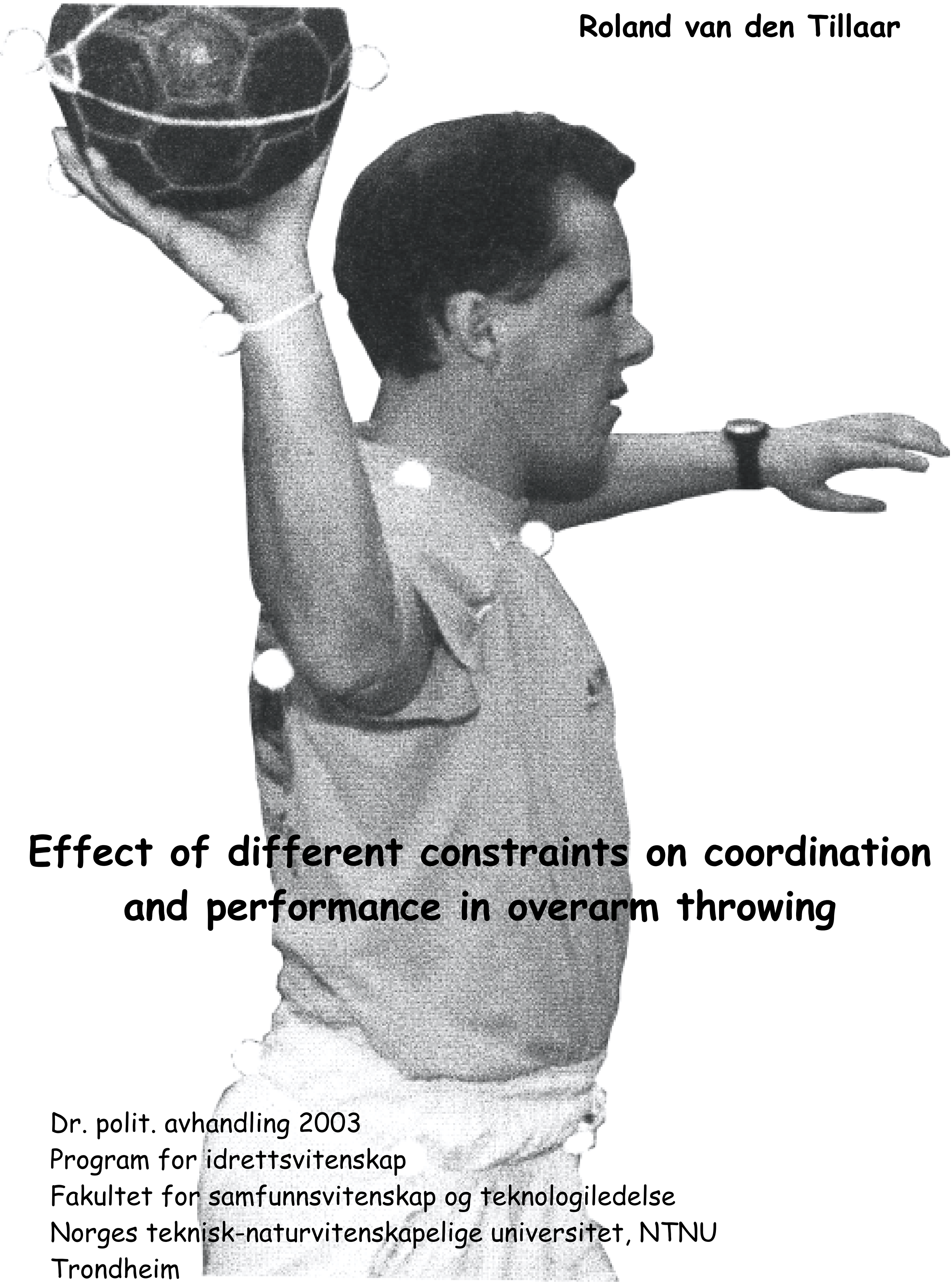
Roland van den Tillaar



Effect of different constraints on coordination and performance in overarm throwing

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Contents

List of papers

This thesis presents a collection of papers dealing with influences of different constraints on the coordination and performance of overarm throwing.

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Paper 2: Van den Tillaar, R., Ettema, G. (2003) Effect of instruction on velocity, accuracy and coordination of overarm throwing. *Perceptual and motor skills* (submitted)

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1. Introduction

Fast discrete complex movements.

Different aspects of daily life, sport, work, and play demand different kind of movements, varying in terms of muscle activity, duration and cyclical nature. Body movements can be classified in three types: discrete, serial and continuous movements (Schmidt and Lee, 1999). This classification is based upon the particular movements that are made and the open/closed dimension, which is determined by the perceptual attributes of the task (Schmidt and Lee, 1999). On one end of the classification scheme are discrete movements. These are movements with a recognisable beginning and end. Generally, these are movements with high intensity and short duration, which can be observed in for example, throwing objects, hitting objects, jumping, reaching, grabbing objects etc. In the literature, these types of movements are also referred to as explosive or ballistic movements. This type of movement differs essentially from so-called continuous or cyclic movements, in which a distinct beginning and end can not be identified as in, for example rowing, running and cycling. These movements are often described in cycles, but it is theoretically impossible to identify a beginning and end of a cycle. For example, in running, does a cycle begin with the supporting phase, which consists of the braking, amortization and propulsion part or with the aerial phase? Continuous movements also tend to have longer movement times than discrete movements. The mechanics and control of a fast discrete action is essentially different from cyclical movements in that one cannot rely on information and mechanical characteristics of the previous cycle to help in executing and controlling the next one. In between these two categories, serial movements can be classified. This type of movement is neither discrete nor continuous, but rather seems to be made up of a series of individual discrete movements tied together in time. Examples are figure skating and gymnastic exercises (Schmidt and Lee, 1999). This classification is shown in figure 1.

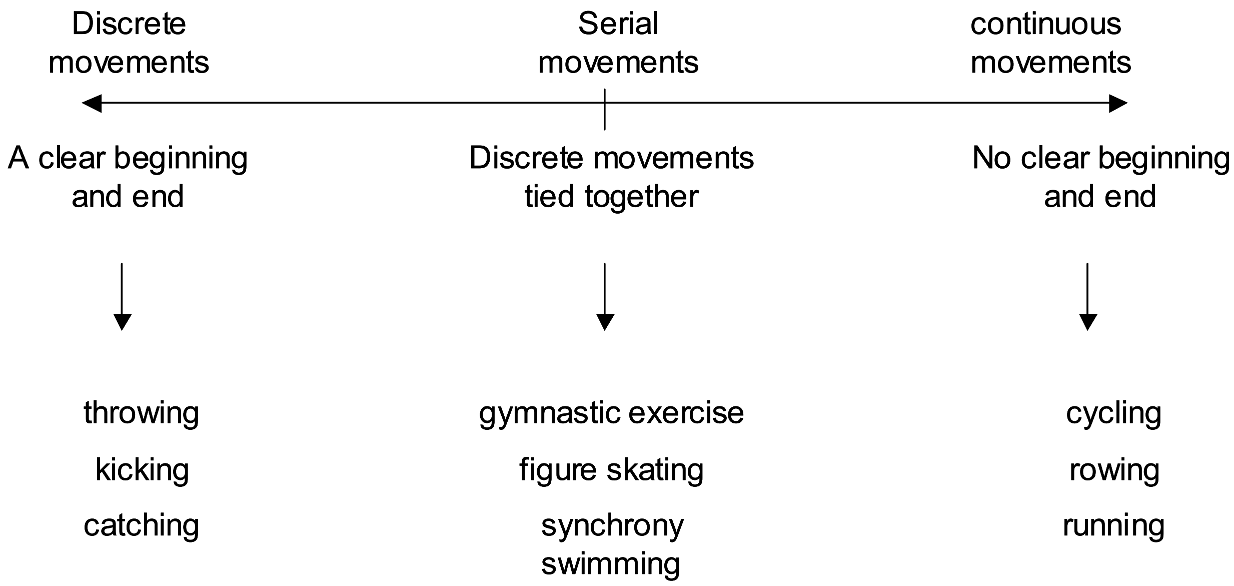

Figure 1. The discrete/serial/continuous classification for motor behaviour as described by Schmidt & Lee (1999)

The particular movement studied in this thesis is overarm throwing, which is classified as fast discrete complex movement. It is a movement that is fast, has a clear beginning and an end (discrete), and several muscles and segments are involved in the movement (complex).

The execution of this type of movement depends on many constraints with velocity and accuracy as two main performance characteristics. Several researchers classified these constraints into categories by different criteria to make the role of the constraint more survey-able (e.g. Pattee, 1972, Newell, 1986, Warren, 1990). Newell (1986) proposed three categories of constraints which interact, to determine the optimal pattern of coordination for a given organism. These are organismic, environmental and task constraints.

Organismic constraints can be divided in relatively time independent and dependent constraints also called structural and functional constraints. Examples of structural constraints are body weight, height and shape. An example of a functional constraint is synaptic connections in the nervous system. However, this structural-functional distinction is not as qualitative as it first appears, due to the qualification that the constraints may be *relatively* time dependent or independent (Newell, 1986).

Environmental constraints are generally defined as those constraints that are external to the organism and are usually not manipulated by the researcher and are relatively time independent. Examples of environmental constraints are natural ambient temperature, gravity, natural light and other natural features that are not essential for the task at hand.

In task constraints the focus is on the goal of the activity and the specific constraints imposed. Three categories of task constraints can be proposed. These are related to: 1) the goal of the task; 2) rules specifying or constraining response dynamics and 3) implements of machines specifying or constraining response dynamics (Newel, 1986). An handball match covers various categories. In handball the goal of the task is to score more goals than the opposite team. This results in attacking the other goal and defending your own (category 1). In this game rules about how to defend and how to handle the ball are prescribed. For example it is prohibited to kick the ball with your foot (category 2). The game would be different if another type of ball is used, for example a tennis or rugby ball. This will probably result in another type of throwing to each other and on the goal (category 3).

The organismic, environmental and task constraints interact, resulting in an optimal performance for the organism (figure 2).

All constraints reside at each level of analysis of the organism. In the present thesis the level of analysis is on a macroscopical level and will investigate the influence of some organismic and task constraints on performance. The organismic constraints are body size, gender and maximal isometric strength and training experience. The investigated constraints set by the task are type of instruction and projectile weight.

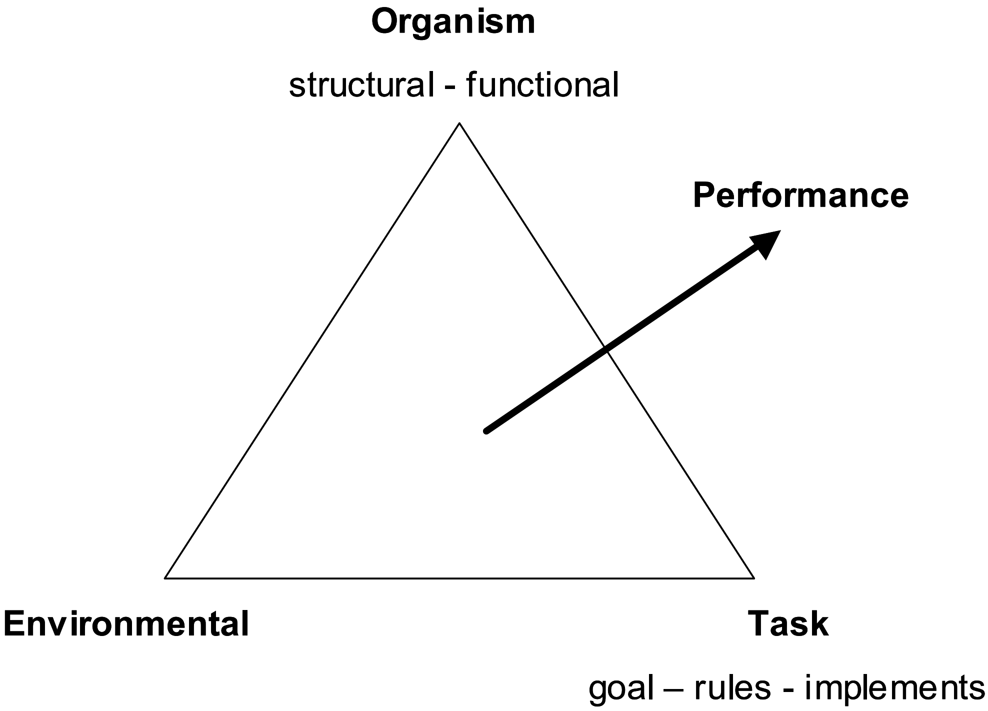

Figure 2. A schematic diagram of the categories of constraints that specify the performance.

Organismic constraints

The structural organismic constraints (body size parameters) are known to affect physical performance. Anthropometrics and body composition variables discriminate between adolescent track and field competitors in different events (Housh, Thorland, Johnson, Tharp & Cisar, 1984). Athletes specialized in throwing events are significantly taller, heavier and more muscular build than the control group (Sidhu, Kansal & Kanda, 1975). Upper body strength correlates ($r>.60$) with performance for discus throwers; fat weight correlates ($r=-.80$) with hammer performance and leg strength correlates ($r=.72$) with shot put performance (Morrow, Disch, Ward, Donovan, Katch, Katch, Weltman & Tellez, 1982).

Two models regarding body size investigate the structural and functional consequences of changes in size among otherwise similar organisms, i.e. isometric and allometric scaling models (Schmidt-Nielsen, 1984). Isometric scaling is based on the assumption that differently sized bodies are geometrically similar (isometric), i.e. that all linear dimensions are related in the same proportion (only differ in ratio). This means that with increasing length (L), the surface area increase with L^2 and mass by L^3 (figure 3) (Åstrand & Rodahl, 1986; Schmidt-Nielsen, 1984).

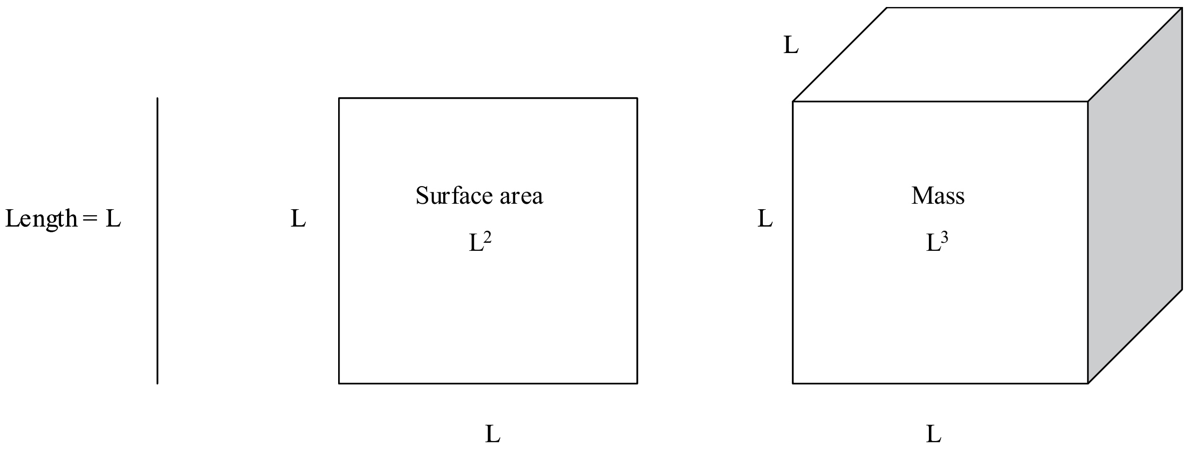

Figure 3. Relation between length (L), area and mass.

According to the allometric scaling theory, differently sized organisms usually are not isometric, but instead, different dimensions change in a regular fashion (for example a logarithmic relationship, Schmidt-Nielsen, 1984). A specific form of allometric scaling is that of elastic scaling (McMahon, 1984). McMahon presented a model based on the mechanical structure of the animal and analysed the supporting columns (the skeleton) in the light of basic engineering principles. In this model, scaling occurs according to an invariable elastic function, meaning that independent of size, all animals deform (bend) in a similar way under their own body weight. For example, the legs of a mouse bend through in the same relative amount under the load generated by its body mass as is the case for an elephant. This means that differently sized bodies are designed with a dissimilar geometry according to the relation $width^2 \nabla height^3$. No distinction is made between width and depth. Thus, in elastic scaling width (d) is related to height or length (L) by l (d ∇ $L^{3/2}$). So with increasing size, length increases to a lesser extend than cross-sections, i.e. the limbs become more bulky with increasing size (for example compare a mouse with an elephant).

Production of force depends on the cross section area of a muscle (Åstrand & Rodahl, 1986), which means that an increase in length results in an increase of force by L^2 according the isometric and L^3 according the elastic scaling theory. Also other Newtonian units like acceleration, velocity, work, etc. can be related to the height (L) of a person by these two theories (table 1).

Table 1. Relations between the height (L) and width (d) mass (M), Force (F), acceleration (a), velocity (v), work (W), time (t) according to the two scaling theories.

Isometric scaling		**Elastic scaling**	
$d \nabla L$		$d \nabla L^{3/2}$	
$M \nabla L^{3}$		$M \nabla L^{4}$	$M \nabla (L*d*d)$
$a= F / M$	$a \nabla L^{2} / L^{3} \nabla L^{-1}$	$a= F / M$	$a \nabla L^{3} / L^{4} \nabla L^{-1}$
$t \nabla L$	$a \nabla Lt^{-2},\ t^{-2} \nabla L^{-1}L^{-1}$	$t \nabla L$	
$F \nabla L^{2}$		$F \nabla L^{3}$	
$v= a * t$	$v \nabla L^{-1}*L \nabla L^{0}$	$v= a * t$	$v \nabla L^{-1} * L \nabla L^{0}$
$W= F * s$	$W \nabla L^{2} * L \nabla L^{3}$	$W= F * s$	$W \nabla L^{3} * L \nabla L^{4}$

According to these two theories a taller person can produce more force than a smaller person. The increased force, that a taller person can produce, enables him to lift a L^2 heavier weight (Schmidt-Nielsen, 1984). However, the size of a subject, according to these two scaling theories (table 1), does not influence velocity of a movement.

Good examples of the scaling theory are the world records in power lifting in the different weight classes. By increasing the weight class, the weight lifted also increases. The correlation between body mass (weight class) and strength (weight lifted) for power lifters is 0.97 (Doodam & Vanderburgh, 2000). This indicates that body mass is important for performances in which maximal strength is involved. Thus, body mass and height influence strength abilities according to the scaling theories (Åstrand & Rodahl, 1986). In this thesis the role of body size (including gender related size) on throwing performance is investigated.

A functional organismic constraint at a muscular level is the relationship between force and velocity. Force and velocity are two major parameters that are often used for describing motor behaviour. Hill (1938, 1964, and 1970) described an inverse hyperbolic relationship between force and velocity for an isolated muscle, which is now referred to as the so-called Hill curve. According to Hill, the basic characteristics of muscles could be described by this relationship. This relationship is used by many other researchers in muscle physiology used to describe and explain phenomena of muscle contraction. Also researchers in the more applied sciences as for example sport sciences use this approach. In many research projects in sports the relationship is used to explain how a subject has to train to become stronger and/or faster. Many training experiments, designed to enhance the performance of the athlete, are based on the force-velocity relationship of Hill (e.g. Komi and Häkkinen, 1988). In this thesis the force and velocity on the macroscopical level of a fast discrete complex movement is investigated by a task constraint: projectile weight. Thus task and organismic constraints are linked.

Another functional organismic constraint that influences the force and/or velocity and thereby the performance of fast discrete complex movements is training experience. Novices in a complex task perform usually worse than an expert in that task (e.g. Marques-Bruna & Grimshaw, 1998; Etnyre, 1998). A novice learns the task by the law of practice, which means that by practice the performance increases by a decelerated relationship. Thus, a subject improves much in the beginning of learning the task and the rate of improvement changes towards zero as practice continues (Fleichman & Rich, 1963; Quesada & Schmidt, 1970).

Two important principles in training practice are the principle of overload and specificity. The principle of overload can be described as physical training exposing the organism to a training load or work stress of sufficient intensity, duration and frequency. This stress is associated with some catabolic processes, such as molecular breakdown, followed by an overshoot or anabolic response that causes an increased deposition of the molecules, which were mobilized or broken down during exposure to the training load (Åstrand & Rodahl, 1986). There are different views on the type of overload needed to become faster. Firstly, there is training based upon the principle of an overload of force (e.g. throwing with overweight balls;

Edwards van Muijen et. al. 1991; Barata, 1992; DeRenne et. al. 1985; 1990, 1994). Secondly, there is training based upon the principle of an overload of velocity (e.g. throwing with underweight balls; Edwards van Muijen et. al. 1991; DeRenne et. al. 1985; 1990; 1994).

Another training principle is the principle of specificity. This principle can be described as the adaptation of the human body to the activity that the individual is exposed to (Åstrand & Rodahl, 1986, Fox & Matthews, 1981). This means that when some one wants to enhance his performance in running, he has to train running and not cycling. In overarm throwing, variable resistance training on the shoulder rotation is more specific for a baseball pitcher than isokinetic resistance training (Wooden, Greenfield, Johanson, Litzelman, Mundrane & Donatelli, 1992). In this thesis the role of different training experiences on throwing performance is investigated by a literature study (Chapter 6). To avoid any effect of inadequate coordination patterns in throwing (see Roberton, 1977), players with at least 10 years of training experience and experience on national level of competition were used in the experiments of the other studies.

Task constraints

A task constraint which is investigated is the influence of the specification of task goals by the type of instruction. Most fast discrete actions require a certain level of accuracy of execution. It is generally accepted that a trade-off (information processing guided) exists between the accuracy and velocity at which a task is performed. The basis of this assumption lies in the work of Fitts (1954). However, Fitts findings were based on fast cyclical tasks, not discrete, and thus Fitts findings do not necessarily apply to this study. Indeed, some tasks seem to show an optimum of intensity of execution (measured in e.g. velocity or force) leading to the most accurate performance (e.g. hitting a specific target) (Sherwood and Schmidt, 1980). Such an optimum was also recently found in soccer kicking (Corrigan, 2000). Instructions with emphasizing on velocity and/or accuracy can play a role in the performance of a fast discrete movement. Etnyre (1998) showed that when subjects were instructed to throw as fast as possible in dart throwing they threw less accurate than they did in normal throwing. However, another study by Cauraugh, Gabert, and White (1990) in tennis serving showed that with near maximal velocity the accuracy increased compared with serves on lower velocity. In this thesis the influence of instruction, emphasising accuracy, velocity or both on the performance in overarm throwing as well as kinematic analysis are investigated. The kinematic analysis is performed to obtain more information about how these instructions influence coordination in fast discrete complex movements.

Coordination

All the organismic and task constraints described earlier can influence the performance of fast discrete complex movements. The change in performance, as mentioned earlier, can be measured by the variables of velocity and/or accuracy. However, the constraints can also influence coordination, which can be defined as the interaction between several segments and joints in time to produce a fast discrete complex movement. This coordination can be regarded as a strategy outcome that can influence the performance outcome in terms of velocity and accuracy. For this reason, the role of coordination on the performance in a fast discrete complex movement task is investigated in this thesis as well.

A study of overarm throwing

In this thesis the overarm throw is used as a paradigm of a fast discrete complex movement. It is a movement that can be classified as a basic form of motor behaviour like jumping, crawling, balancing, walking, climbing, catching, tumbling, pulling etc.

Overarm throwing is used in many different sports disciplines like water polo, baseball, handball, javelin, etc. It also has many similarities with other fast discrete complex movements of the upper limb like smash in volleyball, tennis serve, badminton etc.
The purpose of this thesis is to gain insight in how certain constraints influence coordination and performance of overarm throwing. Thus, by determining the role of these constraints, one can optimise an overarm throw.

Content of the thesis

The present thesis consists of an assembly of papers, which are presented as chapters. In chapter two, the influence of instruction, emphasizing velocity and/or accuracy on the throwing performance is investigated. In chapter three, the influence of these instructions on coordination patterns is studied. Kinematic and temporal parameters of several body segments that play a role in overarm throwing are focused upon. In chapter four, the role of body size, gender and isometric strength is investigated in relation to the velocity of overarm throwing. The influence of projectile mass on the throwing performance and what kind of consequences this has on the kinematics is investigated in chapter five. In chapter six different training studies in overarm throwing are compared to investigate the relation between type of training and training effect. The final chapter summarizes major findings and conclusions, and contains suggestions for further research.

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2. The Influence of instruction on velocity and accuracy of overarm throwing

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3. Effect of instruction on velocity, accuracy and coordination of overarm throwing

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4. Effect of body size and gender in overarm throwing performance.

Summary

The purpose of this study was to examine the relationship between maximum isometric strength, anthropometry, and maximum velocity in overarm throwing for male and female experienced handball players. Twenty male and twenty female handball players were tested. The mean ball velocity was 23.2 ms^{-1} and 19.1 ms^{-1} for male and female handball players, respectively. For males and females, similar correlations were found between maximal isometric strength and throwing velocity (men, $r=0.43$, $p=0.056$; women, $r=0.49$, $p=0.027$). Univariate analysis of variance between isometric strength and throwing velocity for men and women showed no significant effect of gender ($F_{2,36}=0.116$, $p=0.89$).

Body size had a strong positive effect on the throwing performance and isometric strength. Throwing velocity appeared to be affected by gender when size was expressed by mass or height ($p<0.001$). However, this dependence was completely explained by size differences when expressed as fat free body mass (FFM). For strength, no gender effect was found at all, i.e. all gender differences were explained by size differences, irrespective on how this was expressed. The finding that strength and velocity show a gender independent relationship strengthen the notion that gender difference is based on difference in muscle bulk. The conclusion is that FFM, as an approximation for skeletal muscle mass, is the best measure to express body size when related to physical performance.

Introduction

It is well known that body size affects physical performance. Both experimental results (Sidhu et al. 1975; Housh et al. 1984; Doodam and Vanderburgh 2000) and theory on scaling (e.g. Schmidt-Nielsen 1984) indicate that a taller person would perform better in activities with a significant strength component. A clear example of the principle is the relationship between the power lifting world records and weight classes that strongly correlate positively ($r=0.97$, Doodam and Vanderburgh 2000). Also, Housh et al. (1984) found that anthropometric and body composition variables discriminate adolescent track and field competitors in different events. Sidhu et al. (1975) reported that athletes specialised in throwing events are taller, heavier and more muscularly build than non-throwers. World-class throwers of the different throwing events differ in anthropometry and strength variables (Morrow et al. 1982). From a theoretical perspective, theory on scaling predicts an increase in muscular force production with body size. Although relative strength (e.g. when lifting ones own body) does not necessarily increase with body size, the positive relation for absolute strength (e.g. when throwing a given projectile) and body size is obvious. Geometric scaling, for example, suggests that differently sized animals are shaped in proportion. Thus, muscle cross-section and related strength increase proportionally with body height squared (l^2). Elastic similarity scaling, on the other hand, suggests that the limbs of animals are scaled such that, under body mass loading, they bend through in a similar manner. This theory predicts muscle cross-section and strength relate proportionally to l^3. It has recently been debated that the exact value of the power coefficients found for a rather small size range (e.g. studying only humans) may be the result of a fitting artefact, rather than the consequence of a given scaling principle (Batterham et al. 1999). Thus, the exact (theoretical) relationship of strength related performance depends on the adopted scaling principle (McMahon 1984; Schmidt-Nielsen 1984) and may be ambiguous for groups with a small size range.

In the present study, performance of overarm throwing is studied within the light of scaling and the related body composition and gender factors. The subject group was restricted to well trained, high-level handball players. Thus, this study examined if the principles of scaling apply to performance within a relatively homogeneous group, regarding the trained motor task. This is not directly apparent from the literature because usually different groups of athletes are compared. The present study aims at providing more insight in the relevance of body size for specific aspects of athletic performance at high level.

Method

Twenty male and 20 female subjects participated in this experiment. All were experienced handball players, playing in the second and third division of the Norwegian national competition. This study complied with the requirements of the local ethical committee and with current Norwegian law and regulation.

Anthropometry

All anthropometric measurements were performed according to Norton & Olds (1996). The following measurements were taken: mass (balance, Lindells Lindeltronic 4000); height (Holtain stadiometer); skinfolds at the following anatomical landmarks: triceps, biceps, subscapular and suprailiac (Holtain skinfold calliper); girths: arm-relaxed, arm-flexed, arm-tensed, forearm (maximum), wrist (distal styloids), chest and calf (maximum) (Holtain-Harpender anthropometric tape); lengths and breadths: acromiale-radiale, radiale-stylion, midstylion-dactylion, biacromial, iliospinale to floor, trochanterion to floor, trochanterion-tibiale laterale, tibiale laterale to floor, tibiale laterale-maleolis lateralis, bitrochanteric (Holtain anthropometer), bicondylar femur and bicondylar humerus (Holtain Bicondylar calliper).

For the prediction of fat percentage, the sum of four skinfolds (triceps, biceps, subscapular and suprailiac) was used according to Durnin and Womersley (1974): Body density was estimated for men (eq. 1) and women (eq.2) and transformed into fat percentage according to Siri (1961) (eq. 3)

$$BD_{male} = 1.1631 - 0.0632 \log(\sum 4 skinfolds) \quad (1)$$

$$BD_{female} = 1.1599 - 0.0717 \log(\sum 4 skinfolds) \quad (2)$$

$$\%F = \frac{495}{BD} - 450 \quad (3)$$

Fat free body mass (FFM) was calculated as the total body mass minus fat mass. All measurements were taken twice, the bilateral ones twice on each side of the body. The mean of the two measurements was taken for further analysis. Difference between the two measurements of 5% for the skinfolds, 3% for girths (Ross and Marfell-jones, 1991) and 0.5% for length and breadths was allowed (Quinney, Pettersen, Gledhill & Jamnik, 1984). Otherwise a third measurement was performed and the median of these three measurements was used (Norton & Olds, 1996).

Maximal ball velocity

After a general warming up of 15 minutes, throwing performance was tested in an overarm throw towards a target at 7 m distance, using a standard handball (male 450 g, circumference 0.58 m; female 360g, circumference 0.54 m). The subjects performed a standing throw with keeping the front foot on the floor during throwing (Fig. 1). The instruction was to throw as fast as possible aiming at a target of a 0.5 by 0.5m positioned in a handball goal. Each subject performed five throws in total. In order to obtain an accurate measure of maximal throwing speed that could be produced repeatedly by each subject, the fastest three throws were used further for calculating the mean velocity. A digital video camera (JVC, model: GR-DVL9600) positioned, at 15 meters from the subject, was used for data recording at a sample rate of 100 Hz. The ball velocity was calculated from the distance covered by the first five frames after ball release.

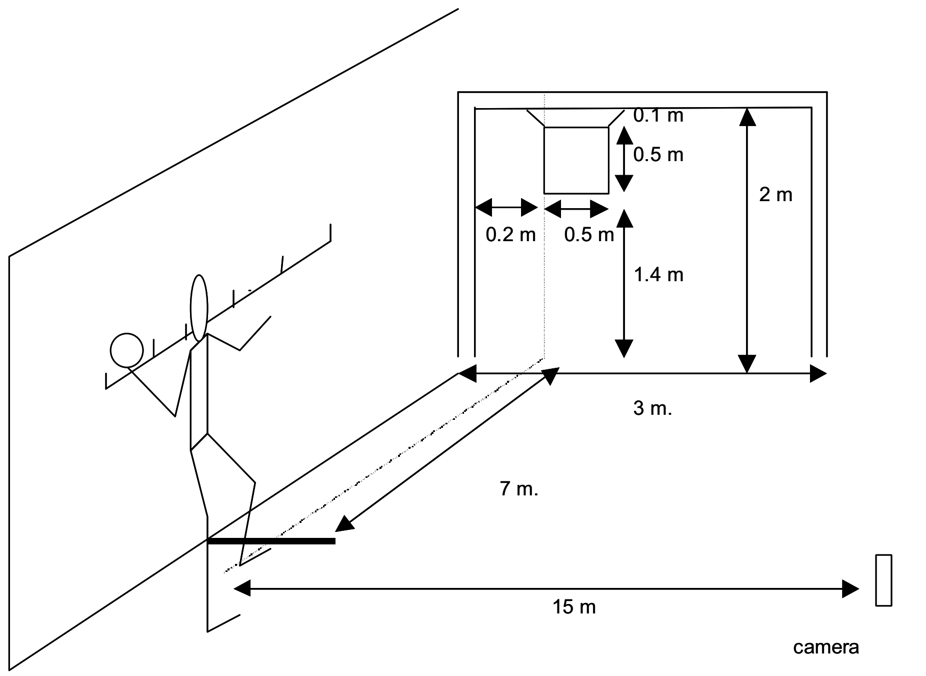

Figure 1. Experimental set up, showing target, throwing distance and position, as well a video camera position.

Isometric strength

Specific isometric strength was measured using a handball connected to a force transducer (Revere transducers, model 363-D3-0, USA). The force transducer was connected to a height adjustable bar. The height of the transducer was set at shoulder height, such that the line of action through the force transducer was approximately horizontal (i.e. about the direction of a handball move during actual throwing).

Isometric strength was measured in four different positions that reflect the entire trajectory of throwing movement before ball release (Fig. 2):

1) The subject standing straight up with the line through hips and bi-acromial axis parallel to the throwing direction; the arm extended backward; the hand behind the ball.
2) Same as in position 1, except for the elbow, which was flexed 90 degrees, forearm pointing vertically upward.

3) The line through hips and bi-acromial line turned 90 degrees, i.e. perpendicular to throwing direction; shoulder abducted 90 degrees, i.e. arm parallel to the hips. The elbow at 90 degrees flexion, forearm vertically upward.
4) The subject stands in the same position with his legs, hips and shoulders. The shoulder 30 degrees horizontally flexed (forward), arm horizontal. The forearm is 90 degrees flexed, vertically upward.

The subjects were required to keep both feet on the ground during the test. It was not allowed to bend the trunk. The feet had to be placed such that the centre of gravity (trunk) was projected in the middle of both feet. Each subject was required to produce a maximum force production effort during the four positions and maintain this for 5 to 6 seconds. The exercise was performed in all positions three times. For each position, the highest force plateau (of at least 1 s) was considered the true maximum. Subject position was checked and if necessary corrected by means of observational techniques.

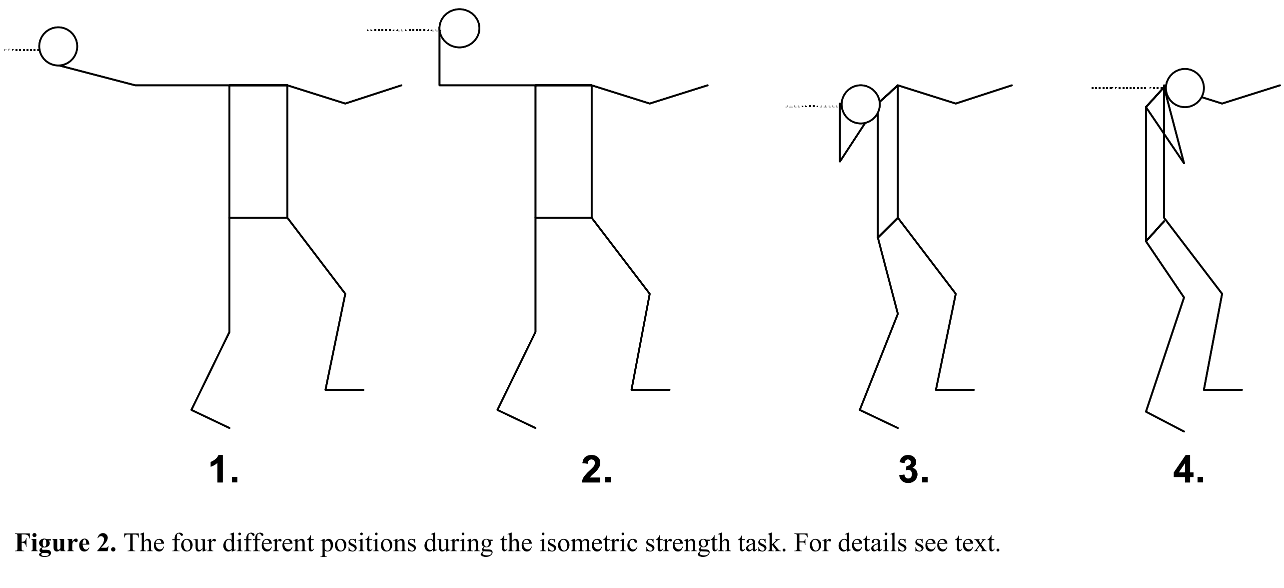

Figure 2. The four different positions during the isometric strength task. For details see text.

Statistics

To assess effects of isometric strength and body size on throwing performance linear and power functions were compared. To assess gender effect, the regression lines on the two gender groups were compared using an F-test as described by Crowder and Hand (1990). The effect of position on isometric strength was tested by a oneway ANOVA with repeated measures. A post hoc test (using Bonferroni probability adjustments) was used to locate significant differences.

Results

Table 1 shows anthropometrical results, maximal isometric strength (of all positions) and throwing performance results averaged for male and female subjects. Significant effects of arm position on isometric strength were found for both men ($p<0.001$) and women ($p<0.001$). Post hoc comparison (Bonferroni) indicated significant differences between all positions except between positions 3 and 4. The highest forces were measured in position 1 and the lowest in position 3 and 4 (Fig. 3). Thus, the forces recorded in position 1 are used as maximal strength values. Both men and women showed the same position-strength relationship. Men, however, produced significantly more isometric strength in each position than women ($p<0.01$).

Table 1. Average and standard deviation of women and men in age, training years, height, mass, fat percentage, throwing velocity, maximal isometric force per kg. total body mass and per kg. fat free body mass (FFM).

	Age (y)	Training (y)	Height (m)	Mass (kg)	Fat (%)	Max force (N)	Velocity (ms^{-1})	F/m (Nkg^{-1})	F/FFM (Nkg^{-1})
Male	24.7	13.3	184.8	84.7	16.7	233	23.2	2.8	3.3
(n=20)	(2.3)	(3)	(8.2)	(10)	(3.2)	(34,4)	(1.6)	(0.3)	(0.4)
Female	22.2*	13.2	170.9*	69*	28.4*	189*	19.2*	2.8	3.8*
(n=20)	(2.6)	(2.7	(6.2)	(8.7)	(3.6)	(33,9)	(1.5)	(0.4)	(0.5)

* significant difference between men and women at p < 0.01

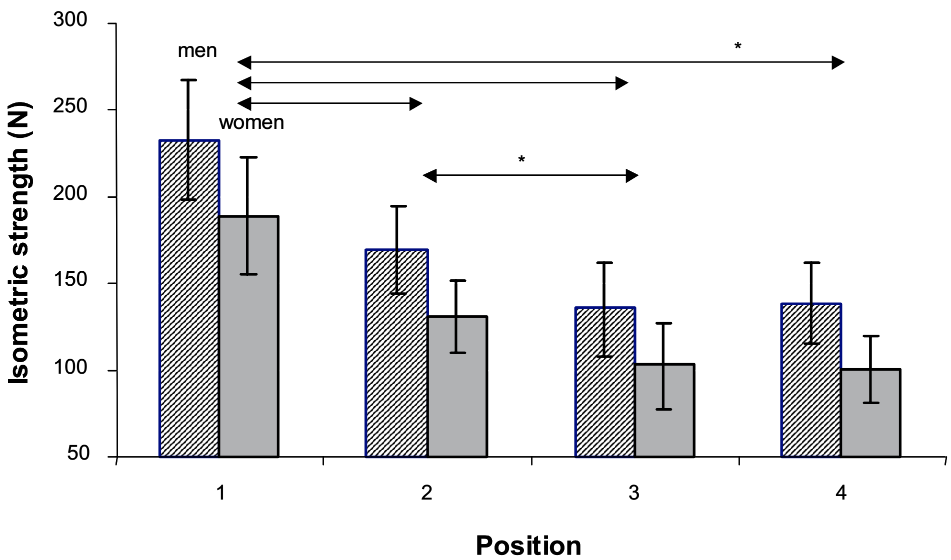

Figure 3. The average isometric strength produced in the four positions by men and women. Men were stronger than women in each position (p<0.01). * indicate significant difference between two positions indicated by the arrows (p<0.001).

All girths and bicondylar measurements demonstrated high positive correlations with mass for both men and women (r>0.72, p<0.001). Lengths and breadths had a high positive correlation with height (r>0.65, p<0.001). These results indicate that the subjects were similarly shaped.

For males and females, similar correlations (Pearson) were found between maximal isometric strength and throwing velocity (men, r=0.43, p=0.056; women, r=0.49, p=0.027). No significant effect of gender was found for the linear regression lines of isometric strength against throwing velocity ($F_{2,36}$=0.116, p=0.89) (Fig. 4).

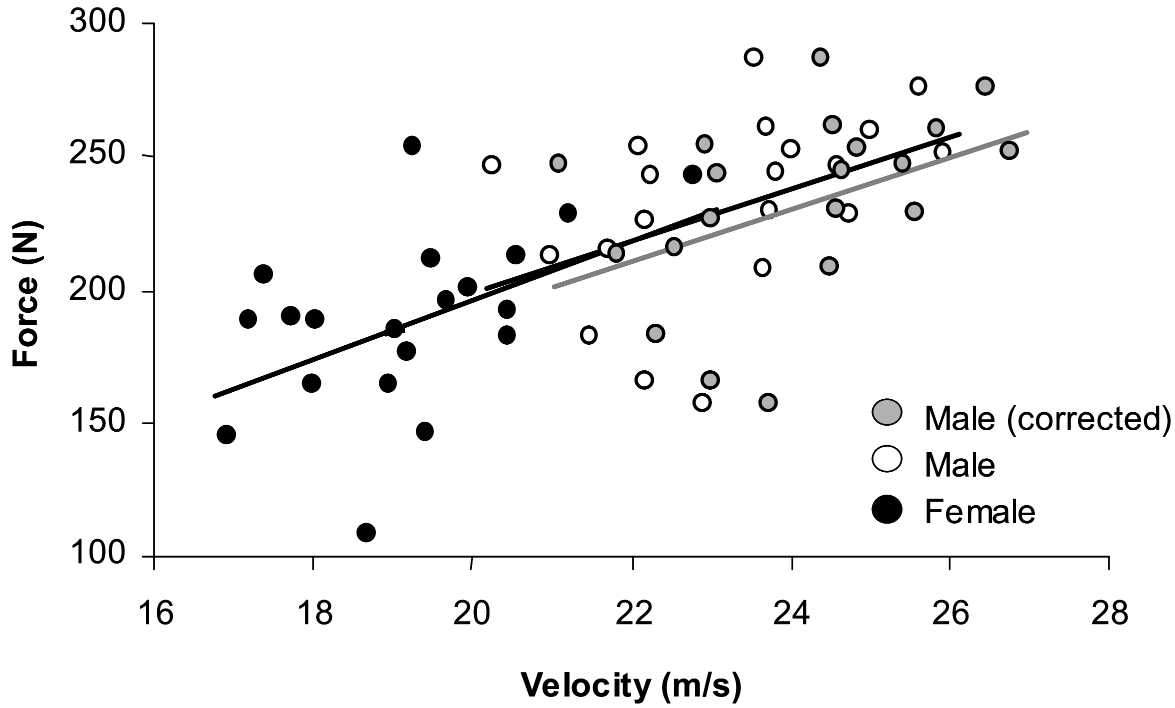

Figure 4. Relationship between velocity and force for men (¹), r = 0.43, p = 0.056, men corrected for velocity (¸) and women (¸), r = .49, p =0.027. The regression lines of men and women are not significantly different (p=0.97).

The relationship between body size and performance was expressed by linear as well as allometric power curves. These two curves were used because of the limited number of data points and body size range with respect to allometric theory (see also Batterham et al. 1999). Throwing velocity and strength related strongly and positively with height, mass and FFM for men and women combined. The power and linear curves were almost identical in the range of the data (Figs. 5 and 6), the linear curves usually with slightly higher correlation coefficients. An effect of gender was found for throwing velocity when related to height (p=0.001) and mass ($p < 0.001$) (fig 5 B and C inset), but not when plotted against FFM (fig. 5 A). Thus, the fitting values on the entire population as shown in Figs. 5B and 5C must be treated cautiously. The male and female subjects threw with balls of different mass, being regular balls according to the rules of the international handball federation (360g and 450g for females and males, respectively). This was done because they were used to throwing with these balls and thus possible effects of throwing with unusual balls were avoided. However, the ball mass difference may have contaminated gender effects as found in this study. To check this, correction on throwing velocity for males was performed based on van den Tillaar and Ettema (2002). They determined the relationship between ball mass and throwing velocity in men, indicating that a difference of 90 grams results in a 0.86 m/s throwing velocity difference. Using the corrected velocities, a significant gender effect between velocity and FFM was found ($F_{2,36}=3.43$, $p=0.043$).

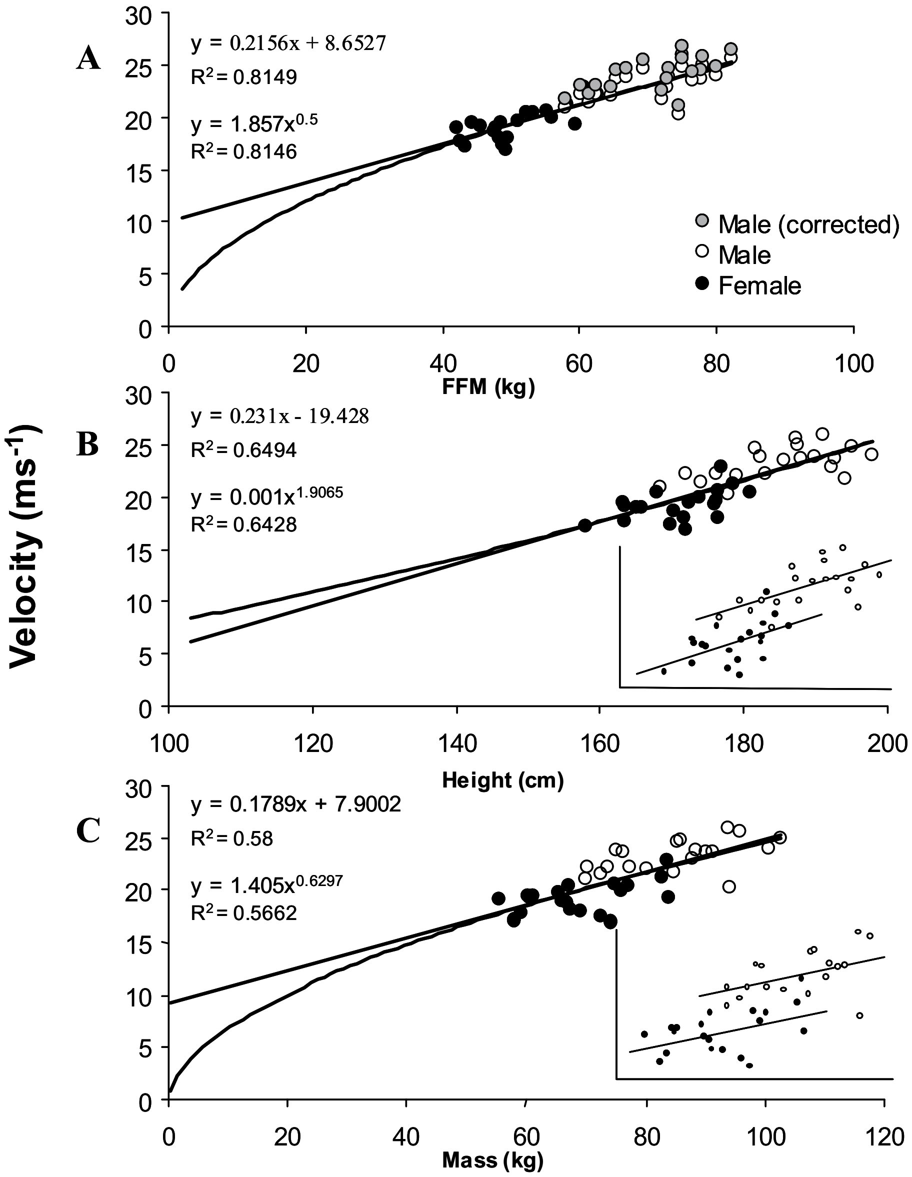

Figure 5. Throwing velocity plotted against (A) FFM: men (¹), r = 0.62, p = 0.056, men corrected for velocity (¸), and women (¸), r = .69, p =0.001. The regression lines of men (corrected velocity) and women are significantly different (p=0.043). (B) height: men (¹), r = .60, p < 0.001 and women (¸), r = .52, p =0.02. The regression lines of men and women are significantly different (p=0.001). (C) mass: men (¹), r = .54, p = 0.014 and women (¸), r = .49, p =0.027. The regression lines of men and women are significantly different (p<0.001).

For strength, no gender effect was found at all (fig 6). When taking females and males separately, the relationships between strength and height were not significant. However, both groups showed a near-significant or significant relationship for strength with mass (p=0.06 and p=0.01, respectively) and FFM (p=0.012 and p=0.013, respectively).

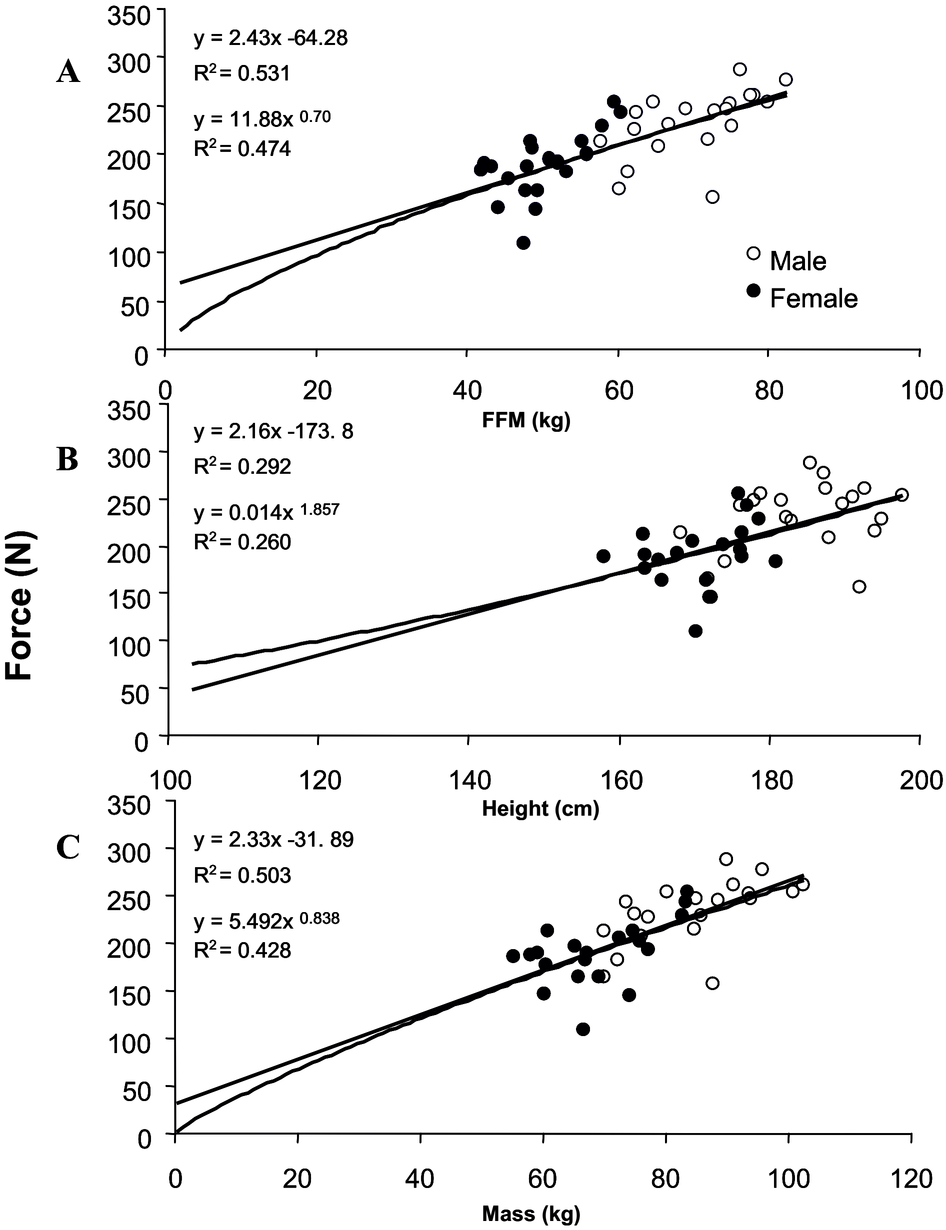

Figure 6. Maximal isometric force plotted against (A) FFM: men (¹), r = .58, p = 0.013 and women (¸), r = .64, p =0.012. (B) height: men (¹) and women (¸), r = .27, p >0.05. (C) mass: men (¹), r = .59, p = 0.01 and women (¸), r = .52, p =0.062. In all cases, the regression lines of men and women are not significantly different (p=0.56, 0.25, 0.59, respectively).

Discussion

In this study, the effect of body size and gender on throwing performance and specific isometric strength was examined. Body size had a strong positive influence on throwing performance and isometric strength. Velocity showed effects of gender, but these were strongly reduced when body size was expressed as FFM.

Isometric strength test

The strength test performed in the study was a whole extremity test rather than an isolated joint test. Thus the findings are more difficult to explain than with regular joint strength tests. In the position 1, where the ball was held with a straight arm, the highest forces were measured. When the throwing arm was bend 90 degrees the force (position 2) was less than in the first position. However, it was higher than in the last two positions, where the hips and shoulders had an angle of 90 degrees with the throwing direction. This difference in isometric strength can be explained by the principle that the strength of a chain is as strong as its weakest link. In this experiment, the difference between the first and second position was the flexed elbow (90 degrees). This flexed elbow introduces an extra link in the chain enhancing the chance of strength decrement, especially when the shoulder joint configuration is not changed between positions. The higher force in position 2 compared to the last two positions can also be explained by the introduction of more (and possibly weaker) links. The position in which the hip and shoulder girdle form a 90 degrees angle with the throwing direction, introduces a large leverage of the upper limb at these girdles. Thus, large internal torques (resisting the one from the upper limb pulling the girdles back into the throwing plane) must emerge.

Effect of size

The present fitting results indicate that data in a relatively small size range cannot be used to identify allometric relationships. As Batterham et al. (1999) found for a sample of over 1000 human subjects, this study, on a much smaller sample, suggests that using allometric curves may result in fitting artefacts because the fitting curve is forced through the origin, a purely theoretical combination of zero size and zero value of the dependent variable. In our study, the allometric relationship (power curve) was compared with a linear regression, leading to nearly identical curves within the range of measurement. Thus, we support the view by Batterham et al. (1999) that a study of a single species (human) and a relative small size range using allometric curves (power curves) may lead to scaling parameters that are misleading. Still, clear significant positive trends were indicated between size and performance. With regard to the general trends, the type of curve used did not affect the comparison of males and females.

Effect of gender

The significant difference in throwing velocity between men and women (23.2 ms^{-1} for men and 19,. ms^{-1} for women) is in line with other studies (Toyoshima & Miyashita 1973; Ohnishi et al. 1980; Jöris et al. 1985; Barata 1992; Fleck et al. 1992; Hoff and Almåsbakk 1995; Tuma and Zahalka 1997). These differences in throwing performance between genders can be explained by two components: the size and the non-size component. The non-size component is identified by comparing scaling curves. No gender effect was found for strength, irrespective what measure for size was used. Throwing velocity showed gender influence, but only to a small extend when size was expressed as FFM. These results are in agreement with Batterham et al. (1999) with regard to the choice of measure of size. They found that when using FFM, the different scaling procedures lead to the same scaling coefficient for peak oxygen uptake ($\dot{V}O_{2peak}$), which was unity (i.e. $\dot{V}O_{2peak} \propto mass^1$). Using FFM removed all uncertainty on the effect of size on $\dot{V}O_{2peak}$. In the present study, FFM also seems to be the best estimate for body size with regard to physical performance. Of the measures used, FFM is the best measure for the amount of muscle, the prime organ for physical performance. The other measures, therefore, introduce gender differences such as females having a higher percentage of fat and being shorter than men. The finding that strength and velocity show a gender independent relationship strengthens the simple idea that any gender difference is based on difference in muscle bulk. Effects of other gender aspects then only become apparent when these aspects are introduced in the measure for size (e.g. mass, including fat; height, representing only one dimension of a 3-D parameter). Anderson et al. (1979) suggested that the difference in movement velocities between men and women could be explained by the difference in distribution of muscle fibre types and by different coordination patterns between men and women. However, in this study the difference in throwing velocity is completely explained by the difference in FFM. This indicates that abovementioned non-size gender differences are proposed possibly on the basis of biased measures for size. Force per kilogram FFM is significantly higher for women than men (table 1). However, no effect for gender was found on the FFM-strength relationship (Fig 6A). This discrepancy can be explained by the choice of method. By expressing strength as force per FFM, one disregards the non-proportional scaling effect of size on strength, regardless whether that is expressed as a power coefficient unequal to unity or an intercept in a linear regression. The expression of strength per kg FFM is, in fact, the slope of a linear regression through the origin, which clearly is not appropriate when scaling effects are taken into consideration.

In summary, body size (FFM) explains the difference in throwing velocity and isometric strength of the upper limb between men and women. Men throw faster and produce more force because they have a higher fat free body mass. The finding that strength and velocity show a gender independent relationship strengthens the notion that any gender difference is based on difference in muscle bulk.

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5. A Force-velocity relationship and coordination patterns in overarm throwing.

Summary

A force-velocity relationship in overarm throwing was determined by using ball weights varying from 0.2 to 0.8 kg. Seven experienced handball players were filmed at 240 frames per second. Velocity of joints of the upper extremity and ball together with the force conducted on the ball were derived from the data. A significant negative relationship between force and maximal ball velocity, as well as between ball weight and maximal ball velocity was observed. Also, with increase of ball weight the total throwing movement time increased. No significant change in relative timing of the different joints was demonstrated, suggesting that the subjects do not change their "global" coordination pattern. However, the change in ball velocity when varying ball weight is explained for 95 % by the change in velocity of elbow extension and internal rotation of the shoulder. The internal rotation of the shoulder (63 %) and elbow extension (32 %) are the main contributors to the total ball velocity at release. These findings suggest that adaptation to alteration of movement resistance and velocity is located primarily in the proximal regions of the upper extremity.

Introduction

In many movements, resistance (load) and velocity are inversely related to each other. This relationship is often ascribed to skeletal muscle properties. Hill (1938) described an hyperbolic relationship between force and velocity for isolated muscles (referred to as the Hill curve). Many other researchers in muscle physiology as well as researchers in the more applied sciences used this relationship to describe and explain phenomena of muscle contraction. In sport science, many training experiments, set up to enhance the performance of the athlete, are based on Hill's force-velocity relationship (e.g. Kaneko et al., 1983; Komi and Häkkinen, 1988): by prescribing a particular speed or resistance, specific effects along the force-velocity description of movement are expected.

For overarm throwing, several studies showed that by increasing ball weight the ball velocity decreases (Toyoshima and Miyashita, 1973; Kunz, 1974; Toyoshima et al., 1976). Toyoshima and Miyashita (1973) and Toyoshima et al. (1976) determined the relationship between maximal ball velocity and ball weight using ball weights varying from 0.1 to 0.5 kg. Kunz (1974) used a larger domain of ball weights varying from 0.08 to 0.8 kg, but with a low resolution (0.08, 0.4 and 0.8 kg). Another aspect studied by several researchers is the contribution of the body segments to the throwing performance. Toyoshima and Miyashita (1973) showed that by constraining more body segments during the throwing task, the maximal ball velocity decreases in the whole range of ball weights, which were used. To our knowledge no data is available regarding changes in coordination due to ball weights. No relationship between force production and movement velocity has been described. Thus, the aim of this study was to describe the force-velocity relationship in overarm throwing with different ball weights. The description had to be expressed as velocity and force applied to the ball, not merely ball weight; in this form, a description would reveal more information regarding neuromuscular characteristics. Furthermore, the aim was to examine if coordination of the throwing technique changes due to these different ball weights. A possible lack of coordinative changes would indicate the importance of muscular force-velocity properties for such explosive movements as the overarm throw.

Methods

Seven subjects participated in this experiment. The subjects were experienced male handball players, playing in the second division of the Norwegian national competition (mean age 25 ± 2.5 years, weight: 84.4 ± 9.9 kg., length: 1.84 ± 0.08 m.). The study complied with the requirements of the local Committee for Medical Research Ethics and current Norwegian law and regulations.

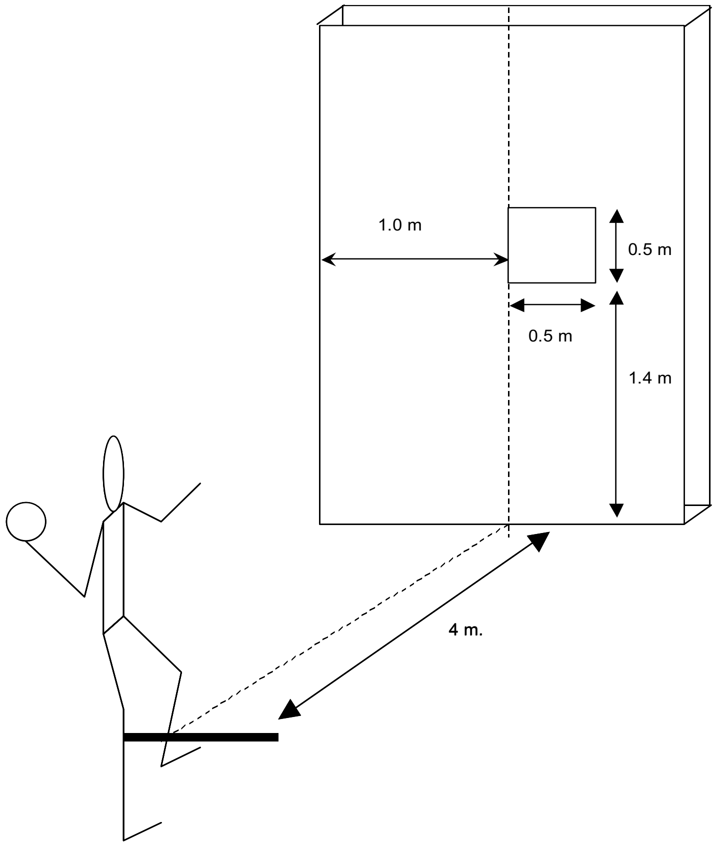

Figure 1. Experimental set-up. Subject at a 4 meter distance from the target drawn on a large mattress that avoids the balls bouncing back toward the subject.

Procedure

After a general warm-up of 15 minutes, throwing performance was tested in an overarm throw towards a target at four meters distance. The subjects performed a standing throw with holding the front foot on the floor during throwing (Fig. 1). The instruction was to throw as fast as possible aiming at a 0.5 by 0.5 m^2 target at 1.65 m height. The subjects threw 5 times randomly with each of 7 different weight adjusted javelin balls (circumference 0.3 m; weights 0.206, 0.305, 0.409, 0.503, 0.616, 0.706 and 0.818 kg).

Measurements

The displacements in time of the different segments of the body were recorded using a Pro-Reflex (Qualisys) system at a 240 Hz sample rate. Reflective markers (2.6 cm diameter) were used to identify the following anatomical landmarks:

a) Hip: Greater trochanter on the side of the throwing arm
b) Shoulder: Acromion process on the side of the throwing arm
c) Elbow: Lateral epicondyle of the throwing arm
d) Wrist: Styloid process of the throwing arm
e) Ball: the ball was taped with reflective tape, which made it possible to identify the centre of the ball during the attempts.

It was not possible to identify a marker on a finger, as the ball and finger marker were too close to each other. Computation of velocity of the different joints and the ball was done using a five point differential filter. The force on the ball was calculated by differentiating velocity which was then multiplied by the ball mass. The velocity at ball release and the moment of release were derived from the change in distance between the wrist and the ball. At the moment the ball leaves the hand the distance between the wrist marker and the ball marker increases abruptly and dramatically.

The total movement time of the throw was defined by the time at which the hip reached the maximal linear velocity (begin of the throw) and the time at which the ball released the hand. Maximal hip velocity was taken as an early and clearly identifiable moment in the goal directed movement. This was done because the actual onset of goal directed movement was hard to identify. Furthermore, at about this moment, the ball velocity started to increase dramatically (Fig. 4; van den Tillaar and Ettema, 2002). Timing of events was presented as time before ball release.

The angular movement of elbow extension and wrist flexion were derived from relative positions between shoulder, elbow, and wrist marker and between elbow, wrist, and ball marker, respectively. External and internal rotation of the shoulder were derived from positions of shoulder, elbow and wrist marker: the orthogonal coordinate system was first translated to centre the system in the shoulder (origin); subsequently, it was rotated to align the shoulder-elbow line with the x-axis; the shoulder rotation angle was calculated as the angle between the shoulder-elbow-wrist plane and the horizontal plane.

Statistics

To assess effects of ball weight on the velocity of the ball and joints, as well as timing, a oneway ANOVA for repeated measures was used. Polynomial contrasts analysis was used to identify trend characteristics. For the force-velocity relationship a linear regression procedure was employed.

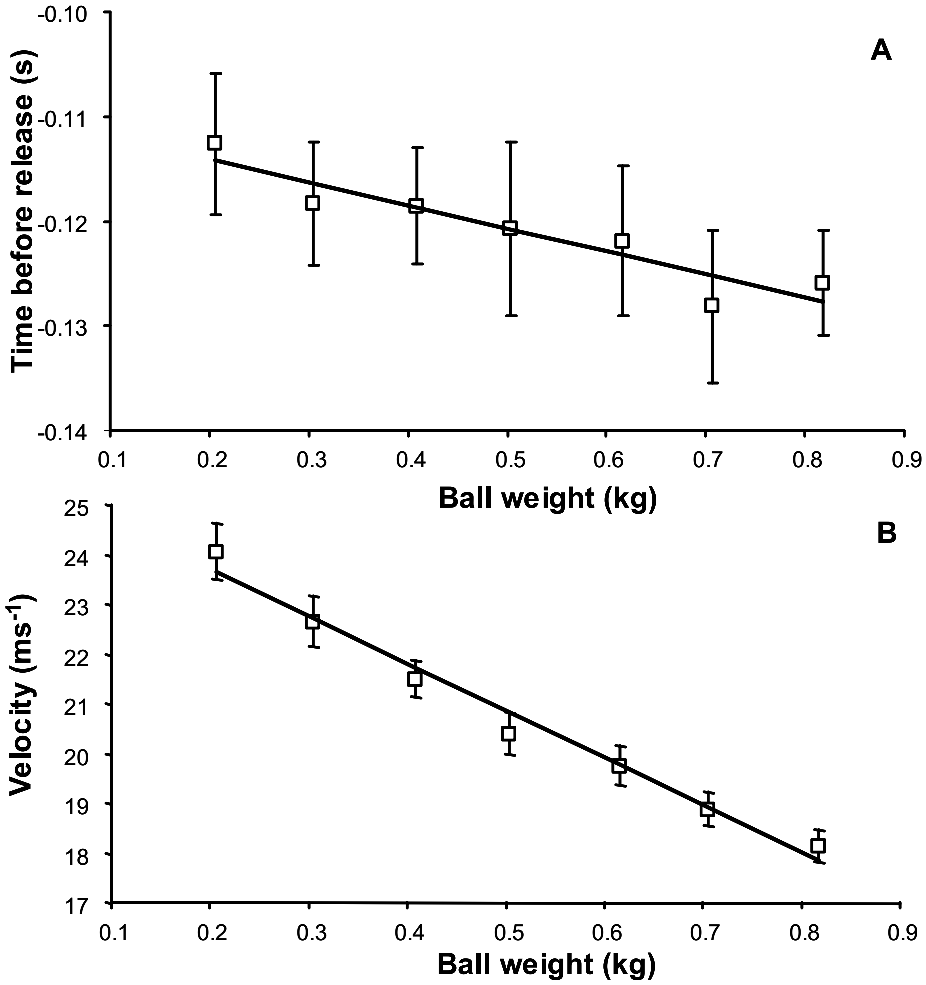

Figure 2. Relationship between ball weight and total throwing time (A) and release velocity (B) averaged over all subjects. Vertical bars indicate standard error of the mean (sem).

Results

The total movement time increased and ball velocity decreased significantly with increased ball weight ($F_{(6,36)}$=2.95; p=0.017 Fig. 2A; ($F_{(6,36)}$=134; p<0.001 Fig. 2B, respectively).

Each subject showed a significant negative linear relationship for ball velocity against both ball weight ($F_{(1,5)}$Ó103; p<0.001, rÓ0.98) and applied force ($F_{(1.5)}$Ó14; p<0.012, rÓ0.87).

When all observations were used in a pooled manner, i.e. irrespective of subject, still a linear relationship for ball velocity against both ball weight ($F_{(1,236)}$=510; p<0.001, r=0.83) and applied force ($F_{(1.226)}$=156; p<0.001, r=0.64) (Fig. 3 inset) was found.

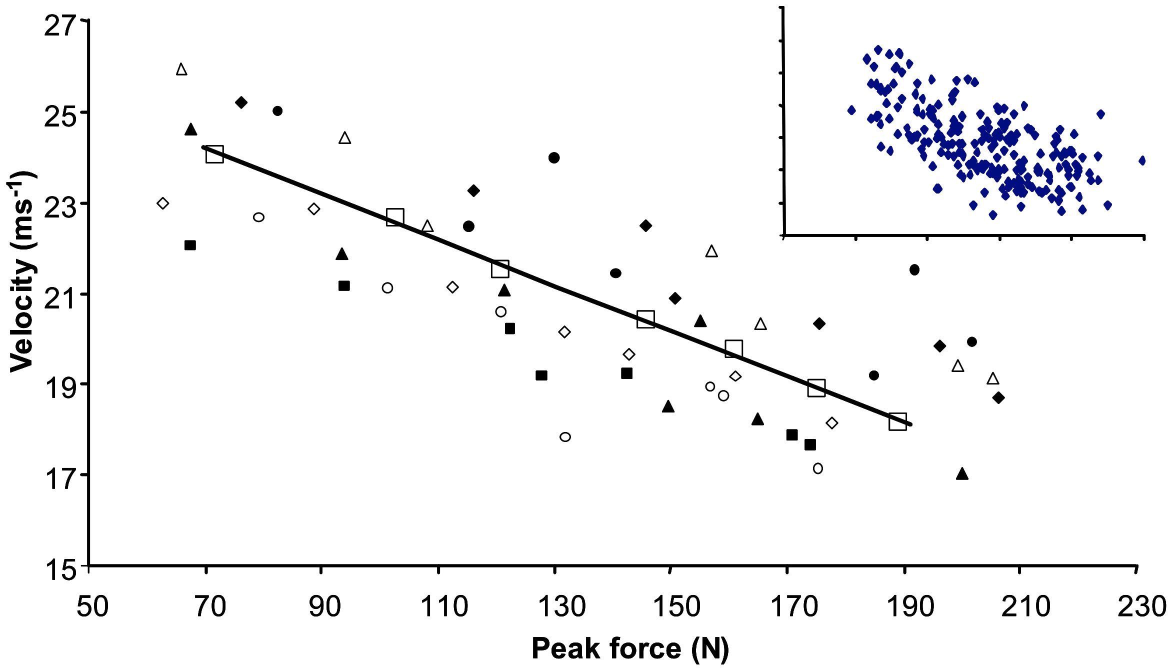

Figure 3. Relation between peak forces on the ball and release velocity of the ball Symbols indicate subjects; mean data are indicated by (ʻ). Inset: all observations.

Joint velocity

Figure 4 shows the development of angular velocity of the different joints and ball over time. The vertical lines indicate the time at which the hip segment (start of movement) and different joints reached the maximal linear velocity and angular velocity during the throw.

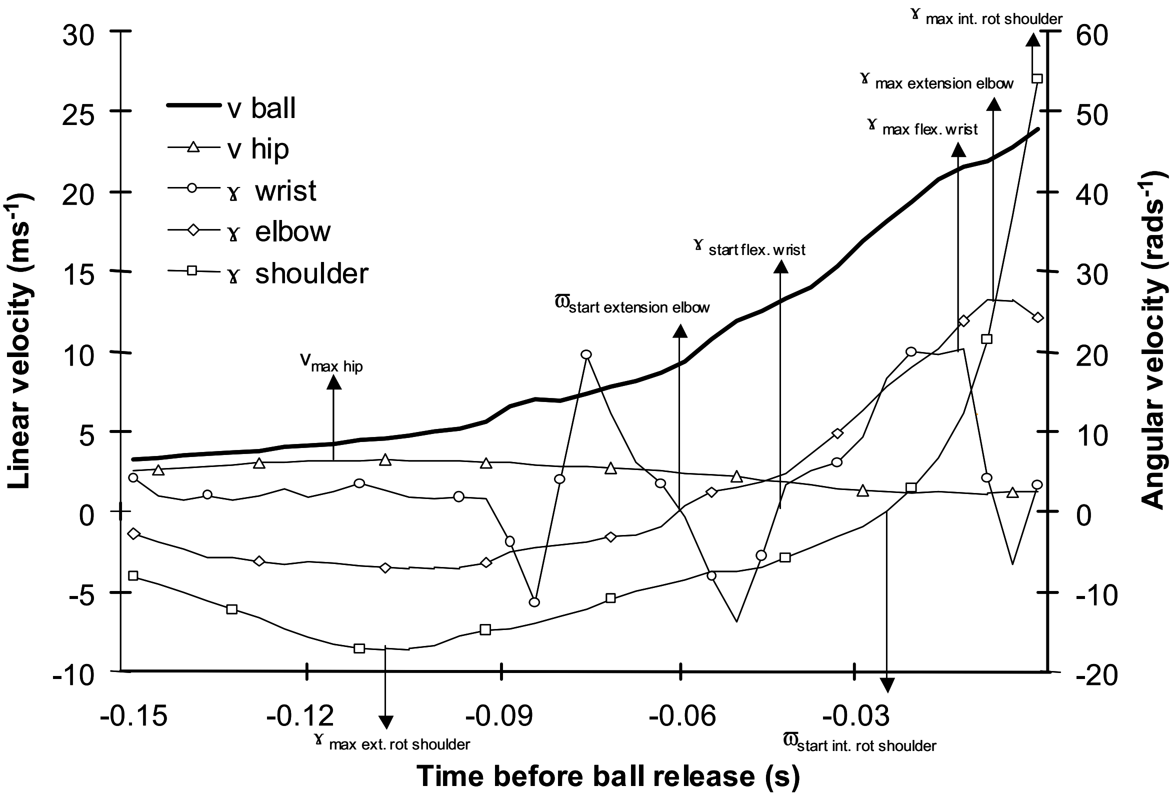

Figure 4. A typical example of development of linear of the hip segment (æ), ball, and angular velocity of the wrist (ʒ), the elbow (ö) and ext/int rotation of the shoulder (ʻ) in time before ball release (the symbols indicate different signals and not points of measurements).

Maximal velocity of wrist flexion ($F_{(6,30)}$=3.73; p=0.007), elbow extension ($F_{(6,36)}$=17.28; p<0.001), and internal rotation of the shoulder ($F_{(6,18)}$=6.33; p=0.001), as well as the angle of the elbow joint at ball release ($F_{(6,24)}$=2.84; p=0.031) were affected by the increase of ball weight. Tests for polynomial contrasts revealed that in all joints all aspects showed a significant negative linear trend (Fig. 5; p<0.04).

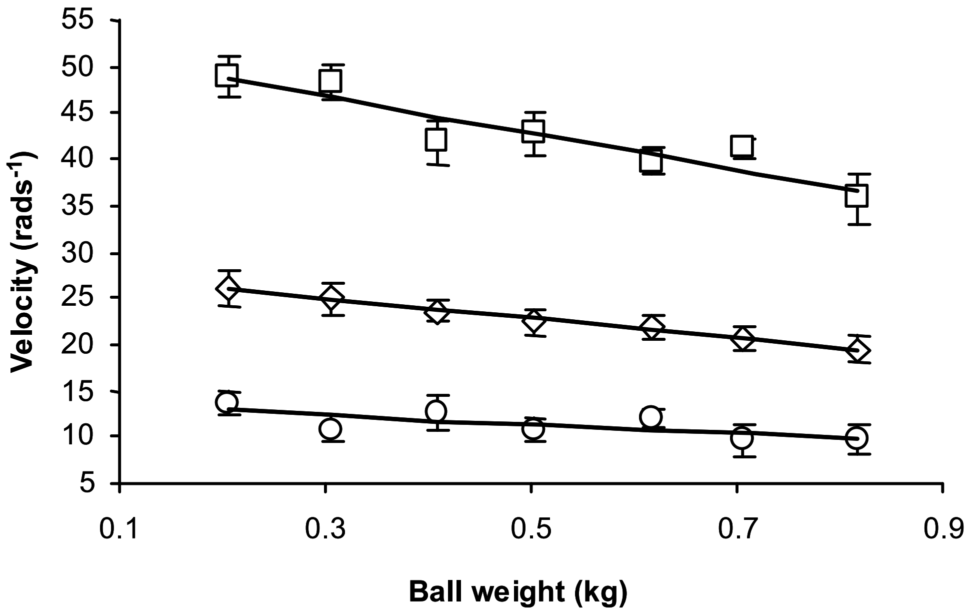

Figure 5. Relation between ball weight and maximal angular velocity of the flexion of the wrist (ȥ), extension of the elbow (ö), and internal rotation of the shoulder (ʹ), averaged over all subjects with sem.

Timing

As already mentioned before, the total time of the throwing movement increased with ball weight (Fig. 2A). This also appeared for the occurrence of initiation of the shoulder ($F_{(1,5)}$=23.17; p<0.005) and elbow ($F_{(1,6)}$=11.37; p=0.015). However, initiation of the wrist flexion ($F_{(1,6)}$=1.91; p=0.216), time of maximal extension elbow ($F_{(1,6)}$=0.328; p=0.59) and time of maximal flexion wrist ($F_{(1,6)}$=1.65; p=0.247), did not show a significant relationship (Fig. 6A). Whereas time to ball release increased for maximal angular velocities (Fig 6A), in accordance with total movement time (Fig. 2A), no ball weight effects were apparent for relative timing, i.e. time of event over total movement time (Fig. 6B).

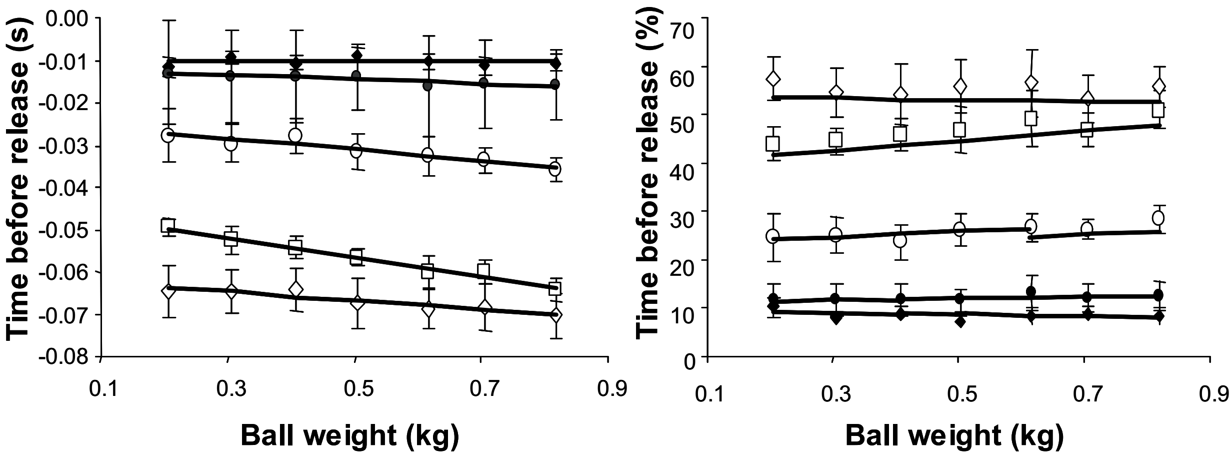

Figure 6. Mean values and sem (n=7) of (A) absolute time before ball release and (B) relative time of the initiation of the internal rotation of the shoulder (ʹ), elbow extension (ö) and wrist flexion (ʒ) together with occurrence of the maximal angular velocity of the elbow extension (Dǯand wrist flexion (ǒ).

Discussion

The objective of this study was to investigate the relationship between load and velocity in overarm throwing, as well as the effect of ball weight on coordination patterns of the overarm throw. The results confirm earlier studies (Toyoshima and Miyashita, 1973; Kunz, 1974; Toyoshima et al., 1976) and indicate that an inverse relationship between load and velocity exists. In other words, high ball velocities are obtained with a low load (ball weight) requiring less force exertion. The angular velocities of the different joints decreased with increasing ball weight. The absolute throwing movement time increased with ball weight. No significant trends or changes in relative timing were notified.

Force-velocity

A significant linear force-velocity relationship per subject was found for the range of ball weights (Fig. 3). Kaneko et al. (1983) found a curvi-linear relationship. The discrepancy may be explained by the small range of ball weight, which results in a small range of force production. Anyway, the force-velocity relationship, demonstrated in this study has strong resemblance with the classic force-velocity curve for isolated muscle as described by Hill in 1938. It should be noted that this curve does not represent the relationship between force and velocity during a single movement. Rather, for several movements in which one parameter was systematically altered (ball weight), standard points in the time traces of two variables (force and velocity) was determined and plotted against each other. Although the curves for throwing and isolated muscle contraction may be similar, the systems and actions from which these performance curves arise are quite different: complexity of the movement, the number of factors [e.g. motivation, muscle activity levels, muscle synergies and coordination] and system elements [e.g. nervous system, various muscles and joints] that are involved). One should therefore take extreme care by interpreting the current force-velocity curve as being mainly determined by muscle properties. Still the overall coordination pattern (relative timing) seems independent of load. For example, no changes in the relative timing of the different joints were found. This was also found in an earlier study (van den Tillaar and Ettema 2000a, b; van den Tillaar and Ettema 2003) regarding effects of instruction regarding accuracy and speed. Thus, with reservation, one may suggest that a force-velocity curve was obtained for a single synergistic musculoskeletal system in overarm throwing with an unaltered neural input. It should be noted that, although the effort was maximal, the muscular effort may not have been maximal as the time to build up a maximal contractile state may have exceeded the total time available to do so in all muscles in a rapid movement as an overarm throw (Bobbert and van Ingen Schenau, 1990). Future studies, including for example electromyography, may elucidate if with varying ball weight the neural input and muscular coordination pattern is unaltered and if maximal contractile state is affected by the short duration of muscular activation.

In figure 4 it was shown that the maximal internal rotation of the shoulder occurred at ball release and that the maximal extension of the elbow occurred on average only 0.010 seconds before ball release. The angular velocity of these two joints (mean: 42.5 $rads^{-1}$: internal rotation shoulder, 22.7 rads^{-1}: extension elbow) was also much higher than the angular velocity of the wrist joint (11.3 rads^{-1}). These findings indicate the importance of these different joints to the total contribution of the ball velocity. Ball velocity can, in principle, be calculated from the joint velocities at ball release. However, the different joint velocities lead to ball velocity in a complex interactive manner. For example, elbow extension and internal rotation independently create ball velocity in perpendicular directions. Therefore, these two joint movements (along with others) must be coordinated well to optimise ball velocity.

Still, in a first approximation, one can estimate the potential contribution of elbow extension, internal rotation and wrist flexion assuming that these three movements are fully transferred to ball velocity. In this case the following applies at ball release:

$$v\ ball_{modelled} = \varpi_{shoulder} \bullet D \bullet \sin(\zeta_{elbow}) + \varpi_{elbow} \bullet D + \varpi_{wrist} \bullet E \qquad (1)$$

D being distance from elbow to ball (approx. forearm length), E distance from wrist to ball (approx. hand length), ϖ joint velocity and ζ joint angle. The wrist approaches zero at ball release (see Fig. 4). Therefore equation 1 can be reduced to:

$$v\ ball_{modelled} = \varpi_{shoulder} \bullet D \bullet \sin(\zeta_{elbow}) + \varpi_{elbow} \bullet D \qquad (2)$$

Equation (2) can be transformed to obtain relative contribution of elbow extension and shoulder rotation by taking the ratio of the components over total ball velocity. The results are shown in figure 7. The model predicts actual velocity well. Correlation between modelled and measured velocity as found by linear regression with zero intercept for mean values is 0.97, for individual subjects data range from 0.79 to 0.93 (see Fig 7A). On average, the model explains about 94% of ball velocity. This contribution increases significantly with ball weight (Fig. 7B), indicating that the proximal joints become more important when increasing ball weight. It should be noted that the model assumed a perfect transfer of joint velocity to ball velocity. As argued above, this is not likely. Thus, the 94% contribution is likely overestimated, but still remains extremely high. Other significant contributions could come from maximal angular velocity of shoulder horizontal adduction, upper torso rotation, forward trunk tilt and pelvis rotation (Matsuo, et. al. 2001). However, wrist flexion can only contribute to minor extent (given the leverage of the hand and maximal wrist flexion speed as found in this study). It should be noted that these data do not indicate that maximal ball speed can be obtained by merely using internal rotation and elbow extension. It is not unlikely that these joints obtain these high speeds by making use of slower movements in other joints in a chain of segments.

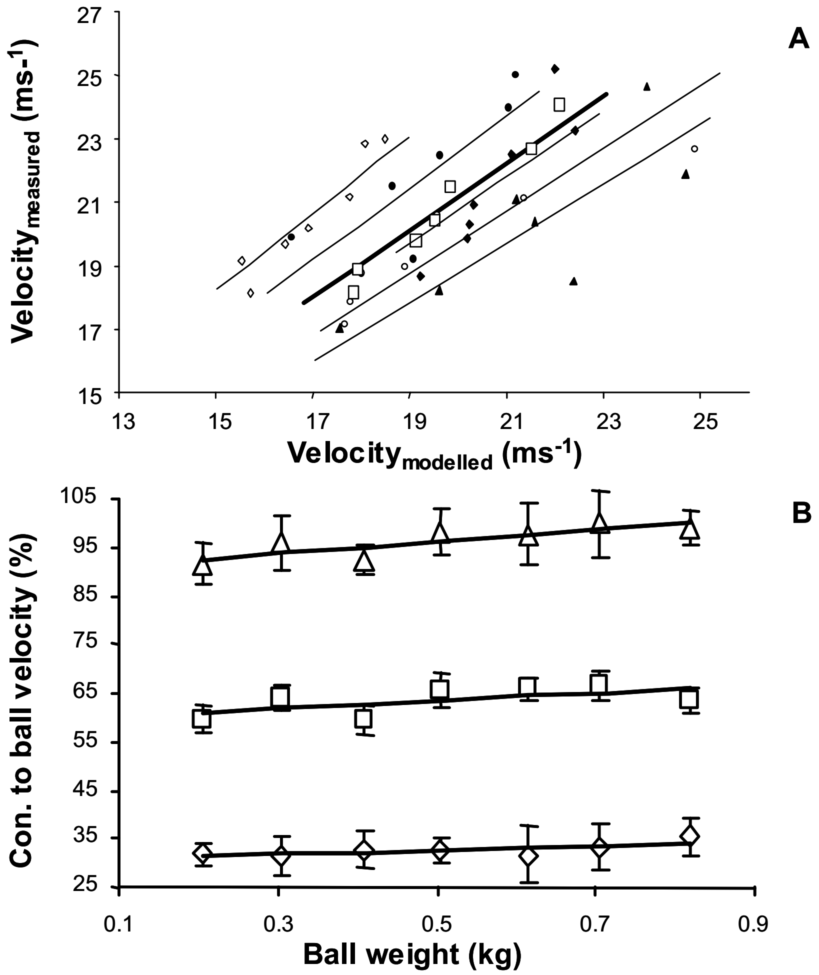

Figure 7. (A) Relationship between measured and calculated ball velocity (eq. 2) per subject and averaged over all subjects( ). Correlation between modelled and measured velocity as found by linear regression with zero intercept (y=1.059x) for mean values is 0.97, for individual subject data range from 0.79 to 0.93. (B) Mean values and sem (n=5) of contribution of the internal shoulder rotation ( ), elbow extension (ö) and shoulder rotation + elbow extension together (æ)

The shoulder appears to be the major contributor with a mean of 62 % (elbow 33 %). Toyoshima et al. (1976) argued that elbow extension at different ball weights (0.1-0.5 kg.) contributed less than 42.5 %, which is in line with the current findings.

Proximal distal sequence

In earlier studies on overarm throwing in handball, a proximal-distal sequence was found (Jöris et. al., 1985; Tuma and Zahalka, 1997). The proximal-distal sequence is the phenomenon of a time lag between movements of proximal and distal joints and segments, where the distal movements are delayed with regard to the proximal movements. Herring and Chapman (1992) showed that the proximal-distal sequence in timing of the segments may be due to anatomical-mechanical principles and appeared to be the most effective strategy in reaching high throwing speeds. In the present findings not all movement characteristics were conform this principle. For example, the onset of the elbow extension preceded the onset of the internal shoulder rotation, (Fig. 4 and 6A). Hong et al. (2001) also stated that the onset of torques was not strictly in a successive proximal-distal order. Hong et al. (2001) found that the forearm extensors and the internal rotators were recruited at almost the same time and kept acting until shortly before release. Another characteristic found here (Fig. 4 and 6A) and by Hong et al. (2001) that is not in line with the proximal-distal sequence is the earlier occurrence of maximal angular velocity of the wrist than that of elbow extension. This early wrist flexion may be explained by the bi-articular function of the wrist flexors. The flexor carpi ulnaris and flexor carpi radialis have a flexor moment on the elbow and a flexor moment in the wrist (Ettema, Styles, and Kippers, 1998). Thus, wrist flexion may be enhanced by the strong elbow extension if these wrist flexors are active and by doing so counteract the original elbow extension movement.

Conclusion

In conclusion it can be stated that there is a linear force-velocity relationship in overarm throwing with ball weights varying from 0.2 to 0.8 kg. Qualitatively, no changes in coordination pattern (relative timing) occur with increasing ball weight. Quantitatively, the internal rotation of the shoulder and elbow extension are the main contributors to the total ball velocity at release. With increased ball weight this contribution enhances indicating that the proximal joints become more important with increased ball weight.

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6. Effect of different training programs on the velocity of overarm throwing

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7. Conclusions and suggestions for further research

In this thesis, the role of several constraints on coordination and performance in fast discrete complex movements was investigated. Overarm throwing was used as the paradigm example for this type of movement. Accuracy and velocity were used as measures for performance in overarm throwing. The general finding was that the constraints that were investigated (instruction, body size, gender, ball mass and level of training or experience) affected performance (i.e. release velocity) but not coordination.

The type of instruction plays an evident role in the performance (Chapter 2). When the instruction emphasises accuracy, velocity decreases. Accuracy, however, does not seem to improve when subjects are instructed to prioritise accuracy. A possible explanation for this finding lies in the specific subject group. The subjects were highly experienced handball players. Thus, the accuracy they demonstrated at high velocity might have been extremely high already and difficult to improve upon when reducing throwing velocity. Furthermore, the velocity of throwing, when instructed with the emphasis on accuracy was around 85 % of the maximal velocity. This suggests that experienced handball players are trained to throw accurately at a relatively high velocity.

Regarding body composition and gender, body size has a strong positive effect on throwing performance and isometric strength (Chapter 4). Throwing velocity appears to be affected by gender if size is expressed as mass or height. However, this gender effect disappears to a large extent when size is expressed as fat free body mass (FFM). For strength, no gender effect is indicated, that is, all gender differences can be explained by size differences, irrespective of how this is expressed. These findings strengthen the notion that gender differences are based on a difference in muscle bulk. It is concluded that FFM, as an approximation for musculo-skeletal mass, is the best measure to express body size with regard to physical performance.

Regarding mechanical constraints of the throwing task, projectile mass affects the release velocity (Chapter 5). A linear negative relationship between ball mass and maximal ball velocity, as well as between force and maximal ball velocity is observed. Also, with increase of ball mass the total throwing movement time increases.

No clear answer can be given to the question which type of strength training increases the throwing performance (velocity) most effectively and if there is any significant improvement at all. However, training that involves throwing with underweight balls seems to have a clear positive effect on the throwing velocity. Neural adaptation can be the reason for the increase in this type of training regimes. Training with just overweight balls, medicine balls or general strength training with load lower than 12 RM gives conflicting results. A possible reason for this can be that workload is a determining factor (Gløsen, 2001), which was not always controlled in training studies.

Generally speaking, the kinematic movement patterns (coordination) are unaffected by the constraints investigated. The difference in ball velocity, due to instruction, is a result of the difference in maximal linear velocity of the wrist, elbow and hip segments together with their absolute timing before ball release. However, the subjects do not change technique (as indicated by the invariance of the relative timing of the different body segments (Chapter 3). Essentially the same is found when altering projectile mass (Chapter 5). When varying ball mass, 95% of the change in ball velocity was explained by the change in velocity of elbow extension and internal rotation of the shoulder. The internal rotation of the shoulder (63 %) and elbow extension (32 %) are the main contributors to the total ball velocity at release.

Proximal distal sequence

A particular movement pattern that is often observed in overarm throwing is the proximal distal sequence (e.g. Jöris et. al., 1985; Herring & Chapman, 1992). The proximal-distal sequence is the phenomenon of a time lag between movements of proximal and distal joints and segments, where the distal movements are delayed with regard to the proximal movements. Herring and Chapman (1992) showed that this proximal-distal sequence in timing of the segments is an effective strategy in reaching high throwing velocities, given the anatomical and mechanical constraints of the upper limb and throwing task. However, in the experiments of this thesis (Chapter 3, Fig. 1), the maximal linear velocity of the shoulder segment occurs later than that of the elbow. These results in timing of the different segments are in line with the earlier studies on female handball players (Yamamoto et al., 1974; Tuma & Zahalka, 1997). Also in overarm throwing in baseball (Hosikawa & Toyoshima, 1976) and the tennis serve (Kleinöder, Neumaier, Loch and Mester, 1994) a similar pattern of timing, i.e. that the maximal linear shoulder velocity occurs later than that of the elbow, is found. However, these studies could not explain the later timing of the shoulder segment compared to the elbow.

In the preferred arm of male baseball players, the maximal linear velocity of the shoulder segment occurs later than that of the elbow (Hoshikawa and Toyoshima, 1976). In the non-preferred arm, a timing pattern according to the proximal-distal sequence occurs. However, after 15 weeks of training, the timing pattern changed toward that of the preferred arm. Perhaps the proximal-distal sequence could be regarded as a functional pattern by default, and changes by fine-tuning into another pattern deviating from the proximal-distal sequence.

An explanation for the deviation from the proximal-distal sequence in experienced throwers may be found in the simultaneous occurrence of maximal linear velocity of the elbow and onset of elbow extension (Fig. 1). After this instance, the velocity of the distal segment (forearm, hand and ball) increases more than that of the arm. This means that the distal segments are generating large (reaction) forces against the proximal segments, resulting in a decrease of velocity of the arm and elbow segment (Jöris et al., 1985). This mechanism does not necessarily play the same role in the shoulder because of the relatively heavy mass of the trunk that is therefore generating a relatively high impulse on the shoulder.

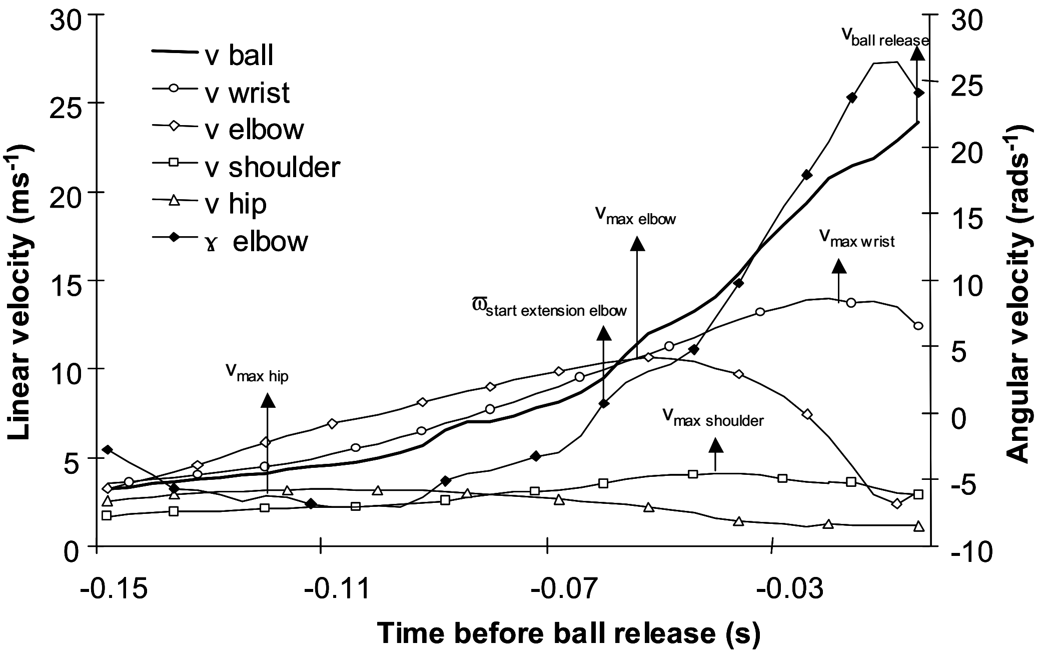

Figure 1. A typical example of development of linear of the hip(æ), shoulder (Ĭ), elbow (ö), wrist segment (ʒ) and ball together with the angular velocity of the elbow (Džin time before ball release (the symbols indicate different signals and not points of measurements).

Also, the kinematic patterns of the joints do not follow the proximal-distal principle. For example, the onset of the elbow extension preceded the onset of the internal shoulder rotation, (Chapter 5, Fig. 4 and 6A). Hong et al. (2001) also state that the onset of torques is not strictly in a successive proximal-distal order. Hong et al. (2001) found that the forearm extensors and the internal rotators are recruited at nearly the same time and keep acting until shortly before release. Another characteristic found here (Chapter 5, Fig. 4 and 6A) and by Hong et al. (2001) that is not in line with the proximal-distal sequence, is the earlier occurrence of maximal angular velocity of the wrist than that of elbow extension. This early wrist flexion may be explained by the bi-articular function of the wrist flexors. The flexor carpi ulnaris and flexor carpi radialis generate a flexor moment at the elbow and a flexor moment at the wrist (Ettema, Styles, and Kippers, 1998). Thus, wrist flexion may be enhanced by the strong elbow extension if these wrist flexors are active. This mechanism may thus shift the occurrence of the maximal velocity of the wrist flexion earlier in time.

Directions for further research

The findings in this thesis have implications for further research and there is a limitation with regard to generalisation. For example, in this study experienced handball players were used to avoid the possible effect of inadequate coordination patterns on the findings. Thus, the findings do not necessarily apply to another population. Ignico (1991), studying kindergarten children (6 years old) , found conflicting results with regard to the effect of instruction, that is, that there is no difference in either throwing velocity or accuracy between groups that trained with emphasis on velocity, accuracy or both. It was shown that age and thereby level of experience influenced throwing velocity (Roberton, 1978; Roberton, Halverson, Langendorf and Williams, 1979; Halverson, Roberton and Langendorf, 1982; Williams, Haywood and Vansant, 1991; 1998; Elliott & Anderson, 1990). Roberton (1978), Roberton et al. (1979), Halverson et al. (1982) observed that the velocity increased with age from kindergarten age (±6 years) to seven graders (±13 years) and that boys threw faster than girls. The boys also increased more in throwing velocity than the girls did from kindergarten age to seven graders. The explanation that was given for this difference was that boys were further in their development of the throw due to the greater participation in throwing of boys than girls over the elementary/middle school years (7-16 years) (Halverson, et al., 1982). Williams et al. (1991, 1998) tested older adults (mean age: 70 years) and found that the throwing velocity of these subjects was lower than that of a seven grader (±13 years) (Halverson, et al., 1982).

Their coordination pattern and throwing velocity was comparable with a third grader (±9 years), which was also explained by the lack of opportunity or interest (level of experience) in throwing. Halvorson et al. (1982) also described that an average 13 year old subject does not show a fully developed overarm throw. However, Elliott and Anderson (1990) found that 13- and 15-years-old experienced subjects showed a mature throwing pattern compared to experienced adolescents, which explains the effect of throwing experience.

Differences in accuracy, due to level of expertise, were also found in dart throwing (Etnyre, 1998). Also, in that study it was observed that throwing with maximal force resulted in more variability. This indicated that the type of fast discrete complex movement is important as well. In this thesis the overarm throw was used as a paradigm for fast discrete complex movements. In many ways the overarm throw shows similarities with other fast discrete complex movements like volleyball spiking and soccer kicking. In the research on volleyball spiking (Chung, Choi, Shin, 1990, Coleman, 1993, Chengfu, Gin-Chang, Tai-Yen, 1999) the observed maximal extension of the elbow was of the same amount as in this study (25.8 rad/s-270 grams: chapter 5). The maximal ball velocity in volleyball spiking for females was also comparable with the velocity in overarm throwing (Chung, 1988, Chenfu, Gin-Chang, Tai-Yen, 1998, Christopher & Ricard, 2002). However, the maximal ball velocity and internal rotation measured in volleyball spiking and overarm throwing differed much (ball velocity: 27 vs. 24 m/s, int. rot. shoulder: 25 vs. 48 rad/s). These differences can be caused by the type of fast discrete complex movement task. In the tennis serve and volleyball spiking the impact aspect and thereby perception is of importance, which is not the case in non-impact movements (throwing). This could also be the case in movements of the upper limb versus lower limb (soccer kick). Amos and Morag (2002) showed that by increasing shoe mass the foot velocity decreases in soccer kicking, which is similar to the findings on overarm throwing in chapter 5. However, the ball velocity did not change with the use of different shoe masses. Thus, the studies in this thesis could give other results in other type of fast discrete complex movements, which makes it difficult to generalize the findings from this research to other fast discrete complex movements. The scientific challenge is to find out to what extent the constraints imposed upon these movements has similar effects on performance.

Coordination and muscle activity patterns

In this study, the throwing performance (velocity and accuracy) was the main dependent variable. However, to obtain information on how this performance was achieved, coordination was examined as well. Kinematic analysis was used for this purpose. The findings in timing of segments and joints that were observed are not conform the proximal-distal sequence that is regarded as a highly effective strategy. Further research needs to be performed to better understand the reason for this disconformity. It would be interesting to measure muscle activity (EMG) of the major muscles of shoulder and upper limb including important bi-articular muscles of the forearm during the throw and to perform a more detailed kinematic analysis of the wrist and finger joints. This may provide useful information at the neuro-muscular level regarding the proximal-distal sequence and the total contribution of the different joints and muscles to the development of the throw. Research at this level may provide answers to this question that cannot be found at the kinematic level of analysis.

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