kiirusega, on uuritud üsna laialdaselt, samas aga vähe on kompleksseid uuringuid erinevas vanuses noormängijate kohta.

Uurimistöö eesmärk ja ülesanded

Käesolevas uurimistöös püstitati järgmised hüpoteesid:

1. Antropomeetrilised näitajad mõjutavad enam üldise motoorse võimekuse näitajaid kui spetsiifilise motoorse võimekuse näitajad ning antropomeetrilised näitajad mõjutavad väheoluliselt kehalisi võimeid, mis nõuavad osavust ja tehnilisi oskusi.
2. Viskekäe antropomeetrilised parameetrid mõjutavad oluliselt viskekäe dünamomeetriat
3. Viskekäe antropomeetrilised näitajad mõjutavad üldiste ja spetsiifiliste visketestide tulemusi suuremal määral kui antropomeetrilised põhinäitajad.

Uurimistöö hüpoteeside lahendamiseks püstitati töös järgmised ülesanded:

1. Selgitada erinevas vanuses (10–17 aastaste noormeeste) noorkäsipallurite antropomeetrilised ning üldise ja spetsiifilise motoorse võimekuse näitajad
2. Uurida antropomeetriliste näitajate ning üldise ja spetsiifilise motoorse võimekuse näitajate vahelisi seoseid erinevates vanusegruppides.
3. Uurida labakäe mõõtude ning antropomeetriliste põhinäitajate seoseid noorkäsipallurite ja -korvpallurite käe dünamomeetriaga.
4. Uurida labakäe mõõtude ning antropomeetriliste põhinäitajate seoseid noorkäsipallurite ja -korvpallurite visketestide tulemustega.

Uuritavad ja metoodika

Kokku osales uuringus 193 noorkäsipallurit ja -korvpallurit vanuses 10–17 aastat. Teostati kolm uuringut:

I uuring – osales 133 noorkäsipallurit vanuses 10–17 aastat, kes jaotati nelja rühma vastavalt nende vanusele:

* 10–11-aastased (n=34)
* 12–13-aastased (n=39)
* 14–15-aastased (n=39)
* 16–17-aastased (n=21)

II uuring – osales uuringus 193 noorkäsipallurit ja -korvpallurit vanuses 10–17 aastat, kes jaotati kuude rühma vastavalt nende vanusele:

* 10-aastased (n=35)
* 11-aastased (n=37)
* 12-aastased (n=37)
* 13-aastased (n=24)
* 14–15-aastased (n=39)
* 17–18-aastased (n=21)

III uuring – osales uuringus 172 noorkäsipallurit ja -korvpallurit vanuses 10–15 aastat, kes jaotati viide rühma vastavalt nende vanusele:

* 10–11-aastased käsipallurid (n=34)
* 10–11-aastased korvpallurid (n=38)
* 12–13-aastased käsipallurid (n=39)
* 12–13-aastased korvpallurid (n=22)
* 14–15-aastased käsipallurid (n=39)

Uuritavatel mõõdeti:

* üldised antropomeetrilised näitajad – kehapikkus (cm), kehamass (kg), kehapikkus väljasirutatud kätega (cm), käte siruulatus (cm), keha istepikkus (cm), arvutati keha massi indeks ($kg \cdot m^{-2}$)
* labakäe erinevad mõõdud – sõrmede siruulatus (cm), sõrmede pikkus (cm), erinevad ümbermõõdud (cm)
* käe dünamomeetria (kg)
* üldise motoorse võimekuse näitajad – 30m sprint (s), topispallivise (m), paigalt üleshüpe käte hoota (cm), paigalt üleshüpe käte hooga (cm)
* spetsiifilise motoorse võimekuse näitajad – 4x10 m süstikjooks (s), slaalomipõrgatamine (s), 30m põrgatamine (s), üleshüpe tõukejalalt (cm), käsipallivise (m), sööt kiirusele ja täpsusele (n x 30s).

Järeldused:

1. Antropomeetrilised näitajad mõjutavad väheoluliselt üldise ja spetsiifilise motoorse võimekuse näitajaid, mis nõuavad käsipalli-spetsiifilist osavust, alajäsemete plahvatuslikku jõudu, täpsust ja kiirust.
2. Antropomeetrilised näitajad mõjutavad oluliselt noorkäsipallurite üldiste ja käsipalli-spetsiifiliste visketestide tulemusi ning ülajäsemete staatilist jõudu.

3. Noorkäsipallurite ja -korvpallurite labakäe jõudu mõjutavad antropomeetrilised põhinäitajad (keha pikkus, keha mass ja KMI) suuremal määral kui käe antropomeetrilised näitajad.
4. Noorkäsipallurite ja -korvpallurite üldiste ja spetsiifiliste visketestide tulemustel esinesid statistiliselt olulised seosed nii antropomeetriliste põhinäitajatega kui ka viskekäe antropomeetriliste näitajatega.

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2004	Käsipallitreeneri V taseme kutse omistamine
1993	Trondheim, Norra naiste käsipallikoondise ettevalmistusega tutvumine

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