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Hand Reach Star Excursion Balance and Power Tests: Do They Predict Overhead Throwing Performance of Elite Level Female Handball Players?

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Abstract

Background: Throwing performance is an important factor for scoring goals in handball. Mobility and power are two physical factors considered to be important for producing high ball speed. Evidence in the literature for a relationship between mobility tests and throwing performance, and power tests and throwing performance, are scarce and variable. One explanation for the variable and poor relationship to throwing performance could be that the conventional mobility and power tests are not specific enough to throwing. **Aim:** The aim of this study was to investigate the influence of mobility and power on overhead throwing with run-up, utilizing more sport specific tests (HSEBT and 1080 Quantum). The hypotheses being that: 1) functional mobility measured by the hand reach star excursion balance test (HSEBT) is significantly correlated with throwing performance, and 2) maximum power measured by the 1080 Quantum is significantly correlated with throwing performance. **Methods:** Thirteen elite female handball players were recruited for the study, with twelve completing the testing protocol. A HSEBT, consisting of twelve hand reaches were used to measure mobility. Power was measured by twelve tests, consisting of six hop, two push, two pull and two rotational tests, using the 1080 Quantum. Throwing accuracy and ball speed were used as the measures for throwing performance. **Results:** No significant correlations was found between any HSEBT tests and throwing performance. For the power tests, only left foot anterior to posterior hop significantly correlated with ball speed ($r = 0.577$, $p<0.05$). Additionally, the non-dominant hand posterior and superior diagonal pull ($r = 0.601$, $p<0.1$) and the right foot anterior hop ($r = 0.538$, $p<0.1$) were correlated with a statistical tendency to throwing accuracy. **Conclusions:** The results of this study suggest that neither the mobility nor the power tests can be used as individual predictors of performance for overhead throws with run-up. The correlations found between the power tests and throwing performance is likely due to coincidence, rather than a statistically relevant relationship. However, the tests and idea of moving away from conventional testing to a more sport specific approach should not be completely discarded, since the study had a limited amount of subjects. Thus, more studies into the use of sport specific mobility and power tests are recommended.

Key words: testing, mobility, power, throwing performance, sport specific

Preface

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Abbreviations

A0	Anterior zero degree vector
Ant	Anterior
B	Bilateral
Dom	Dominant
ICC	Intraclass Correlation Coefficient
Inf	Inferior
L	Left
L45	Left 45-degree vector
L135	Left 135-degree vector
$m \cdot s^{-1}$	meters per second
MAP	Movement Assessment Profile
HSEBT	Hand Reach Star Excursion Balance Test
n	Number of subjects
Non-dom	Non dominant
NSS	No scapular stabilization
P180	Posterior 180-degree vector
Pos	Posterior
R	Right
R45	Right 45-degree vector
R135	Right 135-degree vector
RM	Repetition max
ROM	Range of motion
Rot	Rotation
SD	Standard Deviation
SEBT	Star excursion balance test

SS	Scapular stabilization
Std	Standard Deviation
Sup	Superior
ϕ	Diameter
$^{\circ}\cdot s^{-1}$	Degrees per second

1. Introduction

Team-handball is an Olympic, fast pace ball sport with many offensive and defensive actions throughout a game, with the main objective of scoring more goals than your opponent in order to win (Wagner, Finkenzeller, Wurth, & von Duvillard, 2014). The sport is very demanding and requires superior physical skills including jumping, diving, blocking, sprinting, ball control, agility and throwing (Chelly, Hermassi, & Shephard, 2010; Gorostiaga, Granados, Ibanez, & Izquierdo, 2005). Throwing ability is one of the most important physical skills for a handball player, in order to score goals (Bayios, Anastasopoulou, Sioudris, & Boudolos, 2001; Gorostiaga et al., 2005). The combination of throwing velocity and accuracy is two of the most important factors when it comes to scoring, because a fast and accurate throw at the goal gives the defenders and goalkeeper less time to parry the shot (Gorostiaga et al., 2005).

Throwing performance throughout the game is determined by different physical factors such as: mobility, stability, strength, power and endurance. Additionally, the sequence and timing of movement through the kinetic chain are important to achieve a high ball velocity in the overarm throw (Bayios et al., 2001; Gorostiaga et al., 2005; van den Tillaar & Ettema, 2009b). Joint mobility can be viewed as the basis for any movement. This is reflected by the fact that mobility, or joint range of motion (ROM), is recognized by many as a key component of physical performance (McNeal & Sands, 2006; Nelson, Kokkonen, Eldredge, Cornwell, & Glickman-Weiss, 2001; Talukdar, Cronin, Zois, & Sharp, 2014; Witvrouw, Mahieu, Danneels, & McNair, 2004). However, there is a limit to how much mobility is needed for different activities. Thus, the demands of the sport should be considered, in order to achieve the optimal ROM to optimize performance in specific activities. For example, a ballet dancer has other ROM demands than a handball player. In order to achieve functional movements there also has to be a balance between mobility and stability along the kinetic chain when performing specific movement patterns such as throwing (Okada, Huxel, & Nesser, 2011).

Strength and power are two closely related factors that often are determinant for throwing velocity (Debanne & Laffaye, 2011; Gorostiaga et al., 2005; Granados, Izquierdo, Ibanez, Bonnabau, & Gorostiaga, 2007). Accordingly, the ability to produce and transfer power through the kinetic chain can be considered closely related to overhead throwing velocity. It should be noted that, the endurance also plays a role in maintaining power over the duration of an entire game.

The focus of this thesis lies on the relationship between mobility and throwing performance and between power and throwing performance. Several studies have investigated mobility in overhead throwing athletes (Almeida et al., 2013; Baltaci, Johnson, & Kohl, 2001; Baltaci & Tunay, 2004; Bigliani et al., 1997; Clarsen, Bahr, Andersson, Munk, & Myklebust, 2014; Downar & Sauers, 2005; Laudner et al., 2013; Laudner, Moore, Sipes, & Meister, 2010; Levine et al., 2006; Myers, Laudner, Pasquale, Bradley, & Lephart, 2006; Robb et al., 2010; Scher et al., 2010; Shimamura et al., 2015; Talukdar et al., 2014; Zakas et al., 2003). However, the majority of the studies focuses either on the relationship between mobility and injury risk (Almeida et al., 2013; Clarsen et al., 2014; Myers et al., 2006; Scher et al., 2010) or merely on establishing a mobility reference of different level athletes in different throwing sports (Baltaci et al., 2001; Baltaci & Tunay, 2004; Bigliani et al., 1997; Downar & Sauers, 2005; Laudner et al., 2013; Laudner et al., 2010; Shimamura et al., 2015). To the author's knowledge the only studies that investigated the relationship between mobility and throwing performance, using mobility tests, are the studies from Robb et al. (2010) and Talukdar et al. (2014) in baseball and cricket players, respectively. Even though studies have established common mobility ranges and adaptations to the different sport demands, there is a lack of knowledge about the direct influence of mobility on overhead throwing performance, especially in handball players.

The relationship between (muscular) power and overhead throwing performance for handball players has been investigated using different tests, including various isokinetic tests (Bayios et al., 2001; Fleck et al., 1992; Zapartidis, Gouvali, Bayios, & Boudolos, 2007), as well as isoinertial (often referred to as isotonic) tests (bench press and squats), rotational power tests and medicine ball throws (Debanne & Laffaye, 2011; Gorostiaga et al., 2005; Granados et al., 2007; Marques, Saavedra, Abrantes, & Aidar, 2011; Talukdar et al., 2014; van den Tillaar & Ettema, 2004a). However, the results in these studies are highly variable, and there often is not a strong statistically significant relationship between power and throwing velocity. Thus, more research is required in order to gain greater knowledge into the relationship between power and throwing velocity.

The fact that the overhead throw is a dynamic, complex and multifactorial kinetic chain movement with an elaborate transfer of energy through the entire body, is recognized throughout the literature (Baltaci et al., 2001; Bayios et al., 2001; Bigliani et al., 1997; Bourdin et al., 2010; Chelly et al., 2010; Laudner et al., 2013; Laudner et al., 2010; Pedegana, Elsner, Roberts, Lang, & Farewell, 1982; Robb et al., 2010; Scher et al., 2010; Talukdar et al., 2014). Despite this, there have been no mobility or power tests that can be regarded as functional, because none were able to fully encompass the complexity of the overhead throwing action.

Recently, new tests for mobility and power designed to better reflect the functional complexity of athletic movements have been developed. The 1080 MAP (mobility) (Athletic 1080 AB, Stockholm, Sweden) (Eriksrud et al., 2013) and the 1080 Quantum (power) (1080 Motion AB, Stockholm, Sweden) theoretically provides researchers, therapists and coaches with the possibility to quantify sport specific mobility and power while encompassing the complexity of the overhead throwing performance, by taking into account the kinetic chain, sequencing of dynamic movements, gravity and ground reaction force. Therefore, the purpose of this study was to investigate the influence of mobility and power on throwing performance, utilizing a hand reach star excursion balance test (HSEBT) measured on the 1080 MAP and power tests measured by the 1080 Quantum. The hypotheses were that: 1) functional mobility measured by the HSEBT is significantly correlated with throwing performance, and 2) peak power measured by the 1080 Quantum is significantly correlated with throwing performance.

2. Theoretical Background

2.1 Overhead Throwing Biomechanics

In order to create sport specific tests for the overhead throw it is important to understand the biomechanics and the demands required of the activity. There is a consensus in the literature that an overhead throw is a complex body activity with a sequential activation of body segments (Baltaci et al., 2001; Bayios et al., 2001; Bigliani et al., 1997; Bourdin et al., 2010; Chelly et al., 2010; Fradet et al., 2004; Herring, Mole, Meredith, & Stern, 1992; Laudner et al., 2013; Laudner et al., 2010; Pappas, Zawacki, & Sullivan, 1985; Pedegana et al., 1982; Roach & Lieberman, 2014; Robb et al., 2010; Scher et al., 2010; Talukdar et al., 2014; van den Tillaar & Ettema, 2009b). To achieve a high throwing velocity, the combination of mobility, power and segmental sequence timing seems to be very important factors. Van den Tillaar and Ettema (2009a) performed an investigation of the difference between the dominant and the non-dominant throwing arm in experienced handball players. They found that any difference in throwing velocity was mainly caused by a decreased joint maximum velocity and the timing difference at the start of the movements of the major joints. In addition, the non-dominant arm throws went through less shoulder internal rotation and torso rotation ROM than the dominant throwing arm (van den Tillaar & Ettema, 2009a). Thus, resulting in a longer ball trajectory and thereby the possibility of increasing the velocity more (van den Tillaar & Ettema, 2009a). These findings are in line with the notion that mobility, power and segmental sequence timing were important factors affecting ball velocity.

From a biomechanical perspective the overhead handball throw can be viewed as an open kinetic chain system, which is a combination of movements in which the terminal segment can move freely (Karandikar & Vargas, 2011; Palmitier, An, Scott, & Chao, 1991; Putnam, 1993). This transfers readily to a handball overhead throw since the ball only has a negligible weight of around 0.4 kg. The greatest ball velocity in an overhead throw is achieved using a proximal-to-distal movement sequence in an open kinematic chain (Bayios et al., 2001; Fradet et al., 2004; Herring et al., 1992; Hong, Cheung, & Roberts, 2001; Marshall & Elliott, 2000; Pappas et al., 1985; Roach & Lieberman, 2014; Stodden, Fleisig, McLean, & Andrews, 2005; van den Tillaar & Ettema, 2009b). The principle of a proximal-to-distal sequence is in essence that, in order to produce the maximum possible speed at the end of a linked chain of segments, the motion should start with the more proximal segments and proceed to the more distal segments. The more distal segments begin their motion at the time of the maximum speed of the more proximal one, with each succeeding segment generating a larger end-point speed than the proximal one (Marshall & Elliott, 2000). In other words, the maximum velocity of the ball in a overhead throw is the result of a combination of accelerations and decelerations of different segmental and joint movements through the kinetic chain (van den Tillaar & Ettema, 2009b). Additionally, the speed of at least one of the more proximal segments is greatly diminished by the time the most distal segment reaches its maximum speed. Based on this Putnam (1993) suggested that the speed of the distal end of the link system is built up by adding up the individual speed of all segments participating in the sequence. To support this the resultant linear speed of segment endpoints show that the distal ends of segments progressively gets faster in a proximal-to-distal fashion. Another characteristic of the proximal-to-distal sequence is that the acceleration of the proximal segment causes the distal segment to lag behind (Putnam, 1993). This lag may result in a rapid stretch of the muscles crossing the joint, thus inducing a stretch-shortening cycle type activation that further contributes to generating a higher ball velocity (Grezios, Gissis, Sotiropoulos, Nikolaidis, & Souglis, 2006).

In overhead throws with run-up the leading leg is braced, which allows for the pelvis, trunk and throwing arm to accelerate over the braced leg, thus aiding in the transfer of momentum through the pelvis, trunk and throwing arm (Wagner, Pfusterschmied, Von Duvillard, & Muller, 2012). The transfer of momentum is considered to occur in all throwing movement, but with differences due to the run-up and tactical components of the game (Wagner, Pfusterschmied, Von Duvillard, et al., 2012). The joint motions considered to be contributors in the build up of ball velocity in the proximal-to-distal sequence in the overhead throw, are: 1) pelvic rotation, 2) trunk flexion, lateral flexion and rotation, 3) shoulder flexion, internal rotation and horizontal adduction, 4) elbow extension, 5) forearm pronation, 6) wrist flexion and 7) finger flexion (van den Tillaar & Ettema, 2007, 2009b; Wagner, Pfusterschmied, Von Duvillard, et al., 2012). Additionally, because of the distal segments' lag on the proximal segments, the joint motion will be relatively opposite to the joint motions above, before the distal segments also start accelerating in the throwing direction. For example, the shoulder relative motion of external rotation will occur prior to the internal rotation, at least partially because of trunk flexion occurring faster. This leads to a stretching of the activated muscle (e.g. internal rotators) prior to its shortening, which is thought to enhance the performance of the concentric phase (Bosco, Komi, & Ito, 1981). The enhanced performance in the stretch-shortening cycle is believed to be caused by release of elastic energy stored in series elastic elements of the muscles and the stretch reflex potentiation (Bosco et al., 1981).

However, recent studies looking closer at the biomechanics of overhead throwing in handball suggests that a proximal-to-distal sequence is not always observed (Fradet et al., 2004; van den Tillaar & Ettema, 2009b). Fradet et al. (2004) investigated the proximal-to-distal sequence by looking at timing of the maximum velocity of the wrist, elbow, shoulder and upper torso before ball release. The results of the study indicated that the maximum velocity of the elbow occurs before the maximum velocity of the shoulder (Fradet et al., 2004). Van den Tillaar & Ettema (2009b) found similar deviations from the proximal-to-distal sequence timing when looking at the time of maximum linear velocity of the body segments distal endpoints and the maximum angular velocity of the joint movements. However, in spite of these findings one should not discard the principle of proximal-to-distal sequencing in overhead handball throws, because the deviation from the principle almost only occurs in the distal segments and joints. Additionally, when looking at the initiation of the joint movements the proximal-to-distal sequence still applies. The joint movements studied were: 1) knee extension, 2) pelvis rotation, 3) trunk tilt, side tilt and rotation, 4) shoulder horizontal adduction, abduction and internal rotation, 5) elbow extension, 6) wrist flexion and 7) finger flexion (van den Tillaar & Ettema, 2009b). To further support the fact that the velocity of an overhead handball throw is the result of the power produced throughout the kinetic chain, another investigation showed that 53,1% of the velocity of the throw can be attributed to arm action, while the remaining 46,9% is due to the step and body rotation (Toyoshima, Hoshikawa, Miyashita, & Oguri, 1974). To insure the best possible validity, the kinematic chain, the kinetic chain and the proximal-to-distal sequence should be taken into consideration when designing functional tests to measure physical characteristics to correlate with an overhead throwing performance.

2.2 Mobility and the Overhead Throw

2.2.1 Relationship Between the Overhead Throw and Specific Mobility Tests

As previously stated mobility is considered an important factor in overhead throwing performance. However, the number of studies investigating this relationship does not reflect this. To this author's knowledge there are only two studies that specifically investigate the relationship between mobility and overhead throwing performance; one investigating a cricket throw (Talukdar et al., 2014) and the other investigating a baseball pitch (Robb et al., 2010). No such investigation has been conducted on handball players.

No clear relationship was found when using mobility tests (Robb et al., 2010; Talukdar et al., 2014). In Talukdar and co-workers' (2014) study on the relationship between the overhead cricket ball throw and the rotational ROM of the hip and thoracic spine, a greater external hip rotation and bilateral rotational thoracic ROM was not associated with (increased) ball velocity. However, this research group did not directly correlate mobility and throwing velocity, they divided their subjects into a fast-throwing (11 players) and a slow-throwing (10 players) group and investigated the differences between the two groups in mobility. They found a significant difference in mobility between the two groups, but concluded that greater ROM at the hips and thoracic spine does not increase throwing velocity (Talukdar et al., 2014). Robb and co-workers (2010) also investigated the relationship of hip ROM on throwing velocity in baseball players. They measured a total of 12 passive ROM variables: external rotation, internal rotation, abduction, adduction, total arc of internal and external rotation and total arc of abduction to adduction of both hips. The main finding of the study was that no individual measure of hip mobility significantly correlated with throwing velocity, except for the total arc of hip rotation in the non-dominant leg (left in a right handed thrower). More specifically, less total arc of hip rotation in the non-dominant leg was correlated with throwing velocity, however with a low correlation coefficient ($r = 0.5$) (Robb et al., 2010). One possible explanation is that in baseball pitchers the decreased total arc of hip rotation is an adaptation comparable to the (throwing) shoulder which is characterized by an increased external rotation and a decreased internal rotation (Robb et al., 2010). However, the fact that these two inconclusive studies are the only available in the literature justifies the need for further investigation.

2.2.2 Mobility Adaptations in Overhead Throwing Athletes

Only few studies have investigated the relationship between mobility and overhead throwing performance. However, the literature on adaptive mobility changes in the throwing athlete from repetitive loading of the overhead throw, is abundant. Studies have reported specific adaptive changes of ROM of different joints in high level overhead throwing athletes: at the shoulder (Almeida et al., 2013; Baltaci et al., 2001; Bigliani et al., 1997; Brown, Niehues, Harrah, Yavorsky, & Hirshman, 1988), the hip (Laudner et al., 2010) and the thoracolumbar region (Laudner et al., 2013). While many of the authors look at these ROM adaptations from an injury perspective, some consider the ROM adaptations observed to play a role in the throwing performance (Bigliani et al., 1997; Tullos & King, 1973). For example, Bigliani and co-workers (1997) suggested that using the non-dominant arm as a reference would be ill advised because the treatment/training might result in a throwing shoulder that is not capable of its previous high level of performance. An adaptive change that is commonly observed in overhead athletes is an increased external rotation of the dominant shoulder compared with the non-dominant shoulder found both in handball (Almeida et al., 2013) and baseball players (Baltaci et al., 2001; Bigliani et al., 1997; Brown et al., 1988). This adaptation is considered to help improve efficiency of the internal rotator muscles of the shoulder, thus allowing the ball to be delivered with greater velocity (Tullos & King, 1973).

2.2.3 Evaluation of the Reliability and Validity of Mobility Testing

When testing mobility in the overhead throwing athlete, the shoulder and hip have received the most attention from researchers. Especially the transverse plane have been investigated to a great extent (Almeida et al., 2013; Baltaci et al., 2001; Bigliani et al., 1997; Brown et al., 1988; Clarsen et al., 2014; Downar & Sauers, 2005; Laudner et al., 2010; Levine et al., 2006; Myers et al., 2006; Roach & Lieberman, 2014; Robb et al., 2010; Scher et al., 2010; Shimamura et al., 2015; Talukdar et al., 2014; Van Dillen, Bloom, Gombatto, & Susco, 2008).

Several authors have investigated the intra-rater and inter-rater reliability of the rotational ROM tests of the shoulder (Awan, Smith, & Boon, 2002; Boon & Smith, 2000; Wilk et al., 2009). The tests were done passively with the subjects in the supine position, with 90° of shoulder abduction and 90° of elbow flexion, with the different researchers using different forms of measuring equipment: either a standard goniometer (Boon & Smith, 2000), a standard goniometer with a bubble attachment (Wilk et al., 2009) or an inclinometer (Awan et al., 2002). All the testers performed the measurements both with and without scapular stabilization (Awan et al., 2002; Boon & Smith, 2000; Wilk et al., 2009). Intra-class correlation coefficients were considered to be excellent above 0.75, fair to good from 0.40-0.75 and poor under 0.40 (Boon & Smith, 2000). However, these guidelines are very different from the ones found in statistical literature, stating that in general values of above 0.90 are considered high, 0.80-0.89 moderate, and below 0.80 questionable for physiological data (Vincent, 2005). The intra-rater reliability of internal rotation ROM varied from poor to questionable (0.23-0.71) without ever being good (Table 2.1) (Awan et al., 2002; Boon & Smith, 2000; Wilk et al., 2009). The best ICC scores for internal rotation seem to be achieved when the scapula is stabilized; all studies report ICC values over 0.6 (Table 2.1). The inter-rater reliability when performing internal rotation tests is poor to questionable (0.13-0.66) without scapular stabilization, with all studies reporting slightly poorer ICC values when the scapula was stabilized. Intra-rater reliability of external rotation ranged from 0.58-0.79, whereas the inter-rater reliability ranged from 0.41-0.84 when the scapula was not stabilized (Table 2.1) (Awan et al., 2002; Boon & Smith, 2000). Boon & Smith (2000) were the only ones to investigate external rotation with scapular stabilization, with intra-rater reliability and inter-rater reliability being 0.58 and 0.78 respectively.

To summarize, the results of the shoulder rotational tests seems to vary depending on the tester, type of testing and whether the scapula was stabilized or not. Awan et al. (2002) concludes that the results obtained in their study makes the tests good enough to recommend them for clinical use. The intra-rater reliability scores are similar, but the inter-rater reliability is slightly poorer in the two other studies (Boon & Smith, 2000; Wilk et al., 2009). However, if the results are evaluated according to the guidelines of Vincent (2005), then the results might not be suitable for clinical use. Either way, because of the varying results of these studies, further research on the reliability of current shoulder mobility tests is warranted.

Table 2.1: *Summary of ICC scores for shoulder rotational ROM.*

Studies	Measures	Intra-rater reliability	Inter-rater reliability
Wilk et al (2009)	IR NSS	0.48	0.47
	IR SS	0.62	0.43
Boon & Smith (2000)	IR NSS	0.23	0.13
	IR SS	0.6	0.38
	ER NSS	0.79	0.84
	ER SS	0.58	0.78
Awan et al (2002)	IR NSS (R/L)	0.71/0.64	0.62/0.66
	IR SS (R/L)	0.64/0.65	0.5/0.52
	ER NSS (R/L)	0.58/0.67	0.41/0.51

IR: Internal Rotation, ER: External Rotation, NSS: No Scapular Stabilization, SS: With Scapular stabilization, R: Right and L: Left.

Investigators have also looked into the intra-rater reliability for several ROM tests at the hip, including hip flexion, extension, abduction, adduction, internal and external rotation (Cejudo, Sainz de Baranda, Ayala, & Santonja, 2014; Clapper & Wolf, 1988; Nussbaumer et al., 2010). In contrast to the intra-rater reliability scores of the shoulder, all the studies reported mainly high ICC scores for all the hip mobility tests when performed with a standard goniometer (Cejudo et al., 2014; Clapper & Wolf, 1988; Nussbaumer et al., 2010). A recent study found that the inter-rater reliability of hip ROM tests (using a goniometer measuring to the nearest 5°) was questionable (ICC>0.73), with the exception for hip flexion yielding results of close to moderate reproducibility with an ICC of 0.79 (Poulsen et al., 2012). However, earlier studies have shown better results, ranging from close to moderate to high, with minor exceptions (Cibere et al., 2008; Sutlive et al., 2008). This indicates that both the intra- and inter-rater reliability is better for the hip ROM tests than those of the shoulder.

Finally, to assess the current way of testing, an evaluation of the validity of mobility tests related to the overhead throwing performance is provided. As previously mentioned there is a scarcity of studies looking into the relationship between mobility and throwing performance. Only two studies report on the predictive validity (Robb et al., 2010; Talukdar et al., 2014). Based on the fact that these two studies did not really show a clear relationship between any specific mobility test and overhead throwing ability, it is worth to note that a test having good predictive validity for measuring overhead throwing performance is currently unavailable.

To the authors’ knowledge, no comparative studies on mobility of overhead throwing athletes competing at different levels exist, which makes construct validity difficult to assess. However, several studies have been conducted looking at the difference in mobility between pitchers and positional players in baseball (Baltaci et al., 2001; Bigliani et al., 1997; Brown et al., 1988; Laudner et al., 2013; Laudner et al., 2010), which might provide some clues into the construct validity of different mobility tests. Only Brown et al. (1988) found significant differences when looking at shoulder mobility tests, 9° more external rotation and 9° less shoulder extension for pitchers compared to position players. This, in contrast to Bigliani et al. (1997) and Baltaci et al. (2001) who found no significant differences. A study investigating the thoraco-lumbar mobility of pitchers and positional players, found that the pitchers had significantly more rotation to their non-throwing arm side when compared to the positional players (Laudner et al., 2013). Looking at hip ROM Laudner and co-workers (2010) found that position players exhibited greater internal rotation ROM in their trail leg compared to pitchers.

In summary, the construct validity of mobility tests has not been investigated to a great extent and the results of the (few available) studies are somewhat variable. Due to the limited amount of studies on the predictive and construct validity of mobility tests, it is difficult to find studies of relevance looking into the concurrent validity. The reason being that there is not any way of testing that can be considered a gold standard for testing mobility related to the overhead throwing performance.

Finally, a brief discussion about the logical validity of the current way of testing mobility might offer an explanation why the predictive and construct validity is poor and variable, other than the lack of studies. A considerable shortcoming of the traditional way of testing mobility is that none of the tests encompasses the motion of the entire body in the overhead throw. The existing studies only looked at individual joints, often performed either in a supine, prone or seated position. Thus, neglecting the kinetic chain, which as mentioned earlier, is acknowledged as a critical component of any overhead throwing performance. Additionally, all of the current mobility tests only measure mobility in one plane at a time, while a throwing performance is carried out with motions going on in all joints of the body, in all three planes simultaneously.

2.3 Strength and Power Testing in Handball

Contrary to mobility testing, many studies on the relationship between power and overhead throwing performance have been carried out, both in handball (Bayios et al., 2001; Chelly et al., 2010; Debanne & Laffaye, 2011; Fleck et al., 1992; Gorostiaga et al., 2005; Granados et al., 2007; Marques et al., 2011; van den Tillaar & Ettema, 2004a; Zapartidis et al., 2007) and baseball (L. R. Bartlett, Storey, & Simons, 1989; Pedegana et al., 1982). The equipment and tests for measuring power in the overhead athletes are: isokinetic tests (L. R. Bartlett et al., 1989; Bayios et al., 2001; Fleck et al., 1992; Pedegana et al., 1982; Zapartidis et al., 2007), isoinertial tests, rotational power tests and medicine ball throws (Debanne & Laffaye, 2011; Gorostiaga et al., 2005; Granados et al., 2007; Marques et al., 2011; Talukdar et al., 2014; van den Tillaar & Ettema, 2004a).

2.3.1 Isokinetic Test Methodology

The traditional isokinetic dynamometers are electromechanical or hydraulic instruments measuring force or torque (net moment of force), and calculating work or power in standardized movement conditions, i.e. constant (angular) velocity (Moffroid, Whipple, Hofkosh, Lowman, & Thistle, 1969; Stark, Walker, Phillips, Fejer, & Beck, 2011; Thistle, Hislop, Moffroid, & Lowman, 1967). An isokinetic measurement relies on the use of a machine to control the velocity of movement by providing resistance, through a specific ROM, when the tested limb reaches the preset angular speed (Cabri, 1991; Rothstein, Lamb, & Mayhew, 1987). Many different types of isokinetic dynamometers have been used in research, such as the Cybex II, Cybex NORM dynamometer, Cybex 6000 dynamometer (Lumex Inc., Ronkonkoma, USA), Biodex 4 (Biodex Medical Systems Inc., New York, USA), Con-trex (CMV AG, Duebendorf, Switzerland) and Kin-Com (Isokinetic International, Chattanooga TN, USA). A common denominator of the isokinetic dynamometers, used in relation to throwing performance, is that they consist of a lever arm, attached to a part of the body and guided through a ROM

(Alderink & Kuck, 1986; Bayios et al., 2001; Brown et al., 1988; Li, Wu, Maffulli, Chan, & Chan, 1996; Madsen, 1996; Thistle et al., 1967). In all references found in the literature on throwing athletes, the traditional isokinetic equipment lock out other joints or body segments with bands and straps that may affect the single joint being tested (Alderink & Kuck, 1986; Bayios et al., 2001; Brown et al., 1988; Li et al., 1996; Madsen, 1996; Thistle et al., 1967). However, it varies whether the subjects being tested are in standing (Brown et al., 1988; Karatas, Gogus, & Meray, 2002; Keller, Hellesnes, & Brox, 2001; Madsen, 1996), lying (Sullivan, Chesley, Hebert, McFaull, & Scullion, 1988; Zapartidis et al., 2007) or seated (Bayios et al., 2001) positions.

Many authors claim that isokinetic dynamometers are reliable and valid (Alderink & Kuck, 1986; Connelly Maddux, Kibler, & Uhl, 1989; Karatas et al., 2002; Stark et al., 2011). While others claim that the traditional isokinetic dynamometers have limited validity by the fact that they do not test subjects in a physiological position, and thereby neglect the influence of gravity and the kinetic chain (Kannus, 1994; Keller et al., 2001; Silva et al., 2006). Thus, it appears that an evaluation of validity and reliability in isokinetic testing is warranted.

If the goal were to measure an athlete’s ability to develop power in an overhead throwing motion, then using a test as similar as possible to the actual throw would be preferable in order to insure good logical validity. The traditional isokinetic equipment and methodology isolates joint movements, thus neglecting the complexity of an overhead throwing action by undermining the influence of gravity, ground reaction force, segmental joint sequencing and the kinetic chain principle. To support this, several researchers highlight the problem of testing subjects in a position that bears little resemblance to the athletic movement of interest (Kannus, 1994; Keller et al., 2001; Silva et al., 2006). In addition a review article addressed another problem with using isokinetic data as a predictive value for performance, namely that the maximum velocity of the available isokinetic dynamometers is only able to cover 20 to 30% of the different physiological maxima. Also, many movements (e.g. throwing) demand high accelerations, not solely from the moving limb, but from other parts of the body as well, thus not in isokinetic conditions at all (Cabri, 1991). This is supported by the fact that shoulder internal rotation and elbow extension have been measured to average 5039 $°\cdot s^{-1}$ and 1626 $°\cdot s^{-1}$ respectively in a handball throw (Wagner, Buchecker, von Duvillard, &

Muller, 2010b). This indicates that angular velocities used in isokinetic tests of handball players (maximum 300 °·s^{-1}) are very low compared to the produced angular velocity of different joints in an overhead throw.

An indication of the construct validity is provided by the investigation of Bayios et al. (2001), where a comparison of players with different performance abilities (the first division Greek National League, Second division Greek National League and a random sample of physical education students) was conducted. The Cybex II+ isokinetic dynamometer was used for the power testing. The main findings of the study were a significant difference in ball velocity between the three groups, but no difference between the groups in upper extremity peak torque production (Bayios et al., 2001). The results indicate that the traditional isokinetic tests did not demonstrate good construct validity, because the tests were not able to discriminate between professional handball players and recreational athletes. Furthermore, shoulder rotation peak torque was not a good predictor for throwing velocity, regardless the type of throw and throwing ability.

Several studies investigated concurrent and predictive validity of traditional isokinetic testing (L. R. Bartlett et al., 1989; Bayios et al., 2001; Fleck et al., 1992; Pedegana et al., 1982; Stark et al., 2011; Sullivan et al., 1988; Zapartidis et al., 2007). The predictive validity of the traditional isokinetic equipment is often poor with variable results between different studies (L. R. Bartlett et al., 1989; Bayios et al., 2001; Fleck et al., 1992; Pedegana et al., 1982; Zapartidis et al., 2007). Fleck et al. (1992) were the only of few researchers reporting many different isokinetic test results correlating with throwing performance. However, the majority of the correlations were found with the jump shot, which logically might move the emphasis of power production more to the upper extremities, since the legs are mostly used to generate height in the jump and not power in the throw. The same number of correlations was not seen for the set shot, which is in line with the literature. Bayios et al. (2001) also looked at different types of throws and found most of the correlations between shoulder internal/external rotation torque production and ball velocity during jump shots.

In addition to the fact that validity of traditional isokinetic dynamometers can be deemed highly questionable, different researchers have also found questionable to high intra-class correlation coefficient (ICC) scores regarding intra-rater (Cowley, Fitzgerald, Sottung, & Swensen, 2009; Karatas et al., 2002; Keller et al., 2001; Li et al., 1996; Sullivan et al., 1988) and inter-rater (Karatas et al., 2002) reliability. Questionable to high intra-rater reliability has also been reported for different shoulder tests (ICC: 0.06 - 0.94) (Edouard et al., 2013; Forthomme, Dvir, Crielaard, & Croisier, 2011; Meeteren, Roebroeck, & Stam, 2002; Plotnikoff & MacIntyre, 2002). The reliability as well as the peak torque scores have been shown to vary depending on the position of the subjects, angular velocity and arm being tested (Edouard et al., 2011; Forthomme et al., 2011) and should be considered when comparing results of different studies. A final problem with the isokinetic tests is that the measurement errors increase with increasing angular velocity of the isokinetic test (Delitto, Rose, Crandell, & Strube, 1991; Drouin, Valovich-mcLeod, Shultz, Gansneder, & Perrin, 2004; Karatas et al., 2002; Tunstall, Mullineaux, & Vernon, 2005; Zawadzki, Bober, & Siemienski, 2010).

2.3.2 Isoinertial Test Methodology

Isoinertial and isometric tests are two alternative ways of measuring strength or power and strength, respectively. Isoinertial tasks, such the squat or the bench press, are often used in the assessment of strength and power. Isometric strength is defined as the force generated against an immovable object, without a change in joint angle (Abernethy, Wilson, & Logan, 1995; Frost, Cronin, & Newton, 2010).

Similarly to isokinetic testing, the logical validity of the isoinertial and the isometric tests can be criticized for not bearing enough resemblance to and not encompassing the complexity of an overhead throwing action. Critics of isometric protocols argue that the static strength measured at different joint angles in isometric tests are far away from the dynamic nature of most sporting activities (Ashley & Weiss, 1994; G. J. Wilson & Murphy, 1996). Additionally, the isometric protocol is not capable of measuring external power, due to the absence of movement, and thus no mechanical work being done nor power being produced (Abernethy et al., 1995; Frost et al., 2010). Therefore, isometric test methodology related to throwing performance will not be highlighted further in this thesis. Isoinertial protocols based upon exercises such as squats and bench-press, also has critics based on the argument that it bears little resemblance to many athletic performances in terms of posture, pattern or speed of movement (Abernethy et al., 1995).

Two studies using isoinertial protocols were able to differentiate between elite and amateur level athletes (Gorostiaga et al., 2005; Granados et al., 2007). In both studies the isoinertial tests, bench press and half squat, yielded significantly higher power production in the elite group compared to the amateur group. This was consistent with the higher throwing velocity measured in the elite group (Gorostiaga et al., 2005; Granados et al., 2007). Therefore, these isoinertial tests seem to have better construct validity than isokinetic tests described previously.

Several authors have also tested the predictive validity of isoinertial tests on throwing performance (Chelly et al., 2010; Debanne & Laffaye, 2011; Gorostiaga et al., 2005; Granados et al., 2007; Marques et al., 2011; Marques, van den Tilaar, Vescovi, & Gonzalez-Badillo, 2007). These isoinertial power test protocols are more consistently correlated with overhead throwing velocity than traditional isokinetic protocols. However, the correlations found vary from poor to high, depending on the test and external load (Chelly et al., 2010; Debanne & Laffaye, 2011; Gorostiaga et al., 2005; Granados et al., 2007; Marques et al., 2011; Marques et al., 2007). Only the medicine ball throw, using a light ball (0,8kg) and correct handball throwing technique, reported high correlation (0.904) between the power test and the handball throwing performance (Garcia, Martinez, Grande, & Molinuevo, 2011).

Abernethy et al. (1995) state that those questioning isoinertial assessment tend to emphasize the potential for injuries, poor reliability and objectivity due to test procedure variations. However, the intra-rater reliability of the half-squat and bench press tests performed in the studies of Gorostiaga et al. (2005) and Granados et al. (2007), ranged from questionable to high (Izquierdo, Hakkinen, Gonzalez-Badillo, Ibanez, & Gorostiaga, 2002). The highest ICC values reported for the bench press tests ranged from 0.93 (30% of 1RM) to 0.99 (1 RM). The half-squat showed more variable ICC scores ranging from 0.65 (80% of 1 RM) to 0.93 (60% of 1 RM) (Izquierdo et al., 2002). High reliability of the bench press test is supported by Marques et al. (2007) with an ICC score of 0.91. Garcia and co-workers (2011) reported high reliability between attempts for both heavy (3 kg) (ICC = 098) and a light (0.8 kg) medicine ball throws (ICC = 0.99). This was corroborated by another study, which reported high test-retest reliability of seated chest throws and standing overhead throws (ICC = 0.88-0.97) (van den Tillaar & Marques, 2013).

In summary, isoinertial methodology seems to be adequately reliable for performance testing, but has some shortcomings regarding validity. Even though isoinertial power tests results are correlated with throwing performance its predictive validity is generally not very high.

In light of the above one can conclude that hardly any tests are available adequately predicting throwing performance. Therefore, the purpose of the present study was to investigate the influence of mobility and power on throwing performance.

3. Methods and Materials

To investigate the research questions, a cross sectional study was carried out using quantitative analysis methods.

3.1 Subjects

Thirteen Norwegian, top division, female handball players (age: 21.7±1.7 years; weight: 71.1±9.1 kg; height: 174.8±6.5 cm) were recruited for the study, with twelve completing the entire protocol.

Exclusion criteria were:

- Subjects with previous (within six months prior to testing) or current injuries.
- Subjects were unable to participate in normal handball and throwing activities.
- Subjects reporting pain/discomfort during the adaptation trial in more than one power test.

The study complied with requirements of the regional ethics committee and with current Norwegian law and regulations. Accordingly, all subjects were informed about the purpose of the study, as well as the advantages and risks of participating, after which an informed consent was signed (Appendix 1). Participation was voluntary, and the subjects were informed that they could drop out of the study at any time without any consequences.

3.2 Experimental setup

3.2.1 Lab Setup

All tests were carried out in the Human Movement and Biomechanics Lab of the Norwegian School of Sport Sciences. Detailed description of the lab setup is given in Figure 3.1.

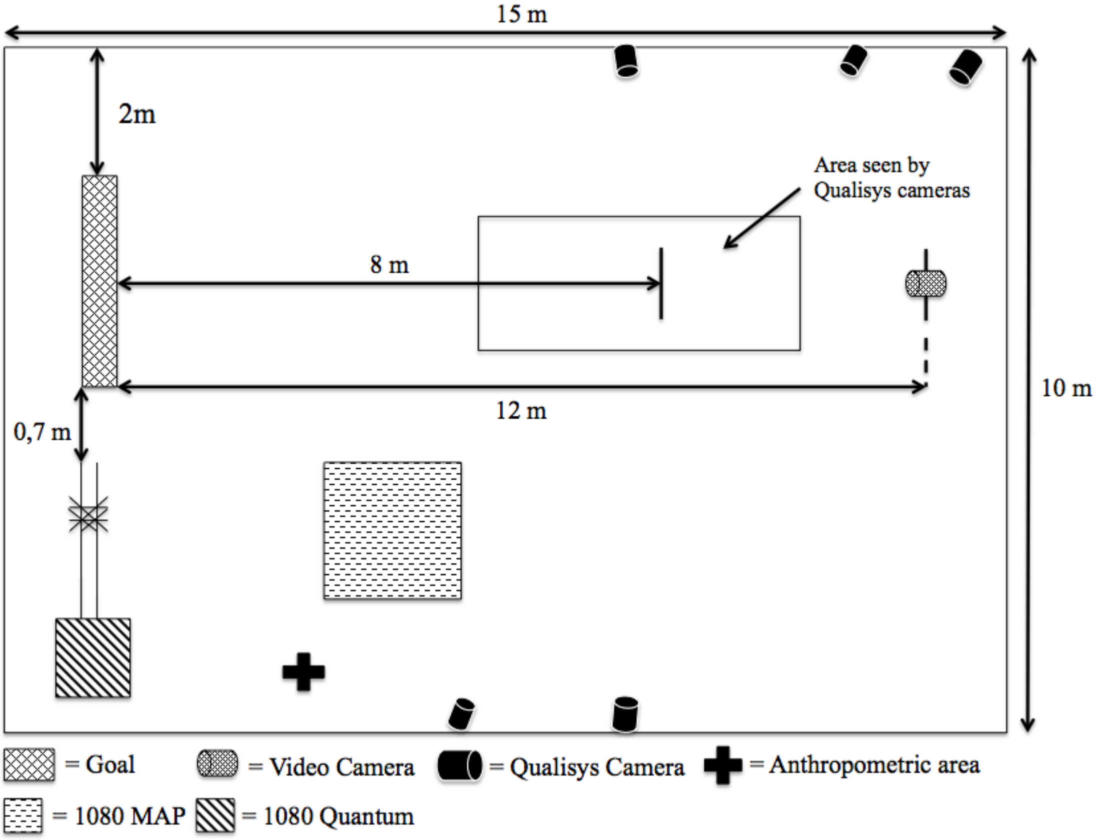


Figure 3.1: *Illustration of the lab setup seen from above.*

3.2.2 The Kinematic Setup

Five Oqus-4 cameras were used (Figure 3.1) to collect kinematic data using the Qualisys Track Manager software (Qualisys AB, Gothenburg, Sweden) to measure ball speed and the speed of the subject in the run-up before ball release (entry speed) (sampling frequency 480 Hz, exposure time 122 μs). The recording volume was calibrated using the Qualysis calibration kit consisting of a 750 mm T-shaped wand with two reflective markers and an L-shaped reference structure with four reflective markers, which defined the direction of the lab coordinate system. After the calibration the cameras covered an approximate recording volume of 6 m (length) x 4 m (width) x 3 m (height).

Five reflective markers (20 mm ϕ) were used in the kinematic setup; two on the ball exactly opposite to each to determine the center of the ball, one on the throwing hand (on the head of the intermediate phalanx of the third digit) and two on the pelvis (left and right highest point of the iliac crest). The two markers on the subjects' iliac crest were used to calculate the maximum entry speed of the run-up before the ball release. The markers on the ball in combination with the marker on the finger were used to calculate the release speed of the ball.

3.2.3 Anthropometric, Throwing, Mobility and Power Testing Setup

The anthropometric equipment consisted of a Seca model 217 stadiometer, with a 437-adapter element that connected the stadiometer to a Seca flat scale (Seca gmbh & co, Hamburg, Germany) to measure the subjects' height and weight. In addition, a standard tape measure was used to measure wingspan, arm- and leg length.

A height jump mat (2 m x 3 m) was used for measuring throwing accuracy and to protect lab equipment (Figure 3.2). Sports tape was used to mark up the target area (1 m x 1 m) (Figure 3.2) and define the throwing distance (8 m; Figure 3.1). A Basler acA2000 – 165uc video camera (Baser AG, Ahrensburg, Germany) was used to measure the accuracy of the throws. Select resin and an International Handball Federation standard size women's handball was used (Select AS, Glostrup, Denmark). The size and placement of the target was based on a combination of different protocols previously used in throwing studies (van den Tillaar & Ettema, 2003b; Wagner, Pfusterschmied, Tilp, Von Duvillard, & Müller, 2014). For right-handed subjects the target was placed 0.1 m below the crossbar at the right side of the goals midline (van den Tillaar & Ettema, 2003b). This was mirrored for the left handed subjects.

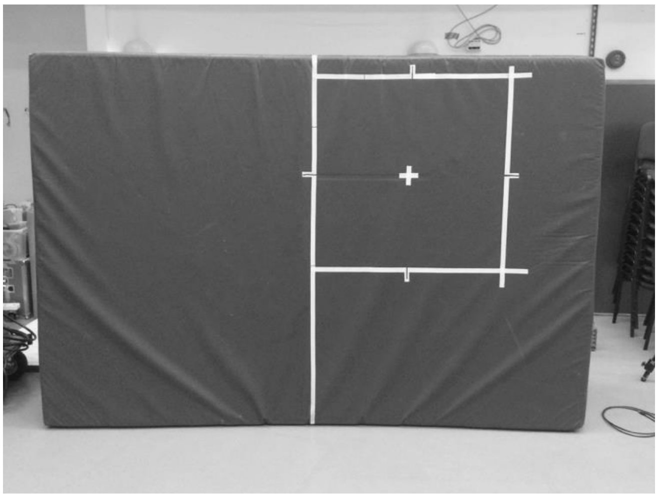


Figure 3.2: *Height jump mat with the target area of 1 x 1m.*

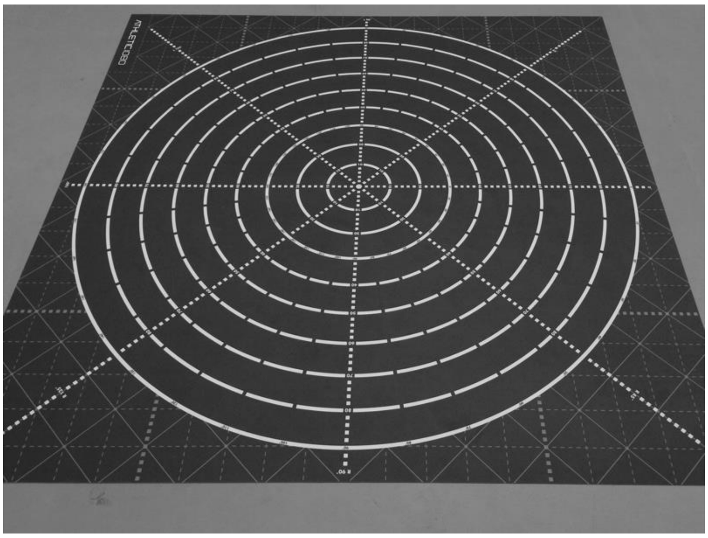


Figure 3.3: *1080 MAP testing grid.*

Functional mobility was tested on a grid (1080 MAP; Athletic 1080 AB, Stockholm, Sweden) (Figure 3.3). The grid consists of nine circles at 10 cm intervals, and vectors from the centre of the mat for every 45°. There is a mark for each 2 cm interval within the 10 cm intervals. The vectors are marked as A0 (anterior), L45 (Left 45°), R45 (Right 45°), L90 (Left 90°), R90 (Right 90°), L135 (Left 135°), R135 (Right 135°) and P180 (posterior) (Appendix 2). The function of the mat is to act as guidelines for the subjects' movements and foot positions, and to measure functional mobility. A plum weight and a stick were used to project a line down to the grid when the subjects performed tests were they did not reach to the ground.

Figure 3.4: *1080 Quantum.*

The power testing was conducted using the 1080 Quantum (Figure 3.4) (1080 Motion AB, Sweden). A belt (Figure 3.11) with different anchors was used to attach the cable for the hop tests. For the push, pull and rotational tests the subjects grabbed a handle attached to the cable. A more detailed explanation of the 1080 MAP and the 1080 Quantum is provided in Appendix 2.

3.3 Test Protocol

All subject performed the same protocol in the following order: Anthropometric measurements, warm-up, throwing performance test, mobility tests and power tests. On the adaptation day only the anthropometric measurements (height and weight), warm-up and the power tests were conducted.

3.3.1 Anthropometrics

Upon arrival the subjects' anthropometrics were measured. The measurements consisted of:

- weight (kg),
- height (cm),
- wingspan (cm),
- arm- and leg length (cm)

The arm length was measured from the tip of the acromion to the end of the third digit with the shoulder abducted to 90°. Wingspan was measured from the left to the right tip of the third digits with bilateral shoulders abducted to 90°. Leg length was measured from the tip of the greater trochanter to the floor. The hand dominance was decided by which hand the subject threw the handball with.

3.3.2 Warm-up Protocol

After the anthropometric measures, the subjects were asked to perform a 15-minute standardized warm-up, which consisted of a general and a handball specific part. The warm-up was performed in a gymnasium. The general part of the warm-up consisted of different exercises and dynamic stretching. The exercises took place on the short side of a handball court (20 m), and were as follows: 1) Jog (2 x 20 m), 2) lateral shuffle with focus on arm swings (ab- and adduction) (2 x 20 m), 3) angled shuffles forward and backwards (2 x 20 m), 4) jog with dominant arm shoulder roll forward and backwards (2 x 20 m), 5) skip with trunk rotation (2 x 20 m) and 6) skip with bilateral shoulder roll forward and backwards (2 x 20 m). The exercises were then repeated with the subject being instructed to slightly increase the intensity of the runs. The exercises took 4 minutes to complete. The dynamic stretching consisted of four exercises: 1) full body dynamic stretches, with three repetitions per leg per movement, with a total of six movements (Appendix 3). 2) Trunk rotation with a gradual anterior bend, 3) anterior bend and toe-reaches and 4) posterior reach with rotation. The dynamic stretching was also performed twice, with the instructions to increase intensity on the second run-through. The dynamic stretching took 6 minutes to complete. After the 10 minutes general warm-up the subjects were asked to perform 5 minutes of standard overhead throws at a wall from 4 m, 6 m, 8 m and 8 m with run-up. The subject spent one minute on the first three throws (4 m, 6 m and 8 m) and two minutes on the last throwing exercise (8 m with run-up). The subjects were instructed to gradually increase the intensity of the throws, according to the distance they were throwing from.

3.3.3 Throwing Protocol

After the warm-up the subjects entered the lab and the reflective markers for the kinematic setup were positioned. The subjects then threw at the target until five valid throws were collected. The instructions were as follows: “Throw the ball as hard as you can and hit the target” (van den Tillaar & Ettema, 2003a). The center of the target was marked with an + (Figure 3.2). The criterion for a valid throw was to hit inside the target.

The throwing technique selected was a standing throw from 8 m with a three-step run-up. This was chosen since this throw is frequently used in team handball when throwing from the backcourt position (Wagner, Pfusterschmied, Von Duvillard, et al., 2012). Between each throw the subjects had a one-minute rest period.

3.3.4 Mobility Tests

The functional mobility was tested using a HSEBT, which consisted of a total of twelve tests (hand reaches), six on each foot. Of the twelve tests, eight were diagonal reaches (measured in cm) and four were rotation tests (measured in °). The results of the tests give a description of subjects’ diagonal flexion and extension, as well as rotational movement capacity.

The twelve tests were performed in the following order:

1) Left leg, left hand R45 reach	Flexion Patterns
2) Right leg, right hand R45 reach	
3) Left leg, right hand L45 reach	
4) Right leg, left hand R45 reach	
5) Left leg, right hand L135 reach	Extension Patterns
6) Right leg, left hand R135 reach	
7) Left leg, left hand R135 reach	
8) Right leg, right hand L135 reach	
9) Left leg, bilateral hands right rotation reach	Rotational Patterns
10) Right leg, bilateral hands left rotation reach	
11) Left leg, bilateral hands left rotation reach	
12) Right leg, bilateral hands right rotation reach	

Criteria for a valid mobility test were:

1) the foot tested was placed in the center of the grid, with the foot covering the same distance anterior and posterior relative to zero, with the anterior-posterior vector running through the second toe and the center of the heel.

2) the heel of the standing leg, as well as the 1st and 5th metatarsal, had to maintain contact with the mat during the entire test.

3) the foot that was not tested was placed on a vector, 135° relative to the vector the subjects were reaching to. The support foot (toe-touch) had to be parallel with the direction of the reach and placed between the 20 and 30 cm radius on the vector. This was done to ensure limited weight-shift to the support foot.

4) an exception to criterion nr. 3 was for the rotational tests, where the support foot was placed 90° relative to the tested foot (L90 or R90) pointing anterior.

5) the tip of the third digit was used for taking the measurements (cm or °) for each test. When reaching anteriorly, the subjects reached to the ground (Figures 3.5 and 3.6). The

subjects were not allowed to support any weight on the reaching hand. In the posterior reaches, the subjects had to keep the elbow extended and the wrist in a neutral position. The plumb weight was used for measuring the posterior tests from the subjects’ tip of the third digit down to the floor (Figures 3.7 and 3.8). For the rotational tests the subjects used both hands, the hands overlapping at the third digit with the hand of the foot tested at the bottom, elbows extended, forearm pronated and wrist joints in a neutral position (Figures 3.9 and 3.10). The stick was used for measuring how many degrees the subjects rotated in each rotational test, from the overlapping third digits down to the floor (Figures 3.9 and 3.10).

6) the hand not performing the reaching, in the diagonal tests, was placed on the same side hip.

7) before initiating the diagonal reaches, the subjects had to align their trunk along the vector they were reaching to.

8) the subjects had to return to the starting position, while maintaining balance.

Before performing three recorded repetitions, all subjects performed three practice repetitions.

Figure 3.5: *Illustration of the left leg, left hand R45 reach. Starting position and ending position.*

Figure 3.6: *Illustration of the left leg, right hand L45 reach. Starting and ending position.*

Figure 3.7: *Illustration of the left leg, right hand L135 reach. Starting and ending position.*

Figure 3.8: *Illustration of the left leg, left hand R135 reach. Starting and ending position.*

Figure 3.9: *Illustration of the left leg, bilateral hands right rotation reach. Starting and ending position.*

Figure 3.10: *Illustration of the left leg, bilateral hands left rotation reach. Starting and ending position.*

3.3.5 Power Tests

There were 12 power tests: six hops, two pushes, two pulls and two rotational tests. Resistance was set to approximately 10% of the subjects' body weight. The concentric speed of the 1080 Quantum was always set at 8 $m\cdot s^{-1}$, which was the maximum speed of the machine. For the eccentric speed the settings were put to 6 $m\cdot s^{-1}$ when performing the hop tests, and 2 $m\cdot s^{-1}$ when doing the other tests.

Six hops, three on each leg were tested in the following directions: posterior, lateral and anterior (Figures 3.12-3.14). The arm of the machine was set at hip-height in all the hop tests, and the cable was attached to the subject via a belt (Figures 3.11-3.14). When performing the posterior hop the cable was attached to the anterior middle anchor of the belt. The subjects were instructed to take a quick step anterior (80-100 cm), before hoping posterior as far as they could (Figure 3.12). When performing the lateral hop the cable was attached laterally via a climbing rope to the two most lateral anchors (anterior and posterior) (Figures 3.11 and 3.14). The subjects were instructed to take a quick step (80-100 cm) laterally towards the machine, before performing a lateral hop in the opposite direction, as far as they could (Figure 3.14). When performing the anterior hop the cable was attached to the middle posterior anchor. When performing the anterior hop, the subject stood on the foot being tested with the other foot in the air (Figure 3.13). The subjects did not take a step posterior before performing the hop. They were instructed to perform a counter-movement type motion induced by the opposite swinging leg (Figure 3.13, picture C to D).

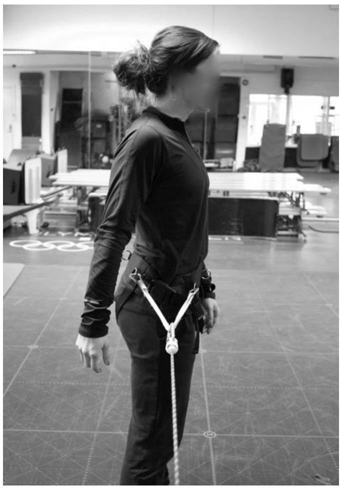


Figure 3.11: *1080 Belt with climbing rope and three karabiners attached to the cable.*

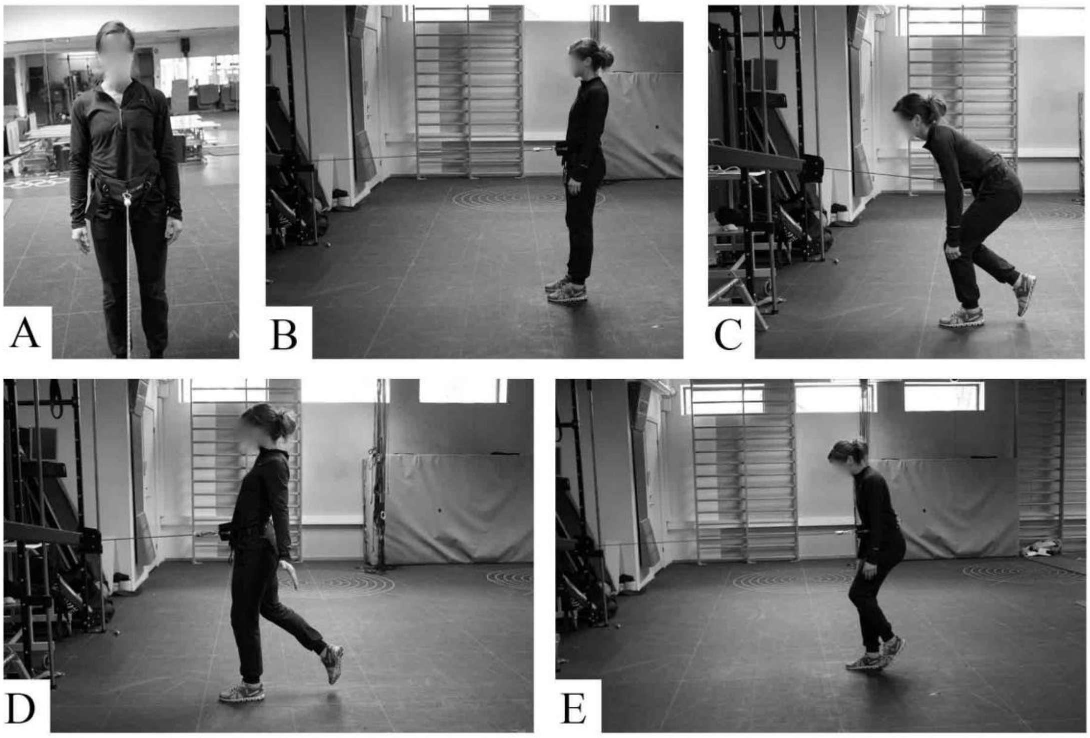


Figure 3.12: *Anterior to posterior hop test. A) Cable attachment to belt. B) Starting position. C) Anterior step. D) Posterior unilateral hop. E) Landing.*

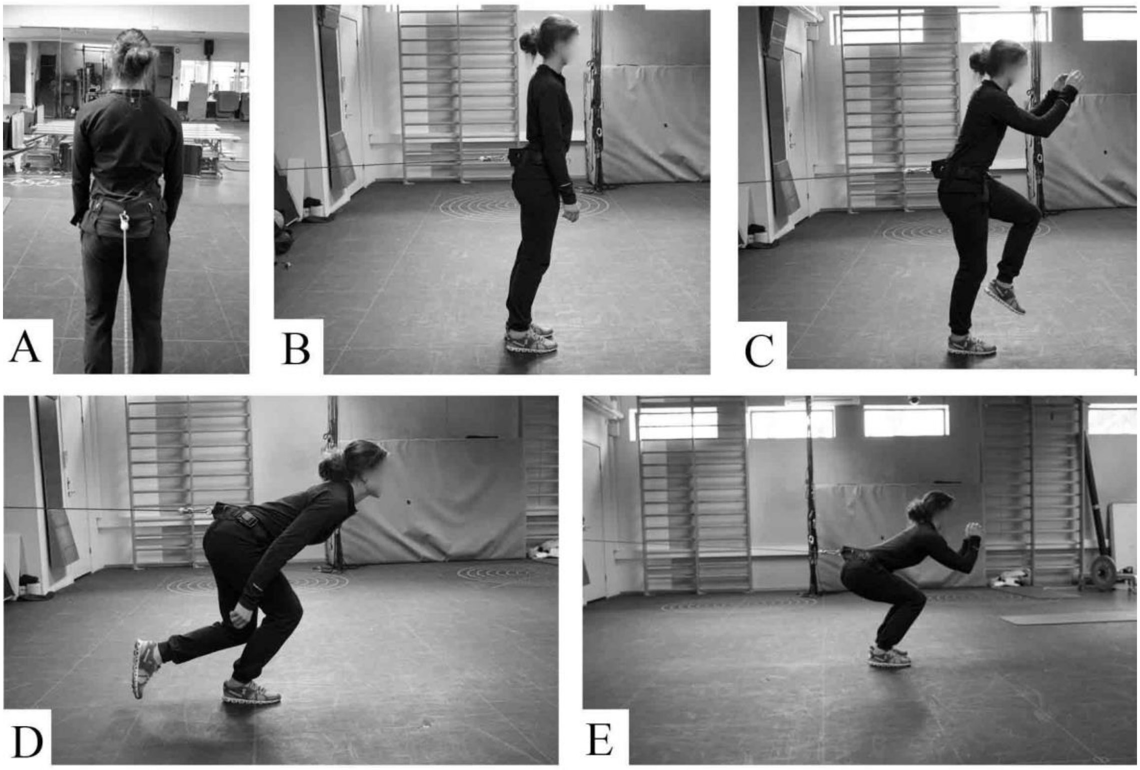


Figure 3.13: *Anterior hop test. A) Cable attachment to belt. B) Starting position. C/D) Countermovement phase. D) Start of the concentric phase of the unilateral hop. E) Landing.*

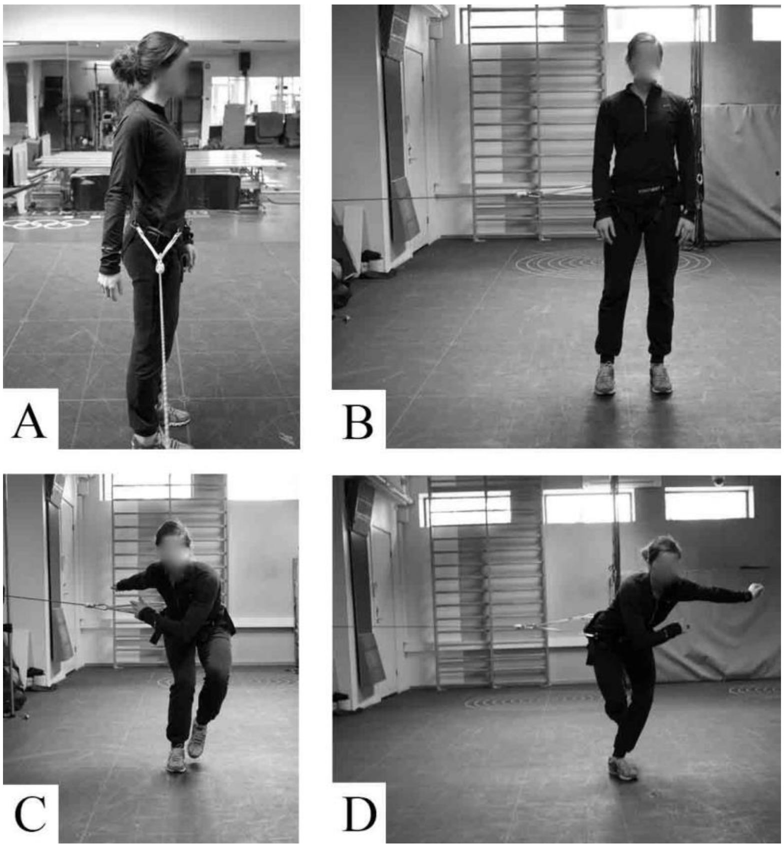


Figure 3.14: *Lateral hop test. A) Cable attachment to climbing rope and belt. B) Starting position. C) Lateral step to unilateral lateral hop. D) Landing.*

The push, pull and rotational tests were performed with either unilateral or bilateral grip to the handle. The feet placement was standardized for each test. In the push tests the arm of the 1080 Quantum was set to its highest vertical position (level 12). Based upon facing the machine, when using the right hand, the right foot was placed 140 cm in front and the subject rotated 135° to the left (Figure 3.15). When performing a left hand push, the subject rotated a 135° to the right. A more detailed description of the foot placement and movements performed for each test is provided in Appendix 4. The subject then performed a unilateral anterior and inferior diagonal push (Figure 3.15).

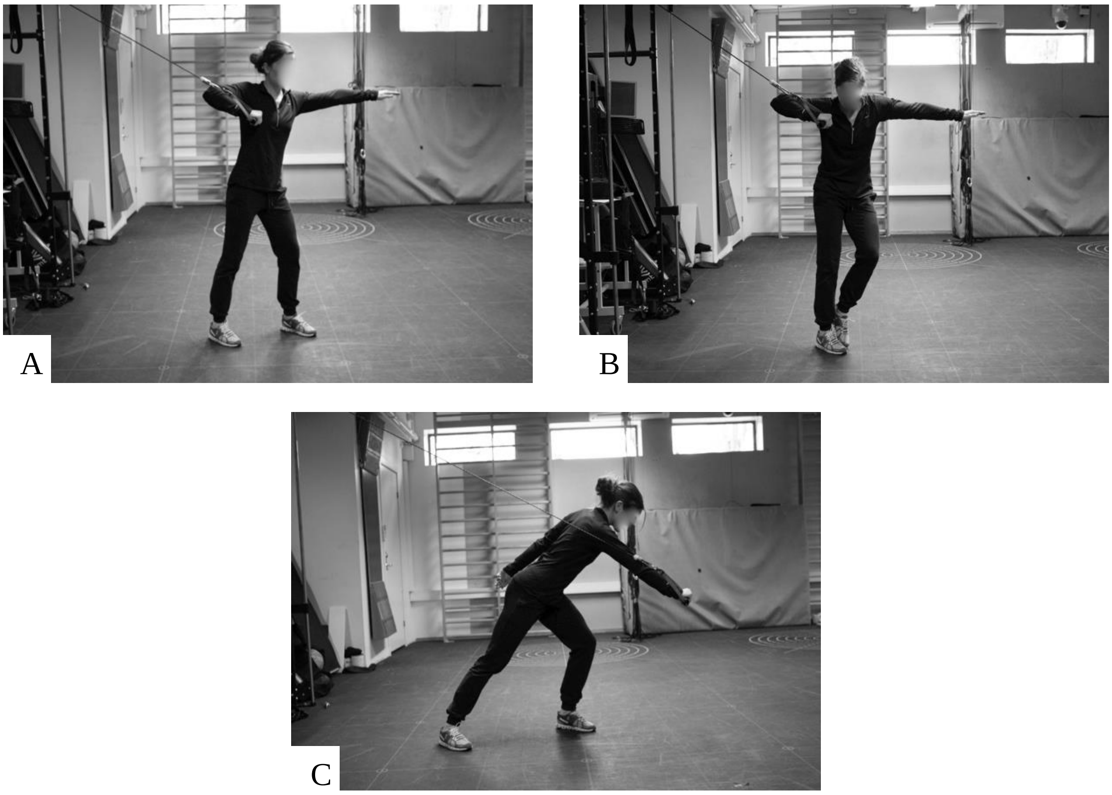
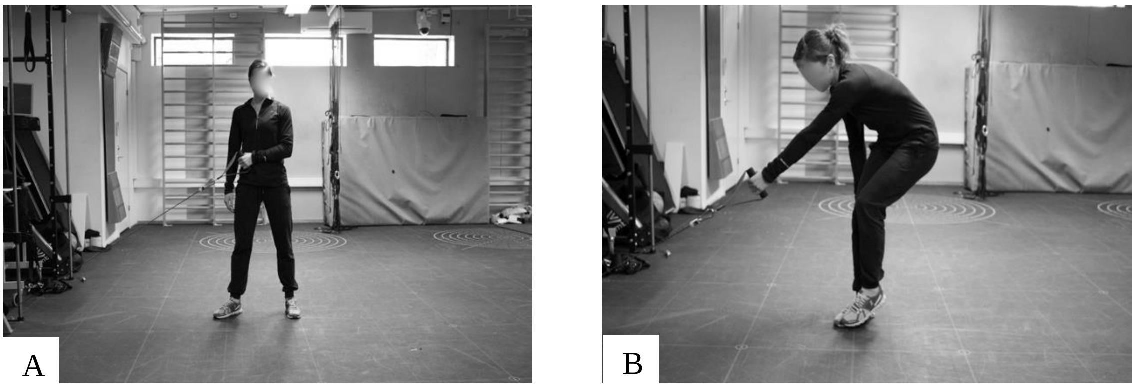


Figure 3.15: *Illustration of the starting (A), middle (B) and ending (C) position of the anterior and inferior push test.*

In the pull tests the arm of the 1080 Quantum was set to its lowest vertical position (level 1). Based upon facing the machine, when using the right hand, the left foot was placed 140 cm in front and the subject rotated 45° to the right. When performing a left hand pull, the subject rotated a 45° to the left (Figure 16). A more detailed description of the foot placement and movements performed for each test is provided in Appendix 4. The subject then performed a unilateral posterior and superior diagonal pull (Figure 3.16).



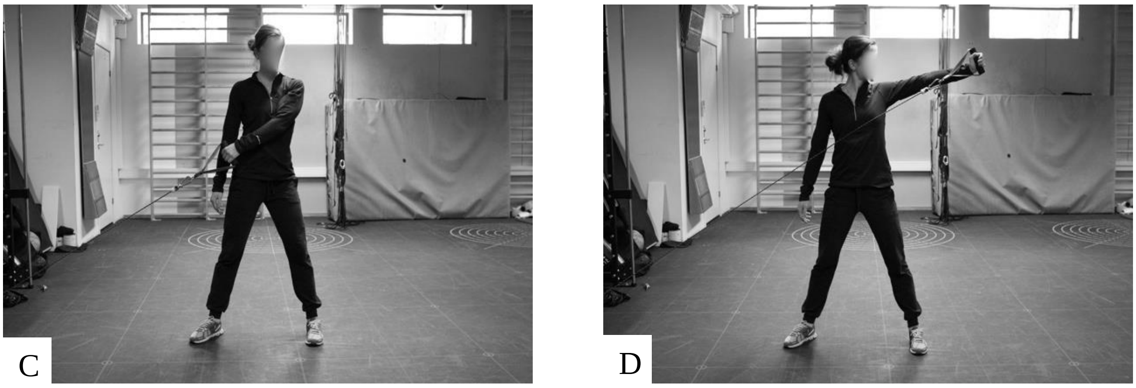


Figure 3.16: *Illustration of the starting (A), middle (B) and ending (C) positions of the posterior and superior pull test.*

In the rotational tests the arm of the 1080 Quantum was set to hip height for each subject. Based upon facing the machine, when performing a right rotational pull, the left foot was placed 160 cm in front and the subject rotated 90° to the right. When performing a left rotational pull, the subject rotated 90° to the left (Figure 3.17). A more detailed description of the foot placement and movements performed for each test is provided in Appendix 4. The subject then performed a bilateral rotational pull (Figure 3.17).

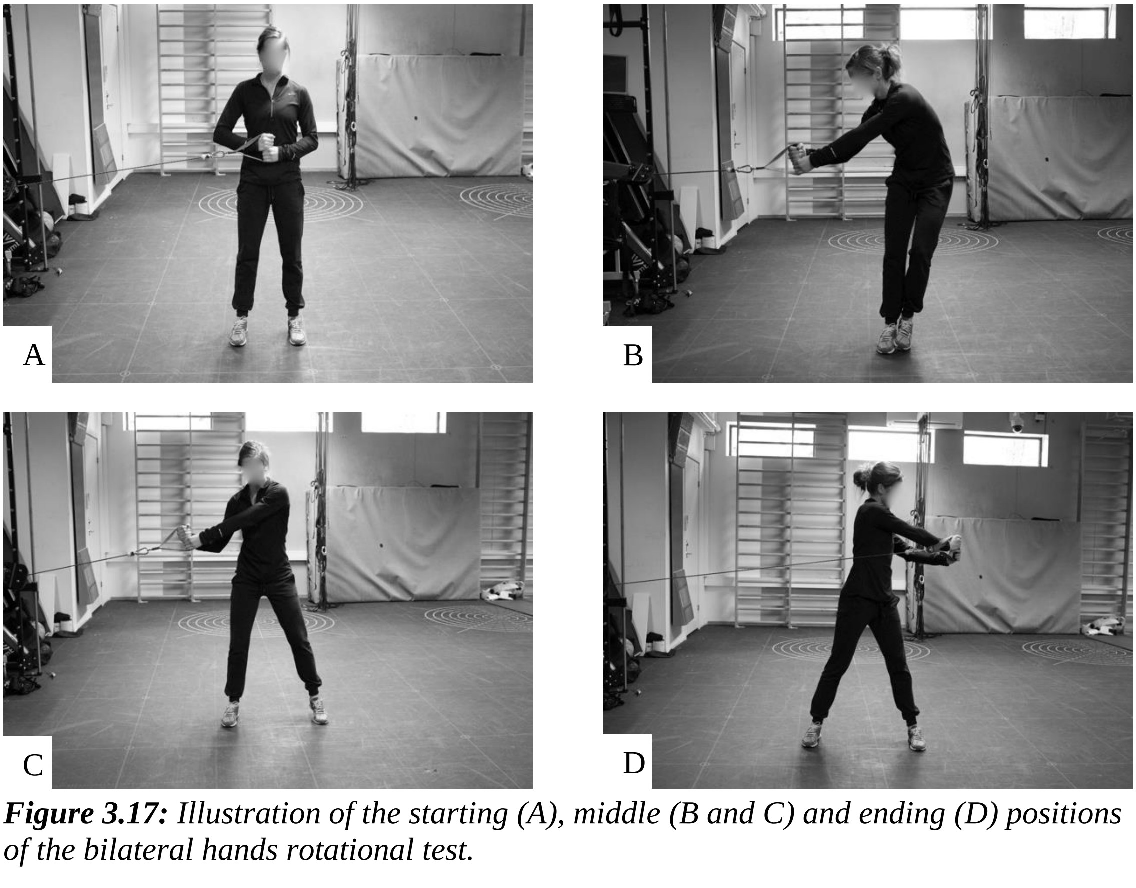


Figure 3.17: *Illustration of the starting (A), middle (B and C) and ending (D) positions of the bilateral hands rotational test.*

The subjects went through an adaptation day for all power tests, because pilot studies indicated that at least one test session would be necessary to get reliable results. On the adaptation day the subjects had an unlimited number of practice attempts before measurements were recorded. Practice attempts were performed until the instructor was satisfied with the sequencing of the movement. This was done to ensure a proximal-to-distal sequencing, especially for the push, pull and rotational tests. On the testing day the subjects performed five practice attempts before measurements were recorded. After the practice attempts the subjects had five minutes of rest before performing at least four maximum repetitions. When the maximum power decreased relative to the previous repetition the test was stopped. The three median scores were recorded, based upon deleting maximum power values for different repetitions in the following sequence: lowest-highest-lowest-highest.

3.4 Analysis

Normalization of diagonal mobility hand reach scores was done by linear regression analysis, using Matlab (Mathworks Inc, Natick MA, USA). The following values were included in the analysis: wingspan, trunk (height - leg length) and leg length. The linear regression analysis calculated a predicted mobility score (predicted value = Y intercept + β_1 (leg length) + β_2 (trunk (height-leg length)) + β_3 (wingspan)) based on the analysis of 28 male subjects in an ongoing validation study of the hand reach tests (Eriksrud, Unpublished data). A mobility score was calculated as a percentage of the measured value compared to the predicted value. The measured values were based on the average of the three recorded tests. This analysis was not done for the rotational tests, since the anthropometrics were not considered to affect the score. The weight measurement was used to determine the resistance in the power tests.

Throwing performance was based on speed and accuracy data. The average of five valid throws was used for the statistical analysis. Ball speed ($m \cdot s^{-1}$) was calculated at ball release, which was defined as the point of greatest acceleration between the marker on the third digit and the center of the ball (midpoint between the two ball markers) using Matlab (van den Tillaar & Ettema, 2009a; Wagner, Buchecker, von Duvillard, & Muller, 2010a). Entry speed ($m \cdot s^{-1}$) was defined as the maximum speed of the midpoint between the two pelvic markers prior (between 3 and 100 ms) to ball release (Wagner et al., 2010a).

Accuracy of valid throws was done by video analysis in Dartfish (Figure 3.18) (Dartfish, Fribourg, Switzerland). The mean radial error was used as the measure (m) and defined as the average of the absolute distance from the center of the ball to center the target for the valid throws (van den Tillaar & Ettema, 2003a). This was done by measuring the distance from the center of the target to the point most distant at the ball at impact, and then subtracting the radius (0.088 m) of the ball.

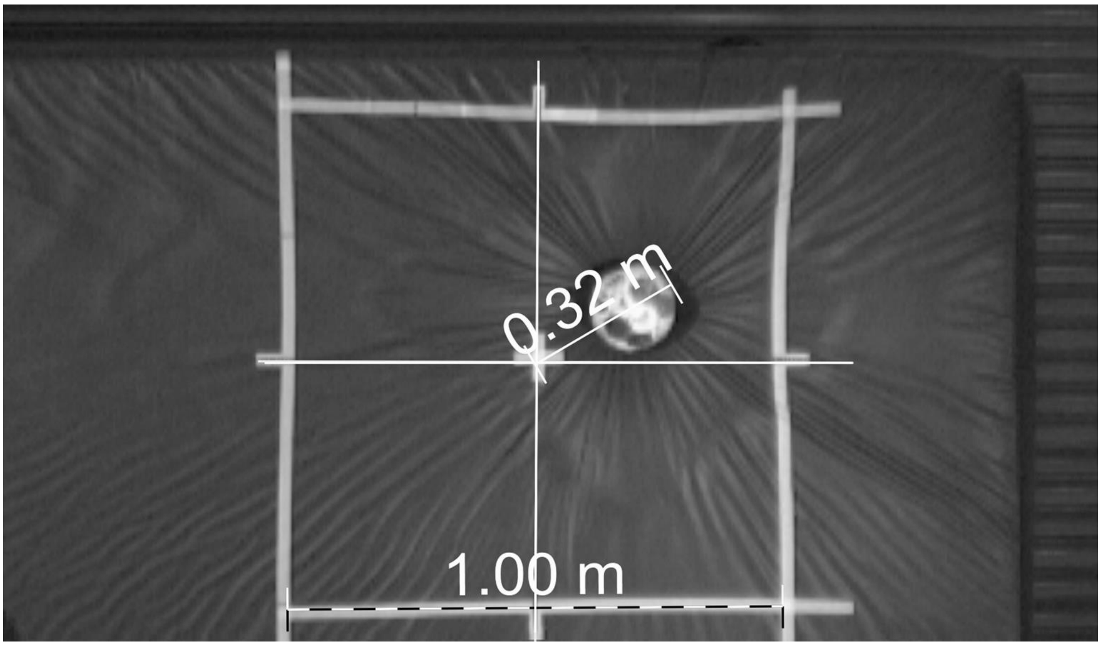


Figure 3.18: *Illustration of how accuracy was measured using Dartfish.*

The diagonal mobility hand reach tests were expressed in cm, while the rotational reach tests were measured in degrees. The average of the three repetitions recorded of each of the twelve tests was used for the statistical analysis. The average of the three median values for each of the maximum power tests (W) was used for the statistical analysis.

3.5 Statistics

The mean and standard deviation of the anthropometrics (age, height and body mass) and throwing characteristics (entry speed, accuracy and ball speed) were calculated using Excel version 14.4.8 (Microsoft Corp, Redmond, WA, USA).

Correlations between mobility, power and throwing performance (speed and accuracy), were calculated by pearsons product moment correlation coefficients using Prism 6 (GraphPad Software Inc., La Jolla, CA, USA). Additionally, the relationships between accuracy and ball speed, height and ball speed, body mass and ball speed, and entry speed and ball speed of the throws were calculated by linear regressions in Excel version 14.4.8. The level of significance for all correlations was set to $p<0.05$, with a statistical tendency set to $p<0.1$.

Test-retest reliability (adaptation day to testing day) for each power test was calculated using ICC scores in SPSS version 22 (IBM Corp., Armonk, NY, USA). These ICC scores defined reliability as follows: questionable = ICC<0.80, moderate = 0.80-0.90 and good = ICC>0.9 (Vincent, 2005).

4. Results

The 12 subjects used (mean ± standard deviation) 9 ± 3 throws to complete five valid throws. The average ball speed of the valid throws was 22.7 ± 1.8 $m \cdot s^{-1}$ with an accuracy of 0.31 ± 0.10 m. The average entry speed of the run-up was 3.1 ± 0.5 $m \cdot s^{-1}$.

A summary of the mean and standard deviations of all twelve mobility and power tests are presented in Tables 4.1 and 4.2, respectively. These tables also show the number of subjects completing each of the mobility and power tests.

Table 4.1: *Summary of mobility tests.*

Mobility tests	**Mean**	**SD**	**n**
L leg, L hand, R45 (%)	5.4	6.7	12
R leg, R hand, L45 (%)	9.3	8.2	12
L leg, R hand, L45 (%)	6.5	10.8	12
R leg, L hand, R45 (%)	12.5	12.2	12
L leg, R hand, L135 (%)	0.8	8.2	12
R leg, L hand, R135 (%)	8.6	8.7	12
L leg, L hand, R135 (%)	10.9	25.4	12
R leg, R hand, L135 (%)	11.1	26.4	12
L leg, B hands, R rot (°)	123.0	9.2	12
R leg, B hands, L rot (°)	123.6	7.7	12
L leg, B hands, L rot (°)	118.2	11.8	12
R leg, B hands, R rot (°)	114.6	10.5	12

L: Left, R: Right, B: Bilateral, rot: rotation, SD: Standard deviation and %: Mobility score.

Table 4.2: *Summary of power tests.*

Power tests	**Mean**	**SD**	**n**
Dom hand posterior & superior diagonal pull (W)	912.5	133.7	11
Non-dom hand posterior & superior diagonal pull (W)	878.9	145.8	10
Dom hand anterior & inferior diagonal push (W)	872.3	157.0	12
Non-dom hand anterior & inferior diagonal push (W)	727.0	147.1	12
Dom bilateral side rotation (W)	1308.2	234.2	12
Non-dom bilateral side rotation (W)	1326.3	216.9	12
Left Foot anterior to posterior hop (W)	319.9	62.8	12
Right Foot anterior to posterior hop (W)	334.0	35.2	12
Left foot right lateral hop (W)	333.6	34.1	12
Right foot left lateral hop (W)	328.0	35.5	12
Left foot anterior hop (W)	684.0	41.5	12
Right foot anterior hop (W)	718.8	54.1	12

SD: Standard deviation, W: watt, Dom: Dominant hand, Non-dom: Non-dominant hand.

Correlation coefficients between the mobility tests and throwing performance (speed and accuracy) are presented in Table 4.3. There were no significant correlations found. Correlation coefficients between the power tests and throwing performance are presented in Table 4.4. Left foot anterior to posterior hop was significantly correlated with ball speed (r = 0.577, p<0.05). Additionally, the non-dominant hand posterior and superior diagonal pull (r = 0.601**,** p<0.1) and the right foot anterior hop (r = 0.538, p<0.1) correlated with a statistical tendency with throwing accuracy (Table 4.4).

Correlation coefficients between the mobility and power tests are presented in Table 4.5. The right leg stance left hand L45 reach test was significantly correlated with the left foot right lateral jump test (r = -0.593, p<0.05) and with the right foot left lateral jump test (r = -0.668, p<0.1), while the left leg R45 reach was correlated with the same power tests (r = -0.534 and r = -0.548, p<0.1). Additionally, the right foot bilateral hands right rotational reach correlated significantly with the right hand posterior and superior diagonal pull power test (r = 0.604, p<0.05).

Table 4.3: *Correlation between mobility and throwing performance.*

Mobility tests	**Ball speed**		**Accuracy**		**Mobility tests**	**Ball speed**		**Accuracy**	
	Pearsons r	p-value	Pearsons r	p-value		Pearsons r	p-value	Pearsons r	p-value
L leg, L hand, R45	-0.004	0.990	-0.302	0.340	R leg, R hand, L45	-0.262	0.411	-0.367	0.241
L leg, R hand, L45	-0.119	0.712	0.015	0.963	R leg, L hand, R45	-0.246	0.441	-0.058	0.857
L leg, R hand, L135	-0.228	0.476	0.231	0.469	R leg, L hand, R135	-0.408	0.188	0.304	0.337
L leg, L hand, R135	-0.119	0.714	0.220	0.493	R leg, R hand, L135	-0.192	0.550	0.020	0.952
L leg, B hands, R rotation	-0.188	0.558	0.160	0.619	R leg, B hands, L rotation	-0.495	0.102	0.189	0.555
L leg, B hands, L rotation	-0.402	0.196	0.068	0.834	R leg, B hands, R rotation	-0.191	0.553	0.094	0.772

R: Right, L: Left, B: Bilateral, L45: Left 45°, R 45: Right 45°, L135: Left 135°, and R135: Right 135°.

Table 4.4: *Correlation between power and throwing performance.*

Power tests	**Ball Speed**		**Accuracy**		**Power tests**	**Ball Speed**		**Accuracy**	
	Pearsons r	p-value	Pearsons r	p-value		Pearsons r	p-value	Pearsons r	p-value
Dom hand posterior & superior diagonal pull	0.057	0.867	0.343	0.302	Non-dom hand posterior & superior diagonal pull	0.501	0.140	0.601^{T}	0.066
Dom hand anterior & inferior diagonal push	0.333	0.290	0.036	0.913	Non-dom hand anterior & inferior diagonal push	0.128	0.692	0.476	0.118
Dom bilateral side rotation	0.221	0.490	0.284	0.371	Non-dom bilateral side rotation	0.070	0.830	0.043	0.894
Left foot anterior to posterior hop	0.577*	0.049	0.063	0.846	Right foot anterior to posterior hop	0.314	0.320	0.358	0.254
Left foot right lateral hop	0.067	0.836	0.436	0.157	Right foot left lateral hop	0.489	0.106	0.445	0.147
Left foot anterior hop	-0.116	0.720	0.478	0.116	Right foot anterior hop	-0.450	0.142	0.538^{T}	0.071

**statistically significant correlation* ($p<0.05$) *and* ^{T}*statistical tendency* ($p<0.1$).

Dom: Dominant and Non-dom: Non-dominant.

Table 4.5: *Correlation between mobility and power tests.*

Power: / Mobility:	R hand Pos & Sup diagonal pull	L hand Pos and Sup diagonal pull	R hand Ant & Inf diagonal push	L hand Ant & Inf diagonal push	B arms L rotation	B arms R rotation	L Foot Ant to Pos hop	R Foot Ant to Pos hop	L Foot R Lat hop	R Foot L Lat hop	L Foot Ant hop	R Foot Ant hop
L leg, L hand, R45	0.366	0.098	0.281	-0.148	0.159	0.152	-0.169	-0.195	-0.534^T	-0.548^T	-0.059	-0.140
R leg, R hand, L45	0.088	-0.274	0.058	-0.231	-0.099	-0.014	-0.275	-0.153	-0.593*	-0.668*	-0.276	-0.181
L leg, R hand, L45	0.276	0.163	-0.150	-0.168	-0.238	-0.211	-0.162	-0.049	-0.384	-0.517^T	-0.049	0.026
R leg, L hand, R45	0.323	0.153	-0.041	-0.005	-0.193	-0.087	-0.086	0.046	-0.423	-0.474	-0.136	0.064
L leg, R hand, L135	0.033	0.013	-0.178	0.111	-0.453	-0.266	-0.023	0.206	-0.170	-0.101	-0.284	0.084
R leg, L hand, R135	0.015	0.000	-0.383	-0.129	-0.270	-0.190	-0.216	0.023	-0.120	-0.324	0.082	0.318
L leg, L hand, R135	0.387	0.441	-0.321	0.009	-0.326	-0.211	0.072	0.250	-0.270	-0.393	-0.047	0.210
R leg, R hand, L135	0.283	0.239	-0.472	-0.296	-0.347	-0.356	-0.003	0.064	-0.413	-0.514^T	-0.035	0.151
L leg, B hands, R Rot	0.246	0.135	0.324	0.479	0.019	0.372	0.131	0.282	0.031	0.121	-0.293	0.213
R leg, B hands, L Rot	0.203	0.023	0.229	0273	0.050	0.363	-0.356	-0.010	-0.021	-0.302	0.016	0.311
L leg, B hands, L Rot	0.479	0.247	0.225	0.098	0.259	0.430	-0.334	-0.095	0.034	-0.448	0.199	0.359
R leg, B hands, R Rot	0.604*	0.479	0.302	0.335	0.192	0.374	0.150	0.056	0.064	0.051	0.033	0.416

**statistically significant correlation ($p<0.05$) and ^{T}statistical tendency ($p<0.1$).*

R: Right, L: Left, B: Bilateral, Sup: Superior, Inf: Inferior, Lat: Lateral, Ant: Anterior, Pos: Posterior and Rot: Rotation.

The linear regression between accuracy and ball speed, and entry speed and ball speed of the overhead throws with run-up is presented in Figures 4.1 and 4.2.

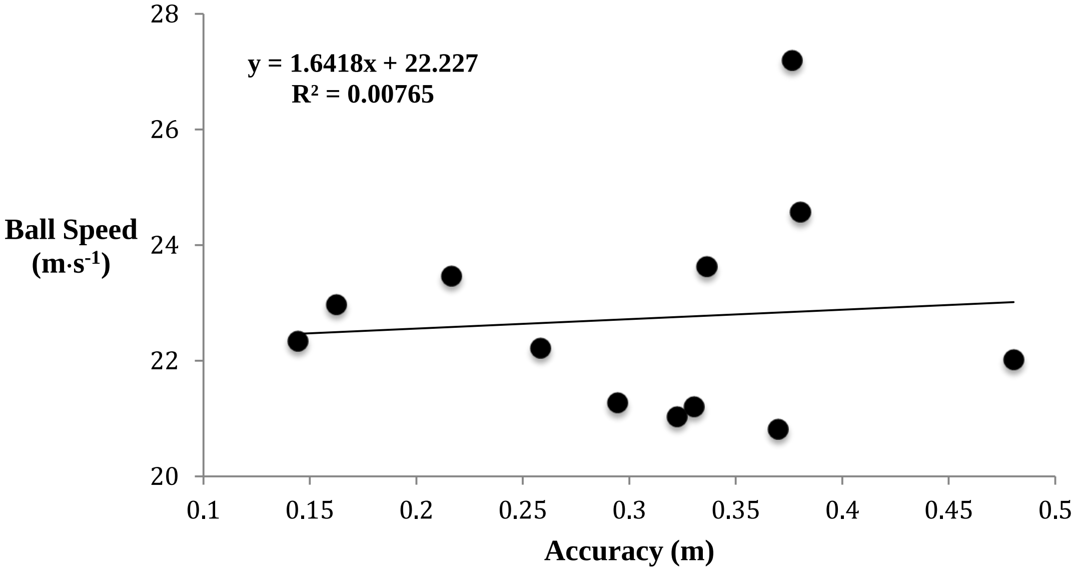


Figure 4.1: *Relationship between ball speed and accuracy.*

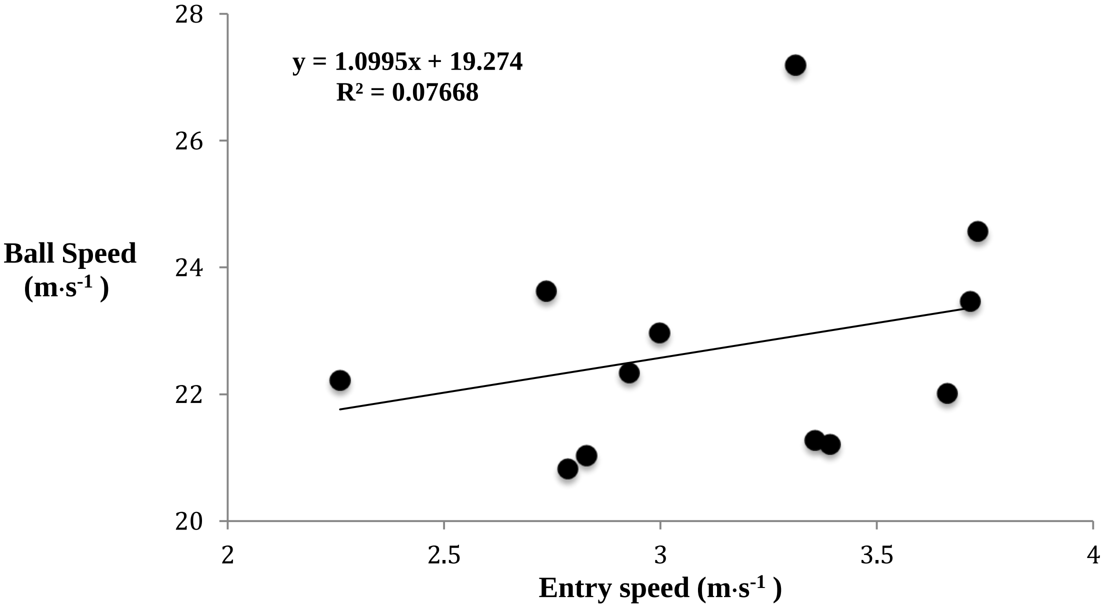


Figure 4.2: *Relationship between ball speed and entry speed.*

Linear regression between ball speed and height, and between ball speed and weight is presented in Figure 4.3 and 4.4, respectively.

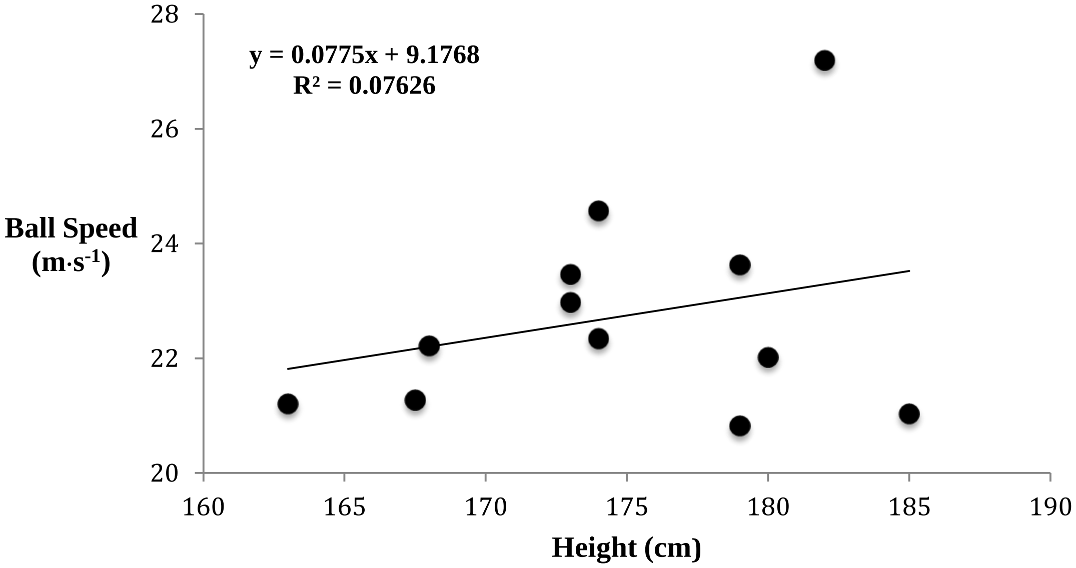


Figure 4.3: *Relationship between ball speed and height.*

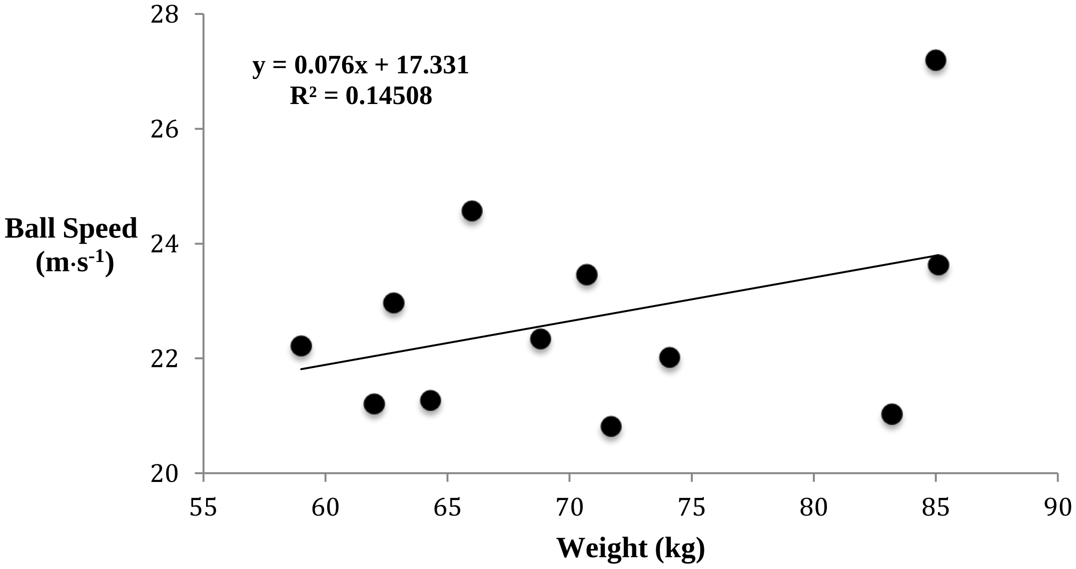


Figure 4.4: *Relationship between ball speed and weight.*

ICC scores for test-retest reliability for all power tests are presented in Table 4.6.

Table 4.6: *Test-retest reliability of the power tests.*

Power tests	**ICC scores**	**Difference between days (W)**	**Student T-test (p-value)**
Dom hand posterior & superior diagonal pull	0.839	-9.5	0.710
Non-dom hand posterior & superior diagonal pull	0.888	23.7	0.348
Dom hand anterior & inferior diagonal push	0.638	82	0.025*
Non-dom hand anterior & inferior diagonal push	0.610	37.7	0.289
Dom bilateral side rotation	0.767	52.1	0.294
Non-dom bilateral side rotation	0.843	104.1	0.034*
Brace foot anterior to posterior hop	0.384	-7.4	0.734
Non-brace foot anterior to posterior hop	0.555	18.6	0.293
Left foot anterior to posterior hop	0.417	-6.3	0.774
Right foot anterior to posterior hop	0.541	17.6	0.306
Left foot right lateral hop	0.558	-3.4	0.694
Right foot left lateral hop	0.347	7.3	0.525
Left foot anterior hop	0.356	56.8	0.036*
Right foot anterior hop	0.649	35.4	0.066^{T}

**Significant difference ($p<0.05$) and ^{T}statistical tendency ($p<0.1$).*

Dom: Dominant, Non-dom: Non-dominant, ICC: Intraclass correlation coefficient.

5. Discussion

The main finding of this study was that both hypotheses should be rejected: mobility measured by the HSEBT and peak power measured by the 1080 Quantum are not significantly correlated with throwing performance. None of the twelve HSEBT tests and only one of the twelve power tests correlated significantly with overhead throwing performance ($p<0.05$) (Tables 4.3 and 4.4).

5.1 Relationship Between Mobility and the Overhead Throw

None of the HSEBT tests correlated with throwing performance (Table 4.3), which is in line with the few previous studies investigating the relationship between mobility and overhead throwing performance (Robb et al., 2010; Talukdar et al., 2014). However, this is not in line with the argument that mobility is important for the overhead throw (Bigliani et al., 1997; Tullos & King, 1973).

Intra- and inter-rater reliability is fundamental to any clinical test. A study on the intra- and inter-rater reliability of the HSEBT was conducted simultaneously to this study (Data from an unpublished NIH master thesis, 2015). In this study the intra-rater reliability was found to be moderate (seven out of twelve tests) based upon the criteria previously described, two tests being questionable (ICC between 0.70 and 0.80) and three tests out of twelve being high (ICC>0.90) (Vincent, 2005). The inter-rater reliability was poorer, with ICC scores being poor (two with ICC < 0.70) questionable (seven) and moderate (five out of twelve). These results are slightly poorer than the same type study performed on the star excursion balance test (SEBT), which reported moderate to high ICC scores (Gribble, Kelly, Refshauge, & Hiller, 2013; Hyong & Kim, 2014). However, these results are generally better than those reported for shoulder internal and external rotation (Table 2.1) (Awan et al., 2002; Boon & Smith, 2000; Wilk et al., 2009). Based upon these findings it seems that reliability might not be the main limiting factor resulting in the poor correlation between the mobility tests and throwing performance.

The HSEBT used in this study differ from traditional mobility tests. The tests are performed in a standing position, with the subjects affected by gravity while performing hand reaches, which triggers movement of the full kinematic chain. The hand reach tests do not test the full ROM capacity of individual joints (Data from an unpublished NIH master thesis, 2015), since most likely elements of balance, stability, strength and coordination affect the results. The tests reflect how the full kinematic chain utilizes joint excursions to perform the hand reaches. Thus, HSEBT reflects the overall full body mobility from a standing position. The reason for using the HSEBT in this study, was that traditional single joint isolated tests poorly reflects the specificity of movement patterns performed in the overhead handball throw. The principle of specificity relating to training states that the body adapts to exercise according to how it is exercised, and applies to muscles and movements, energy systems and speed of movement (Cissik, 2011). Assuming that the principle of specificity is also applicable to testing, then the interdependent relationship between segments and regions should be considered when creating tests that aim to assess sport performance. The HSEBT, with its different hand reach tests is an attempt to test mobility in a more specific manner to athletic performance. However, all HSEBT tests used in this study were not expected to be equally predictive of overhead throwing performance, since not all tests reflect joint motions related to generating high throwing velocities. Flexion patterns were not expected to correlate with the throwing performance, while the extension patterns where, because extension patterns were considered important to the acceleration distance in the overhead throw. However, none of the four extension tests correlated with the throwing performance (Table 4.3).

There are several possible reasons why correlations between HSEBT and overhead throwing performance were not found in this study. The HSEBT performed in this study might not be specific enough to throwing performance. Furthermore, movements in the concentric (acceleration) phase of throwing are: 1) pelvic rotation, 2) trunk rotation, flexion and lateral flexion, 3) shoulder flexion, horizontal adduction, internal rotation, 4) elbow extension, 5) forearm pronation, 6) wrist flexion and 7) finger flexion (van den Tillaar & Ettema, 2007, 2009b; Wagner, Pfusterschmied, Von Duvillard, et al., 2012). Joint motions based on the ones described above, but in the opposite direction of the concentric phase might therefore be most relevant for assessing mobility related to the overhead throw. In other words, in the right-handed thrower, the test ideally should include the motions of 1) left hip extension and external rotation, 2) right hip extension and internal rotation, 3) thoraco-lumbar extension, right rotation and right lateral flexion, 4) shoulder extension, external rotation and horizontal abduction, 5) elbow flexion, 6) wrist extension and 7) finger extension. However, not all of these joint motions are equally important for the overhead throwing performance in handball. Creating a single mobility test that quantifies and encompasses all these joint motions would be difficult. Furthermore, some of these joints motions, such as elbow flexion and trunk lateral flexion, should not be restricted in injury free players, thus there is no need to test these motions. The main contributing motions of relevant joints and regions to a particular performance should therefore be prioritized when creating tests. However, here in lies one of the problems with this version of the HSEBT, since shoulder rotation, which is a key contributor to throwing speed, (van den Tillaar & Ettema, 2004b, 2007) is not challenged. Furthermore, the standardization of the tests by prepositioning the subjects in the diagonal reach direction might limit the ability of the test to describe thoraco-lumbar rotation. However, thoraco-lumbar rotation is challenged in the rotational tests, but then without extension of the hip, spine and shoulders as well as rotation of the shoulders. Therefore, it is possible that none of the HSEBT tests individually is able to test the joint motions most relevant for the overhead throw with run-up. A possibility could be to combine tests to create a profile score. However, this was not the scope of this study.

Movement variability might help explain the lack of a significant relationship between the mobility tests and the overhead throwing performance. Movement variability at the individual level is associated with the complexity of the neuro-musculoskeletal system and the abundance of degrees of freedom (Davids, Glazier, Araujo, & Bartlett, 2003; Preatoni et al., 2013). Every time the same task is performed, a certain amount of change may be observed between its subsequent repetitions, regardless of how skilled or familiar we are with performing it (Stergiou, Harbourne, & Cavanaugh, 2006; C. Wilson, Simpson, van Emmerik, & Hamill, 2008). Wilson et al. (2008) suggests that the coordination variability present in the system provides movement flexibility so that the system can search for the optimal solution. Differences in movement patterns among players may develop over time, and could be a consequence of environmental changes, learning phenomena, latent pathologies or incomplete recoveries. These underlying factors may easily be masked by the presence of movement variability (Preatoni et al., 2013). Therefore, it is likely that the individual players in this study used slightly different movement patterns when performing the overhead throw, which might be related to different backgrounds (playing position, tactical role, ROM, injuries and external conditions). This can then be used to describe between-subject movement variability or individual strategies in solving the same task. For example, some players may perform the task of throwing utilizing a more transverse plane strategy (hip and trunk rotation), while others may solve the same task with a more sagittal plane strategy (hip and trunk extension). Therefore, if some players utilizing either a transverse plane or a sagittal plane strategy throw with the same speed, then no significant correlations between mobility and throwing performance can be found. In support of this argument a review concludes that different athletes performing the same task (e.g. javelin) do so with an individual pattern in relation to timing and movements (R. Bartlett, Wheat, & Robins, 2007).

The multifactorial and complex nature of the throw itself might be another reason for the lack of significant correlations between throwing performance and the outcomes of the HSEBT. The results reported by van den Tillar & Ettema (2009a) is consistent with the notion that throwing performance is multifactorial in nature and affected by mobility, power and the sequencing of motion. Several authors argue for the importance of mobility (Bigliani et al., 1997; Tullos & King, 1973), power (Debanne & Laffaye, 2011; Fleck et al., 1992; Garcia et al., 2011; Marques et al., 2007) and sequencing (Garcia et al., 2011; Herring et al., 1992; Marshall & Elliott, 2000; Roach & Lieberman, 2014; Stodden et al., 2005) to overhead throwing performance. With this in mind the throwing performance can originate from any combination of these factors. The best combination would be: sport specific mobility and high power production in the proper proximal-to-distal sequence. However, with overhead throwing being multifactorial and complex in nature there is a possibility that players throwing with equal speed emphasize different factors in order to achieve this ball speed. For example, one player could be mainly reliant on mobility and sequencing while another player's throw with the same ball speed could rely predominantly on power. Consequently, different players might therefore rely on different combinations of joint and regional mobility, sequencing and power generation. This can be described as "between-subject variability", or "strategy", by choosing the optimal combination of factors for solving the throwing task.

5.2 Relationship Between Power and the Overhead Throw

The results of the power tests were generally not significantly correlated with performance in the overhead throw, with the only exception being the left foot anterior to posterior hop (Table 4.4). Additionally, the right foot anterior hop and the non-dominant arm superior and posterior diagonal pull showed a statistical tendency ($p<0.1$) to correlate with throwing accuracy (Table 4.4).

One possible explanation for the correlation of the left foot anterior to posterior hop with ball speed could be due to this being the lead leg being braced in throwing (Wagner, Pfusterschmied, Von Duvillard, et al., 2012). The brace of the lead leg transfers horizontal momentum from the run-up to the throwing arm, thereby increasing throwing speed (Wagner, Pfusterschmied, Von Duvillard, et al., 2012). It can be argued that the lead leg performs a similar task in the brace of the run-up as it does in the anterior to posterior hop. A closer look into our data showed that this might not be the case. Since two of the subjects where left-handed, their lead leg in the throw with run-up was be the right leg. When corrected for the lead leg, the correlation analysis did not yield a significant correlation for the anterior to posterior hop, but showed a statistical tendency with a p-value of 0.0905. Thus, this correlation is likely to be coincidental.

The traditional methods for testing power for throwing performance have been criticized and often failed to show statistical significance with throwing performance (L. R. Bartlett et al., 1989; Bayios et al., 2001; Debanne & Laffaye, 2011; Fleck et al., 1992; Gorostiaga et al., 2005; Marques et al., 2011; Marques et al., 2007; Pedegana et al., 1982; Talukdar et al., 2014; van den Tillaar & Ettema, 2004a; Zapartidis et al., 2007). One of the arguments against the use of isokinetic and isoinertial power and strength tests is that these methods have low specificity to overhead throwing performance based upon posture, movement pattern and speed of movement (Abernethy et al., 1995; Kannus, 1994; Keller et al., 2001; Silva et al., 2006). One exception was the lightweight medicine ball throw with correct handball technique, performed in the study of Garcia et al. (2011), where a high correlation ($r=0.904$) with throwing velocity was reported. However, it is rather obvious that using a ball weighing only 325-375 g more than a normal handball and instructing the subjects to throw the ball like a handball, will yield high correlations between the power test and the overhead handball throw. In addition, this is only an indirect way of measuring power, since they only measured distance but neither force nor speed (Garcia et al., 2011). The intention of using the 1080 Quantum was to be able to measure the subjects' power (calculated from force and velocity) directly, with the subjects conducting what was thought to be more handball specific movement patterns than what has traditionally been done. 1080 Quantum with its adjustable arm and 5 m line allows for any functional movement pattern to be performed (Appendix 2). However, due of the machines speed and weight resistance limits it was not possible to perform tests with the desired movement patterns specific to the overhead handball throw. The reason was that the subjects would be at risk for shoulder injuries, considering that the minimum resistance from the machine is 1 kg (650 g more than a handball), and that the highest speed in the concentric direction is 8 $m\cdot s^{-1}$ (ball speed in this study was 22.7 ± 1.8 $m\cdot s^{-1}$, which reflects hand speed). Thus, to avoid injuries the power tests performed in this study were based around a general set of tests: hops, push, pull and rotational pull. The push, pull and rotational power tests had the most logical validity to overhead throwing performance. The one test with the best expected specificity to the overhead throw was the dominant hand anterior and inferior diagonal push. The diagonal pull and bilateral rotational pull were done to reflect movements of the eccentric phase after ball release and the rotational components (hip and trunk) of the throw, respectively.

Neither push nor pull power tests correlated significantly with the overhead throwing performance. One reason might be that none of the power tests simulated specific enough movement patterns to the overhead throw. The test thought to be the most specific (anterior and inferior diagonal push) was performed with a proximal-to-distal sequence, with the lead foot initiating the movement and bracing before ending with dominant hand pushing inferiorly. However, this face validity movement specificity did not result in a significant correlation with throwing performance. A possible cause for the poor relationship may be that the arm pushing action is very different from the whipping/pulling motion of the arm in the handball throw. A change of arm action is likely to have a substantial influence, considering that more than half of the ball speed is attributed to arm action (Toyoshima et al., 1974). Additionally, the push was in an inferior direction, which further deviates from the throwing movement pattern.

Test-retest reliability of the power tests performed in the 1080 Quantum was calculated between the adaptation day and testing day, and displayed poor to moderate reliability

(Table 4.6). This poor reliability can be attributed to both a learning effect of the complex movements tested and the different protocols being used on the two days. However, the student T-test showed a significant difference (three out of twelve tests) and a statistical tendency (one out of twelve tests) between the two days (Table 4.6). Thus, a learning effect is not supported by the results for all the tests. However, a general tendency seems to be that the subjects are improving in the power tests between days. The same learning effect was also found in a pilot study of test-retest reliability conducted prior to this study. Six subjects performed the same power tests on four separate occasions. The same general tendency of a learning effect from session 1 to session 2 was observed. Therefore the decision was made to include one adaptation day in this study. The ICC scores reported in this study should be interpreted cautiously since the protocols are substantially different with possible effects of fatigue due to the number of repetitions not being controlled for the adaptation day, limited control of subjects' pre-testing condition (type of training, nutrition and general activity level) and an expected learning effect. Further research should be conducted on the reliability of the power tests conducted in the 1080 Quantum.

Despite the validity of the power tests to overhead throwing performance not being proven in this study, this approach to testing should not be discarded, but instead further refined. One major issue related to throwing performance is the specificity of the arm action and direction of arm movement.

5.3 Additional Findings

The ball speed of the overhead throw with run-up was 22.7 ± 1.8 $m \cdot s^{-1}$, which is similar to what was reported in other studies in elite female handball players (Granados et al., 2007; Granados, Izquierdo, Ibanez, Ruesta, & Gorostiaga, 2008; Moss, McWhannell, Michalsik, & Twist, 2015; Vila et al., 2012).

Previous studies have reported a relationship between body size (height and mass) and playing level, with elite players being significantly taller and heavier than amateurs (Granados et al., 2007; van den Tillaar & Ettema, 2004a). Additionally, a significant relationship between throwing velocity and body size (fat free mass, total mass and height) has been reported for elite players (van den Tillaar & Ettema, 2004a). However, the results of the present study contradict these findings with height and weight showing poor relationships with ball speed (Figure 4.3 and 4.4).

The ball speed of the overhead throws with run-up did not correlate with the accuracy calculated by the mean radial error (Figure 4.1), which is in accordance with previous research (van den Tillaar & Ettema, 2003a; Wagner, Pfusterschmied, Klous, von Duvillard, & Muller, 2012). Since there is no velocity-accuracy trade-off when comparing throwing performance in different level athletes, velocity seems to be the main factor in determining throwing performance in handball (Wagner et al., 2010b; Wagner, Pfusterschmied, Klous, et al., 2012). The correlation between maximum entry speed (3.1 ± 0.5 $m \cdot s^{-1}$) and ball speed (22.7 ± 1.8 $m \cdot s^{-1}$) was also investigated in this study, with results showing a poor relationship (Figure 4.2), which contradicts a previous study, finding a significant relationship between the center of mass goal directed movement (3.0 ± 0.3 $m \cdot s^{-1}$) and throwing velocity (23.9 ± 1.2 $m \cdot s^{-1}$) (Wagner, Pfusterschmied, von Duvillard, & Muller, 2011). Wagner and co-workers' (2012) results are consistent with results from a different study conducted on javelin throwers, which found that the javelin release velocity is the sum of the thrower's center of mass velocity and the velocity applied to the javelin by the thrower during release (R Bartlett, Muller, Lindinger, Brunner, & Morris, 1996).

Only a few correlations between mobility and power were observed (Table 4.5). One rationale for the relationship between mobility and power is that, similar to the argument of mobility being important to throwing velocity, a larger trajectory/displacement to develop force/velocity can result in a greater outcome velocity (van den Tillaar & Ettema, 2009a). However, similar to the relationship between mobility and ball speed in the overhead throw with run-up, few correlations were found (Table 4.5). There were a few exceptions, with some results probably being a coincidence, rather than a statistically relevant relationship. Based on the assumption that more ROM will increase power production, because one can develop power over a greater distance, it was surprising to find negative correlations between flexion pattern mobility tests (Right foot stance with right hand L45 reach and Left foot stance with left hand R45 reach) and the L/R lateral hop power tests (Table 4.5). It cannot simply be discarded as coincidental findings, since all of the tests correlated with either a tendency or significant relationship (Table 4.5). A possible explanation to these results is that there might not be a linear relationship between mobility and power development, but rather an optimal range of motion for development of power in specific tasks based on the force-length relationship of sarcomeres (Rassier, MacIntosh, & Herzog, 1999). The subjects were instructed to perform a swift lateral hop, since this was thought to be a more sport-specific motion. This might have led to some subjects not performing as deep a movement as they normally would. If this specific power task demanded “too little” mobility from the knee and hip extensor muscles, then there is a possibility that some subjects were too mobile and thus their muscles were working outside their optimal range for generating force and power. Thus, even if the subjects had the same potential for generating force, the more mobile players were not able to generate their maximum force because they were more mobile than required for this test (Figure 5.1). This is a simplification, since the task is complex, in addition to the fact that the results of this study do not say anything about the length-tension relationship. In support of these speculations, a study that measured differences in isometric knee flexion peak torque generated with different knee angles, with subjects having little or normal mobility in the knee flexors, displayed a shift in the torque produced at a certain knee angle (Alonso, McHugh, Mullaney, & Tyler, 2009). This study reported a shift in the less flexible hamstring with an increased knee flexion torque at short muscle lengths, and decreased at long muscle lengths (Alonso et al., 2009).

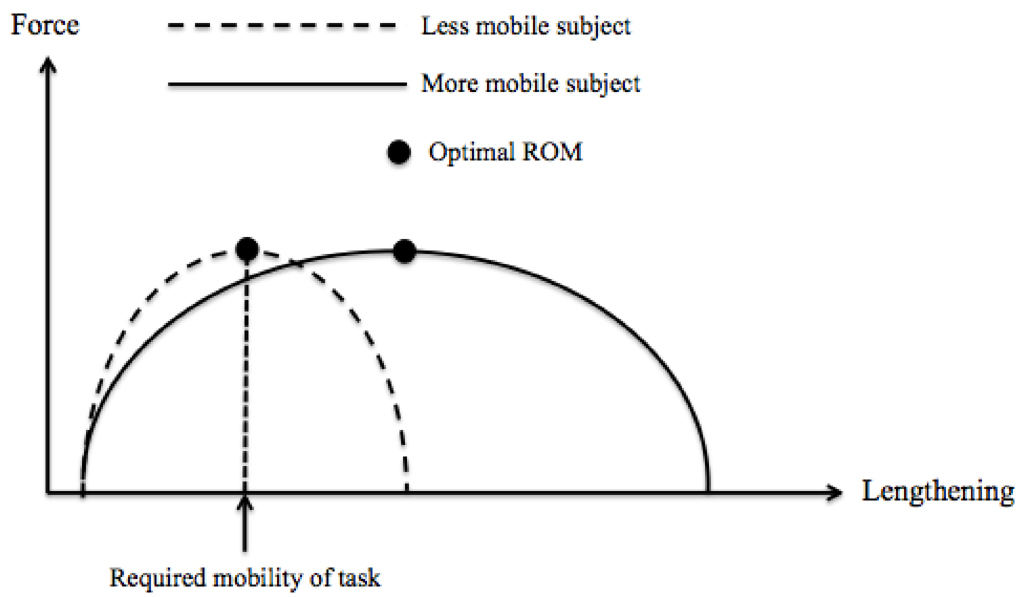


Figure 5.1: *Proposition to why a negative correlation occurs between flexion pattern mobility tests and the lateral hop tests.*

5.4 Limitations

The main limitation of this study was that only a small sample of elite handball players was tested (n = 12). Furthermore, there was no control for any confounding factors leading up to the tests. The fact that the testing period was performed in-season made recruiting subjects difficult since only players from the top-division in Norway were of interest. Controlling pre-testing conditions (type of training, nutrition and general activity level) was not compatible with the subjects' busy schedule with team training or games every day, in addition to work or studies. This led to an inability to re-schedule the test days, even though several subjects complained about fatigue. The low number of subjects increases the likelihood of a Type II error, which might offer some explanation as to why the correlations were so low. Additionally, no statistical power analysis was performed prior to the study. Therefore, no indications of the minimal sample size required to detect an effect were acquired.

6. Conclusion

The goal of this study was to investigate an unconventional and more sport specific approach to test the physical factors considered to be important to throwing performance in elite handball players, and to explore if increased specificity of physical tests would lead to better correlations between the physical tests and the throwing performance.

The hypotheses that functional mobility measured with the HSEBT is significantly correlated with throwing performance, and that peak power measured by the 1080 Quantum is significantly correlated with throwing performance, were rejected. The main reason why no significant correlations were found is probably that no individual test was specific enough, and neglected important joint motions in the overhead throw.

The results of this study suggest that neither the mobility nor the power tests can be used as individual predictors of performance for overhead throwing. However, the tests and the idea of moving from conventional testing and training to a more task and sport specific approach should not be discarded. This study was the first step towards developing more specific tests and equipment, which will enable scientist, therapists and trainers to improve assessment of the factors that determine athletic performance. Even though the tests used in this study seem too general to be predictors for throwing performance, they could possibly be useful as a general screening for functional mobility and power in athletes, and may serve as predictors for injury or athletic performance other than in throwing. However, further research is required to validate these assumptions.

Future studies should continue to develop tests and equipment that enables a better understanding of the multifactorial nature of athletic performance.

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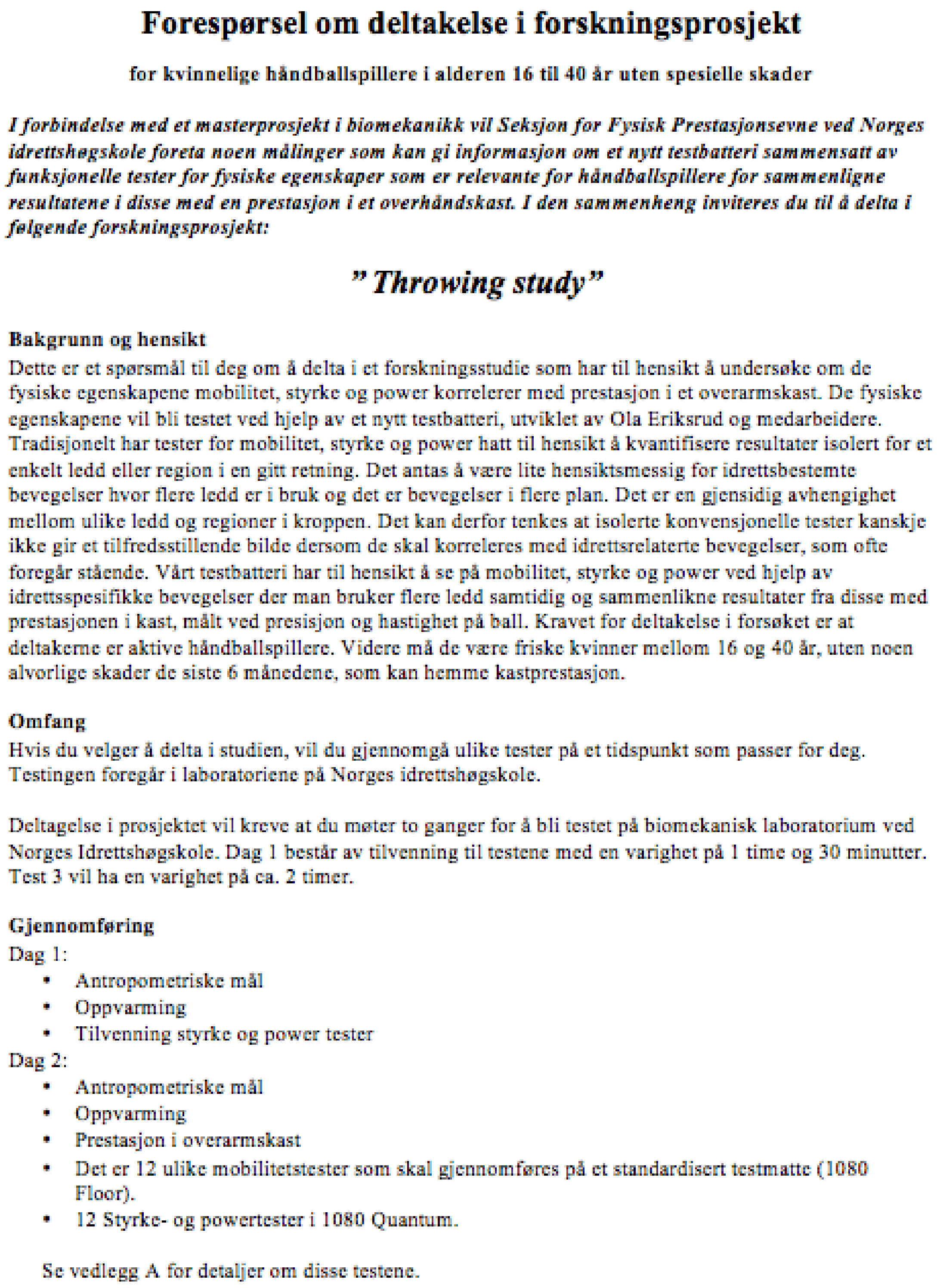
Appendix 1: Informed Consent



Forespørsel om deltakelse i forskningsprosjekt

for kvinnelige håndballspillere i alderen 16 til 40 år uten spesielle skader

I forbindelse med et masterprosjekt i biomekanikk vil Seksjon for Fysisk Prestasjonsevne ved Norges idrettshøgskole foreta noen målinger som kan gi informasjon om et nytt testbatteri sammensatt av funksjonelle tester for fysiske egenskaper som er relevante for håndballspillere for sammenligne resultatene i disse med en prestasjon i et overhåndskast. I den sammenheng inviteres du til å delta i følgende forskningsprosjekt:

" Throwing study"

Bakgrunn og hensikt

Dette er et spørsmål til deg om å delta i et forskningsstudie som har til hensikt å undersøke om de fysiske egenskapene mobilitet, styrke og power korrelerer med prestasjon i et overarmskast. De fysiske egenskapene vil bli testet ved hjelp av et nytt testbatteri, utviklet av Ola Eriksrud og medarbeidere. Tradisjonelt har tester for mobilitet, styrke og power hatt til hensikt å kvantifisere resultater isolert for et enkelt ledd eller region i en gitt retning. Det antas å være lite hensiktsmessig for idrettsbestemte bevegelser hvor flere ledd er i bruk og det er bevegelser i flere plan. Det er en gjensidig avhengighet mellom ulike ledd og regioner i kroppen. Det kan derfor tenkes at isolerte konvensjonelle tester kanskje ikke gir et tilfredsstillende bilde dersom de skal korreleres med idrettsrelaterte bevegelser, som ofte foregår stående. Vårt testbatteri har til hensikt å se på mobilitet, styrke og power ved hjelp av idrettsspesifikke bevegelser der man bruker flere ledd samtidig og sammenlikne resultater fra disse med prestasjonen i kast, målt ved presisjon og hastighet på ball. Kravet for deltakelse i forsøket er at deltakerne er aktive håndballspillere. Videre må de være friske kvinner mellom 16 og 40 år, uten noen alvorlige skader de siste 6 månedene, som kan hemme kastprestasjon.

Omfang

Hvis du velger å delta i studien, vil du gjennomgå ulike tester på et tidspunkt som passer for deg. Testingen foregår i laboratoriene på Norges idrettshøgskole.

Deltagelse i prosjektet vil kreve at du møter to ganger for å bli testet på biomekanisk laboratorium ved Norges Idrettshøgskole. Dag 1 består av tilvenning til testene med en varighet på 1 time og 30 minutter. Test 3 vil ha en varighet på ca. 2 timer.

Gjennomføring

Dag 1:

- Antropometriske mål
- Oppvarming
- Tilvenning styrke og power tester

Dag 2:

- Antropometriske mål
- Oppvarming
- Prestasjon i overarmskast
- Det er 12 ulike mobilitetstester som skal gjennomføres på et standardisert testmatte (1080 Floor).
- 12 Styrke- og powertester i 1080 Quantum.

Se vedlegg A for detaljer om disse testene.

Fordeler og ulemper
Testene i prosjektet vil ikke forårsake store ubehag, men ved svært sjeldne tilfeller kan muskelstrekk eller stølhet forekomme. Dermed innebærer studien svært få ulemper for deg som forsøksperson.

Ved å delta i studien vil du få informasjon om din mobilitet, styrke og power ved funksjonelle bevegelser. Når studien avsluttes, vil du kunne sammenligne dine egne målinger med gjennomsnittsverdiene fra alle deltagerne i prosjektet.

Målemetoder
Det er manuelle målemetoder (måleband) for de ulike antropometriske målingene. Prestasjonen i kast måles ved hastighet og presisjon. Videre kvantifiseres de ulike mobilitetstestene i centimeter eller grader på en testmatte (1080 Floor). Styrke og power måles ved hjelp av robotteknologi i kabelmaskinen, 1080 Quantum.

Hva skjer med informasjonen om deg?
Informasjonen som registreres om deg skal kun brukes slik som beskrevet i hensikten med studien. Alle opplysningene og testresultatene vil bli behandlet uten navn eller andre direkte gjenkjennende opplysninger. En tallkode knytter deg til dine opplysninger og testresultater gjennom en navneliste.

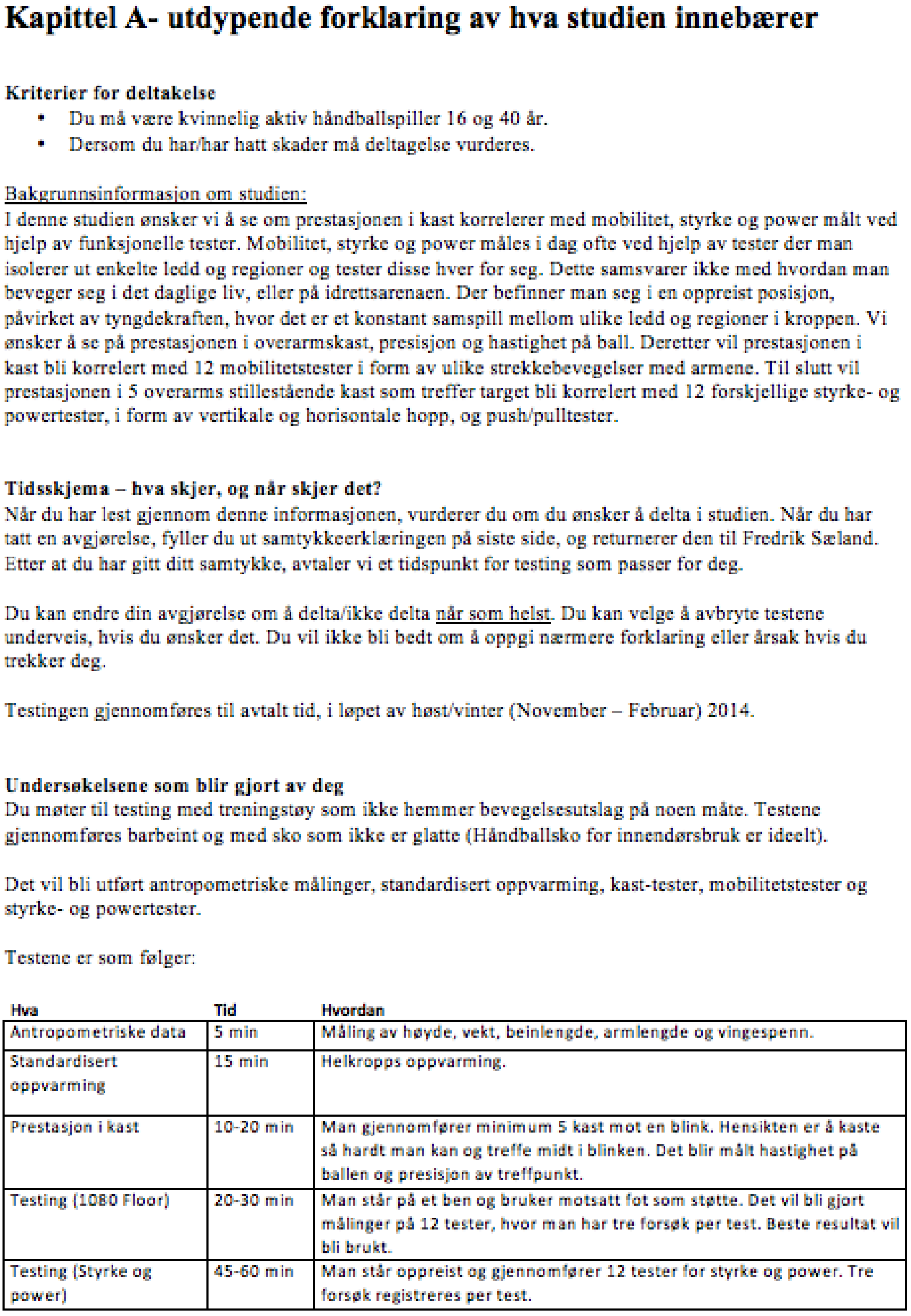
Det er kun autorisert personell knyttet til prosjektet som har adgang til navnelisten og som kan finne tilbake til deg. Når resultatene fra prosjektet er ferdig behandlet og prosjektet er avsluttet, vil navnelisten bli slettet, slik at dine resultater ikke kan spores tilbake til deg. Prosjektet planlegges å avsluttes innen utgangen av 2015.

Det vil ikke være mulig å identifisere deg i resultatene av studien når disse publiseres.

Frivillig deltakelse
Det er frivillig å delta i studien. Du kan når som helst, og uten å oppgi noen grunn, trekke ditt samtykke til å delta i studien. Dette vil ikke få konsekvenser for deg. Dersom du ønsker å delta, undertegner du samtykkeerklæringen på siste side. Om du nå sier ja til å delta, kan du senere trekke tilbake ditt samtykke uten at det vil få konsekvenser for deg. Dersom du senere ønsker å trekke deg eller har spørsmål til studien, kan du kontakte Fredrik Sæland, telefon +47 93 20 85 44 eller fredriksaeland@gmail.com.

Ytterligere informasjon om studien finnes i kapittel A – *utdypende forklaring av hva studien innebærer.*
Ytterligere informasjon om personvern og forsikring finnes i kapittel B – *Personvern, økonomi og forsikring.*

Samtykkeerklæring følger etter kapittel B.



Kapittel A- utdypende forklaring av hva studien innebærer

Kriterier for deltakelse

- Du må være kvinnelig aktiv håndballspiller 16 og 40 år.
- Dersom du har/har hatt skader må deltagelse vurderes.

Bakgrunnsinformasjon om studien:
I denne studien ønsker vi å se om prestasjonen i kast korrelerer med mobilitet, styrke og power målt ved hjelp av funksjonelle tester. Mobilitet, styrke og power måles i dag ofte ved hjelp av tester der man isolerer ut enkelte ledd og regioner og tester disse hver for seg. Dette samsvarer ikke med hvordan man beveger seg i det daglige liv, eller på idrettsarenaen. Der befinner man seg i en oppreist posisjon, påvirket av tyngdekraften, hvor det er et konstant samspill mellom ulike ledd og regioner i kroppen. Vi ønsker å se på prestasjonen i overarmskast, presisjon og hastighet på ball. Deretter vil prestasjonen i kast bli korrelert med 12 mobilitetstester i form av ulike strekkebevegelser med armene. Til slutt vil prestasjonen i 5 overarms stillestående kast som treffer target bli korrelert med 12 forskjellige styrke- og powertester, i form av vertikale og horisontale hopp, og push/pulltester.

Tidsskjema – hva skjer, og når skjer det?
Når du har lest gjennom denne informasjonen, vurderer du om du ønsker å delta i studien. Når du har tatt en avgjørelse, fyller du ut samtykkeerklæringen på siste side, og returnerer den til Fredrik Sæland. Etter at du har gitt ditt samtykke, avtaler vi et tidspunkt for testing som passer for deg.

Du kan endre din avgjørelse om å delta/ikke delta når som helst. Du kan velge å avbryte testene underveis, hvis du ønsker det. Du vil ikke bli bedt om å oppgi nærmere forklaring eller årsak hvis du trekker deg.

Testingen gjennomføres til avtalt tid, i løpet av høst/vinter (November – Februar) 2014.

Undersøkelsene som blir gjort av deg
Du møter til testing med treningstøy som ikke hemmer bevegelsesutslag på noen måte. Testene gjennomføres barbeint og med sko som ikke er glatte (Håndballsko for innendørsbruk er ideelt).

Det vil bli utført antropometriske målinger, standardisert oppvarming, kast-tester, mobilitetstester og styrke- og powertester.

Testene er som følger:

Hva	Tid	Hvordan
Antropometriske data	5 min	Måling av høyde, vekt, beinlengde, armlengde og vingespenn.
Standardisert oppvarming	15 min	Helkropps oppvarming.
Prestasjon i kast	10-20 min	Man gjennomfører minimum 5 kast mot en blink. Hensikten er å kaste så hardt man kan og treffe midt i blinken. Det blir målt hastighet på ballen og presisjon av treffpunkt.
Testing (1080 Floor)	20-30 min	Man står på et ben og bruker motsatt fot som støtte. Det vil bli gjort målinger på 12 tester, hvor man har tre forsøk per test. Beste resultat vil bli brukt.
Testing (Styrke og power)	45-60 min	Man står oppreist og gjennomfører 12 tester for styrke og power. Tre forsøk registreres per test.

Kapittel B - Personvern, økonomi og forsikring

Personvern

Opplysninger som registreres om deg er: Navn, alder, antropometriske mål og resultater fra de beskrevne testene.

Informasjonen som registreres om deg skal kun brukes slik som beskrevet i hensikten med studien. Alle opplysningene og prøvene vil bli behandlet uten navn og fødselsnummer eller andre direkte gjenkjennende opplysninger. En tallkode knytter deg til dine opplysninger og testresultater gjennom en navneliste.

Det er kun autorisert personell knyttet til prosjektet som har adgang til navnelisten og som kan finne tilbake til deg. Når resultatene fra prosjektet er ferdig behandlet og prosjektet er avsluttet, vil navnelistene bli slettet, slik at dine resultater ikke kan spores tilbake til deg. Prosjektet planlegges å avsluttes innen utgangen av 2015.

Andre forskere ved Norges idrettshøgskole vil kunne be om tilgang til det anonyme materialet, til bruk i sammenligning med andre grupper idrettsutøvere eller personer.

Norges idrettshøgskole ved administrerende direktør er databehandlingsansvarlig.

Rett til innsyn og sletting av opplysninger om deg

Hvis du sier ja til å delta i studien, har du rett til å få innsyn i hvilke opplysninger som er registrert om deg. Du har videre rett til å få korrigert eventuelle feil i de opplysningene vi har registrert. Dersom du trekker deg fra studien, kan du kreve å få slettet innsamlede opplysninger, med mindre opplysningene allerede er inngått i analyser eller brukt i vitenskapelige publikasjoner.

Økonomi og Norges idrettshøgskoles rolle

Studien er finansiert gjennom midler fra Norges idrettshøgskole. Denne finansieringen innebærer ingen interessekonflikter, etiske eller praktiske utfordringer.

Forsikring

Staten er selvassurandør

Informasjon om utfallet av studien

Som deltager i prosjektet har du rett til å få opplyst både dine egne resultater, og informasjon om resultatene av studien totalt sett. Du kan få tilsendt informasjonen ved å kontakte fredriksaeland@gmail.com

Samtykke til deltakelse i studien

Jeg er villig til å delta i studien

(Signert av prosjektdeltaker, dato)

Jeg bekrefter å ha gitt informasjon om studien

(Signert, rolle i studien, dato)

Appendix 2: Evaluation of 1080 MAP and 1080 Quantum

1080 MAP

The 1080 MAP provides a quantitative way of testing mobility with tests performed in a standing position, with the subjects affected by gravity, while doing reaches creating movements throughout the kinematic chain. In some regard the 1080 MAP test can be viewed as a modified star excursion balance test (SEBT) (Hyong & Kim, 2014), where arm reaches is applied instead of foot reaches. The 1080 MAP can be considered to have better logical validity than traditional mobility tests related to overhead throwing, which focuses on testing mobility of isolated joints. Like the SEBT, the 1080 MAP test is a multifactorial test assessing dynamic mobility/stability. By using arm reaches instead of foot reaches along a set of vectors (see figure below) the 1080 MAP test are also able to include mobility of the spine, scapula and shoulder, unlike the SEBT that is only measuring dynamic mobility/stability of the hip, knee and ankle joint.

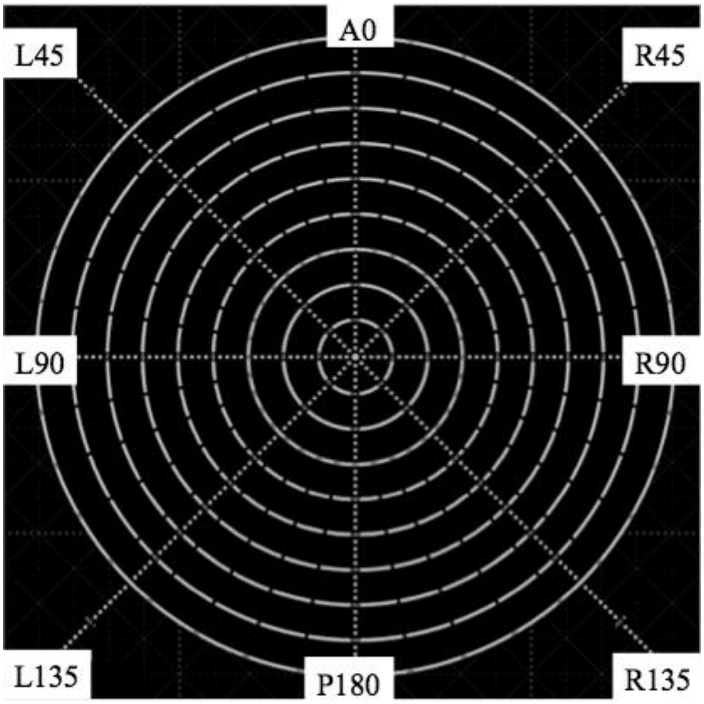


Illustration of the 1080 MAP testing grid with the directional vector names (A0, L45, L135, R45, R135 and P180).

1080 Quantum

According to the manufacturer the 1080 Quantum, with its robotic technology and functional design, is a flexible training and measurement system capable of obtaining accurate documentation of physical factors (force, speed and power) in a wide variety of movement patterns. The adjustable arm with a 5 m line allows for any functional movement pattern to be performed. The speed and resistance of the concentric and eccentric phases of movement can be set independent of each other. The resistance can be three times as high in the eccentric as compared to the concentric phase. Difference in speed between the concentric ($0.1 – 0.8\ m{\cdot}s^{-1}$) and eccentric ($0.1 – 0.6\ m{\cdot}s^{-1}$) phase has no restrictions since it can be manipulated freely within the speed ranges given. Furthermore, the speed setting can also serve as a speed limit for the movement performed. A lower speed can therefore translate any movement into isokinetic testing or training. Additionally, the 1080 Quantum has four basic settings that can be applied in both testing and training:

1) Normal, where the load mimics a regular mass.

2) No flying weight, in which the inertia of the mass is rapidly reduced as the force output of the athlete is decreasing.

3) Vibration at 25 Hz with a selection of different amplitudes.

4) Isotonic resistance mode.

Finally, two gears are available to generate resistance. Gear 1 allows for a resistance range from 0-25 kg and gear 2 0-50 kg. The resistance settings can only be put at integer numbers.

The 1080 Quantum single specifications:

- 1-25 kg of continuous concentric load
- 1-37 kg of continuous eccentric load
- 1-50 kg of continuous concentric load with Gear 2
- 1-74 kg of continuous eccentric load with Gear 2

- Maximum con/ecc load during 3 seconds: 75 kg, 150 kg with Gear 2
- Concentric velocity: 0.1–8 m·s^{-1}
- Eccentric velocity: 0.1–6 m·s^{-1}
- In Gear 2 maximum speed is halved
- Sampling frequency of force, speed and power: 333 Hz
- Tablet with touch screen interface or laptop
- Operating system: Windows 7 or 8
- Weight: 180 kg
- Body height: 1.7 m
- Max cable travel: 5 m

The technical summary of the 1080 Quantum provided by the manufacturer is as follows:

“Speed is measured by a high resolution (20 bit) optical encoder, directly attached to the motor. The encoder measures the position of the motor axis. By system design, this position measurement directly corresponds to the position of the line when it is being unwound or retracted on to the drum. The sampling frequency of position data is 333 Hz. The position signal is then used to calculate both speed and acceleration, which is the first and second derivative of position with respect to time, respectively. A low pass (LP) filter is used in both derivations to eliminate noise caused by the derivation. The LP filter is a first order filter with a time constant of 0,01 s, which corresponds to a cutoff frequency of 15,9 Hz. The LP-filter is implemented in discrete time using bilinear transformation (Tustin).”

“The load/resistance offered by system in both the eccentric and concentric phase of the movement is electromagnetic. The force applied to the system is internally recorded based on the amount of current and voltage that are being sent to the motor by the servo drive. This information is used by the drive to calculate the actual torque that is delivered to the motor shaft. However, the force experienced at the end of the line is not only directly related to the shaft torque, but also to the acceleration of the line-drum. This acceleration is used to compensate for the inertia caused by the motor and drive shaft in 1080 Quantum.”

“Based on the design of the system there will be friction between the motor axis and the end of the line at the user. This is especially true for the 1080 Quantum. These friction losses are not measured by the system. They are dependent on both the magnitude of the force at the end of the line and the direction of the force relative to the arm/pulley”.

Validation

A validation of the accuracy of the time, position, speed and force of measurements of the 1080 Quantum was conducted by Dala Sports Academy (Hallegren, Unpublished data). The accuracy of the position was validated using a standard measuring tape. Prior to the tests the position of the line was calibrated, with line fully retracted. Position data in the software was based on this position. The calibrated position was noted on the measuring tape on the floor. Then measurements were obtained at 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0 m. The accuracy of the measurement of time, and subsequent calculation of speed, was validated by obtaining and verifying the time of the machines internal clock. “The system calculates speed of the motor shaft by counting the number of encoder pulses (Δp) that have passed during a fixed interval of time (ΔT). Speed is therefore proportional to: $Speed \sim \frac{\Delta P}{\Delta T}$. The optical encoder has a resolution of 20 bits. This means that the encoder has a resolution of 1 048 576 points during each rotation of the motor shaft. The speed of the motor shaft is calculated at fixed intervals of time ΔT=3 ms in the system. A test was conducted to verify that ΔT was in fact 3 ms. The test was made in the software using a counter that got its value increased by 0.003 (=3ms) at each interval. It was setup to run exactly one hour in order to determine the drift in time. The time value of the software counter was then compared to an external clock”.

The investigation into the accuracy of the position measurements showed a measurement error of -3 mm at 0.5 m and 11 mm at 4.0 m. Therefore the total error was 14 mm, yielding an average of 4 mm/m. Additionally, the validation of the internal clock showed an error of less than 1 s in an hour. Since both the accuracy of the time and position are highly accurate, the speed calculation can also be deemed highly accurate.

To validate the accuracy of the force measurements in the 1080 Quantum an external force sensor was used (Model 333AL, K Toyo co., Ltd, South Korea). The force sensor was calibrated before testing, with known masses ranging from 5-90 kg. The force sensor was then attached to the line between and the user and the machine. The subject was then asked to perform pulling motions at an estimated 25, 50 and 75% of maximum effort. This was repeated using different load ranging from 4 to 24 kg and three different concentric speeds (0.5, 1 and 8.0 $m \cdot s^{-1}$). The maximum force from both the 1080 Quantum and the force sensor was noted for all of the 97 trials. The accuracy between the force measurements acquired from the 1080 Quantum show little no linearity errors to the measurement of the force sensor ($r = 0.9995$). Additionally the tests showed a slight offset error of 4.7 N of the 1080 Quantum. "Given a normal distribution and a standard deviation of 4.0 N it is 95% and 99,7% certain that a true value lies within ± 8.0 N and ± 12.90 N respectively".

Even though the 1080 Quantum can be deemed highly accurate to determine position, speed and force based on the tests conducted there are some limitation that should be considered when testing athletes:

The ability to perform functional movement patterns is a great feature of the machine, but also poses some challenges. The type of exercise selected, since functional movements include major muscle groups and/or joints of the body, may affect the accuracy of the force measurement. Factors such as: 1) the angle of the line relative to the pulley, 2) position of the athlete, 3) angular position of the joints and 4) distance of the line to axis of rotation of different joints will influence force measurements. According to the manufacturer these issues are addressed by carefully designing testing and training protocols where position of the arm of the 1080 Quantum, position of the subject relative to the machine and the action performed are standardized.

Appendix 3: Full Body Dynamic Stretches

Beneath, illustrations of the ending positions of all six movements of the Full body Dynamic Stretch warm-up is presented. The subjects started the motions from a normal stance. The six motions performed three times on each leg consisted of two sagittal, frontal and transverse plane full body motions. The motions were:

Sagittal:

1) Anterior stretch: Unilateral anterior step with bilateral hands posterior overhead reach.

2) Posterior stretch: Unilateral posterior step with bilateral hands and foot/ankle reach.

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Frontal:

3) Lateral stretch: Unilateral hip abduction step with opposite side bilateral hands overhead lateral reach.

4) Lateral stretch: Unilateral hip adduction step with opposite side bilateral hands overhead lateral reach.


3


4

Transverse:

5) Hip external rotation: unilateral external rotation step with same side bilateral hands rotational reach at chest height.

6) Hip internal rotation: Unilateral internal rotation step with same side bilateral hands rotational reach at chest height.


5


6

Appendix 4: Foot Positions in the 1080 Quantum Push, Pull and Rotational Tests

The coordinates for the foot placement have the following order in each of the arm driver test: (X linear position, Y linear position, XY rotation). Linear position is based upon the position of the big toe of the stance foot. Rotation is the orientation of a line bisecting the stance foot from the calcaneus to the second toe in the XY plane. Facing 1080 Quantum is given a 0° rotation. Rotating clockwise at 45° increments from this position is defined as: R45, R90, R135, P180, L135, L90 and L45.

Push, Pull and Rotational Power Tests with Explanation of Test

1. Right hand posterior and superior diagonal pull:

Position of left foot relative to 1080 Quantum was 140 cm in front rotated 45° to the right. Allow the 1080 Quantum to pull the right hand anterior and inferior to knee height. At the same time allow the right foot to slide toward the left stance foot. No weight is put on the right foot. Then pull as fast a possible posterior and superior while at the same time taking a right foot right rotational step/lunge.

2. Left hand posterior and superior diagonal pull

Position of right foot relative to 1080 Quantum was 140 cm in front rotated 45° to the left. Allow the 1080 Quantum to pull the left hand anterior and inferior to knee height. At the same time allow the left foot to slide toward the right stance foot. No weight is put on the left foot. Then pull as fast a possible posterior and superior while at the same time taking a left foot left rotational step/lunge.

3. Right hand anterior and inferior diagonal push

Position of right foot relative to 1080 Quantum was 140 cm in front rotated 135° to the left. Allow the 1080 Quantum to pull the right hand posterior and superior. Maintain the forearm parallel with the line of pull from the 1080 Quantum. At the same time allow the left foot to slide toward the right stance foot. No weight is put on the left foot. Then push as fast a possible anterior and inferior while at the same time taking a left foot left rotational step/lunge.

4. Left hand anterior and inferior diagonal push

Position of left foot relative to 1080 Quantum was 140 cm in front and rotated 135° to the right. Allow the 1080 Quantum to pull the left hand posterior and superior. Maintain the forearm parallel with the line of pull from the 1080 Quantum. At the same time allow the right foot to slide toward the left stance foot. No weight is put on the right foot. Then push as fast a possible anterior and inferior while at the same time taking a right foot left rotational step/lunge.

5. Bilateral arms left rotation

Position of right foot relative to 1080 Quantum was 160 cm in front and rotated 90° to the left. Allow the 1080 Quantum to pull both hands to the right. Maintain the forearms parallel with the ground/floor. At the same time allow the left foot to slide toward the right stance foot. No weight is put on the left foot. Then push as fast a possible into left rotation while at the same time taking a left foot left rotational step/lunge.

6. Bilateral arms right rotation

Position of left foot relative to 1080 Quantum was 160 cm in front and rotated 90° to the right. Allow the 1080 Quantum to pull both hands to the left. Maintain the forearms parallel with the ground/floor. At the same time allow the right foot to slide toward the left stance foot. No weight is put on the right foot. Then push as fast a possible into right rotation while at the same time taking a right foot right rotational step/lunge.