MASTER THESIS

Course code: **MKØ210_1** Candidate name: **106**

The effect of rotational core exercises in slings on throwing velocity for elite female handball players, through alterations of core kinematics and strength

Effekten av kjernetrening ved bruk av rotasjonsøvelser i slynger på kasthastighet for kvinnelige elite håndballspillere, gjennom endring av kinematiske variabler og styrke i kjerne

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Abstract

The aim of this study was two folded, where the main goal was to investigate if rotational core exercise in slings might improve maximal ball velocity in various throwing techniques. The second aim of the study was to examine how (and to what degree) the employed exercise protocol affects core strength, peak angular velocities of pelvis and trunk, the timing of these, and movement pattern in participating athletes, and thereby altering ball velocity. This study was conducted in two stages, first through a pilot study examining the effect of sling training on ball velocity at 7 m throw with run-up, and thereafter a main study investigating the effect on three throwing techniques, where also 3D-analysis and core strength was tested. In both studies, a pretest-posttest design was employed, with a training intervention between tests, where participant either took part in sling exercise or plyometric training (control group). In the pilot study a mixed gender group of 14 participants (aged 15) completed the study, where either group (n = 7) carried out a training intervention lasting six weeks. In the main study, 21 elite female handball players (aged 19,5 ± 2,03, training exp. 10.3 ± 2,4 years) were divided into a sling (n = 11) or control group (n = 10) taking part in additional exercise for 8 weeks.

In the pilot study, maximal ball velocity significantly increased (p = 0.028) by 3.1% for the sling-based training group. In the main study, a significant improvement was found of 4.5% in 7m standing throw (p = 0.007), and 3.6% in jump throw (p = 0.013) for the sling group, while no significant improvement (1.2%) was found for 7 m standing throw with run-up. There was however a significant decrease (p = 0.003) by the control group. In all techniques in the main study there was also a significant interaction between groups. When examining kinematical data, there was only a significant alteration (p = 0.048) of timing of trunk velocity in the sling group, which caused a change in movement pattern between tests at 7 m throw with run-up. The lack of progress for the sling group in this technique might be caused by this altered movement pattern as the transfer of power output seems to be affected. For all techniques there was a non-significant increase in peak angular velocities of both segments, where the increase in 7m throw with/without run-up displayed either significant or trend values in interaction between groups. The same trend for angular velocity was apparent for core strength, where both the dominant and non-dominant side improved in 1RM, while only the non-dominant was found to be significant (p = 0.045). Through a steady increase in angular velocities and core strength there appears as core training have had an impact on performance, but due to the lack of consistent significant increase in variables tested, it is possible that the sum of improvement in various variables may be more important for ball velocity than one single factor.

1.Introduction

Throwing is an ability that is utilised in many sports, such as baseball, basketball, javelin, and team handball. In team handball, different techniques of throwing are applied, among others, jump throw and standing throw with or without run-up, which are considered fundamental skills for handball players (Wagner, Pfusterschmied, von Duvillard, & Müller, 2011). These techniques are mainly used to score goals and are a big part of the repertoire of skilled players (Wagner, Buchecker, von Duvillard, & Müller, 2010). Throwing is classified as a *fast-discrete complex movement*, involving several joints and muscles, and therefore the player must deal with numerous degrees of freedom during a throwing motion with a distinct beginning and end (van den Tillaar & Ettema, 2006, 2007). This means that several joints and muscles must be coordinated into one coherent action, to maximise the throwing performance.

Kinematic analysis of throwing has shown that the level of internal rotational velocity of the shoulder and elbow angle at ball release, are the two factors which influence maximal ball velocity the most in standing overhand throw in isolation (van den Tillaar & Ettema, 2007). While examining kinematic contribution across several techniques (pivot throw, jump throw, and standing throw with/without run-up), Wagner et al. (2011) found that there was only a small, yet significant correlation between these shoulder and elbow movements, and maximal ball velocity. They argued that since the shoulder and elbow movements seem close to identical across all techniques, while there are differences in maximal attainable ball velocity between them, other factors influencing an overall throwing performance must be equally important in throwing.

Though findings demonstrate that these shoulder and elbow movements are important to attain maximal ball velocity, further findings of van den Tillaar and Ettema (2007) and Wagner et al. (2011) shed light on other variables as well. Findings demonstrate that hip and trunk movements are among those factors, playing a role in attaining maximal ball velocity. Van den Tillaar and Ettema (2007) found that better throwers initiate temporal rotational movement of their pelvis sooner, than slower ones in standing overhand throw. Whereas Wagner et al. (2011) discovered high correlations between both maximal pelvic and trunk rotational angular velocity, as well as moderate correlation of the timing of maximal internal trunk rotational angle, with maximal ball velocity. They also observed a significant difference between the four throwing techniques regarding these pelvic and trunk movements, where rotational angles and angular velocities for 7 m standing throw and 7 m throw with run-up were quite similar, but differed to a greater degree to the techniques involving a jump in the execution of the throw.

Another reported finding was that there was a great difference in velocity of centre of mass in goal-directed movement, between standing throw and throws involving a run-up. This indicated that muscles contribute differently, and at various degrees, between these four techniques (Ibid, 2011).

Since pelvic and trunk rotation seem so important to achieve the highest performance possible, a strong core might prove to be of utmost importance to team handball players. The term “core” is used to refer to the trunk and pelvis area, acting as a link between the lower and upper extremity (Willardson, 2007b). The core has been divided into a passive-, active muscle- and neural system, and these classifications describe their role in movement and stability of the spine (Bergmark, 1989; Willardson, 2007a). Bony and cartilaginous elements, ligaments, tendons, and fasciae are considered the passive system, which the active muscles can act upon (Bergmark, 1989). It is the job of the neural subsystem to ensure sufficient stability, as well as make the muscles execute desired movements. This system relies on feedback provided by the muscles’ spindles, Golgi tendon organs, and spinal ligaments to monitor and adjust the muscle force acting on the passive system (Willardson, 2007a). The active muscle system has been divided further into a global and local system, where muscles acting directly on the lumbar spine to maintain mechanical stability have been signed to the local system. Whereas the muscles in the global system mainly have the mechanical role of transferring load directly between the thoracic cage and pelvis, as well as to change position between the two in various movements (Bergmark, 1989).

Core movements and their importance for throwing can be explained through what is called a proximal-to-distal sequence. The proximal-to-distal sequence in throwing can be understood as the temporal order of movements in joints and segments, where the movement starts proximally (core, but in truth it start distally at the knee in throwing) and end distally (hand) (Marshall & Elliott, 2000). Both Wagner and colleagues (2011), and van den Tillaar and Ettema (2009) found evidence supporting a proximal-to-distal movement in various throwing techniques, where the different components in the core logically would be involved in the execution of these. This leads to questioning how this sequence might affect throwing performance in athletes. Jöris, Edwards van Muyen, van Ingen Schenau and Kemper (1985) theorised, that an acceleration of a proximal segment (e.g. trunk) through concentric contraction of involved muscles would make muscles in the succeeding, distal segment (e.g. shoulder) to rapidly contract eccentrically, leaving them pre-stretched. The shoulder muscles would in turn contract concentrically with a higher force output due to their pre-stretched characteristics, pre-stretching muscles in the upper arm in a similar matter. By doing so, they build up a momentum that transmit enhanced power output further through the chain of movement, eventually resulting in a greater ball velocity. Based on this theory, it would seem logical that strong local and global muscles in the core, would act as an important foundation in achieving the highest ball velocity possible, and therefore it seems beneficial to train core muscles regularly.

In training for better performance, several principles can be of help to physicians, coaches, and athletes to manipulate the structure of training regimes, while only the principle of specificity and loading will be discussed in this paper. The principle of specificity encompasses both exercise selection and force-velocity characteristics. Coaches and athletes must consider which muscle groups to train, which energy systems to target, and which speed and range of motion to apply to help athletes better their performance in their main activity (Kraemer & Ratamess, 2004). In short, specificity can be described as *what to do*. The principle of loading, however, will closely intertwine with specificity, where loading can be considered a combination of the intensity applied, and the amount (e.g. duration and frequency) of training carried out by the athlete (Bompa & Haff, 2009). Thus, loading can be a description of *how much to do,* or when considering the intensity component, *how to do*.

The intensity is the qualitative component of loading, and is related to power output against opposing force, where energy expenditure or work per unit of time can be a measurement of the intensity carried out by the athlete (Bompa & Haff, 2009). The intensity component applied would acquire neuromuscular activation, which enhances with greater load, speed of performance, and amount of fatigue developed (ibid, 2009). The intensity also seems to be exercise-dependant. This means that there is no definite amount of repetitions, that can be performed with the highest rate of force development (RFD) across all muscle groups (Kraemer & Ratamess, 2004). This makes this component challenging to apply in varied exercises, when the goal is to perform with maximal effort, at the same level, through the whole set.

Based on the findings and theories previous mentioned, it seems possible to raise throwing performance in team handball players through core training, if the exercise protocol is well designed. A few studies have attempted to examine if core training can increase sports performance, and so far with varying success (Manchado, García-Ruiz, Cortell-Tormo, & Tortosa-Martínez, 2017; Pedersen, Magnussen, Kuffel, & Seiler, 2006; Saeterbakken, van den Tillaar, & Seiler, 2011; Scibek, Guskiewicz, Prentice, Mays, & Davis, 1999; Seiler, Skaanes, Kirkesola, & Katch, 2006; Stanton, Reaburn, & Humphries, 2004). Both Scibek et al. (1999) and Stanton et al. (2004) reported increased levels of core strength in athletes, but neither experiment found an increased performance in swimming or running respectively. The lack of progress in these studies can be due to the level of specificity of the chosen exercises, loading, and intensity applied. However, another explanation might be that core muscles do not play the same part in repetitive, more long-lasting activities, such as running and swimming, as it would in short, explosive movements. Therefore, these results might not be as relevant to the current study, due to the discrete complex characteristics in throwing.

Manchado et al. (2017), Saeterbakken et al. (2011), Pedersen et al. (2006) and Seiler et al. (2006) on the other hand, investigated whether core training might raise performance in what can be considered fast discrete complex movements (throwing, kicking and maximal golf club-head swing velocity). They all observed significant improvements in the desired skills, ranging between 3,5-4,9 %, and showed that core strength training can have a positive effect on such movements. The core strength programs were different between studies, where Manchado et al. (2017) carried out floor-based core training, while the others used sling-based training. Apart from the differences in applied training method, they all trained both stabilizing and rotational exercises, and therefore none of the studies could explain which types of exercises (and to what extent) contributed to the enhanced performance. In addition, none of them addressed what changed within the subjects after completing the training period, or could explain if the increased performance was due to enhanced core strength, adjusted coordination pattern, or just a learning or test effect.

Therefore, the aim of this study was two-folded, where the main aim was to investigate if sling-based training focusing on rotational exercises would improve throwing performance in outfield handball players. Due to the nature of the neural and active muscle system in the core, and its adaptability, the second aim was to investigate what changes in kinematics of the core movement (trunk and pelvis rotation) and strength within subjects after a training a period. Are the potential alterations in throwing performance due to altered levels of strength, rotational velocity, coordination patterns in core movements, or a combination of these?

2.Method

To investigate the effect of sling-based training upon throwing velocity, two training experiments were conducted. The aim of the first training study was to examine if the planned training protocol in fact could enhance the throwing performance, and possibly if it needed some adjustments (e.g. longer training period or alteration in exercises). In the second study, measurement of ball velocity, 3D-analysis, and a core strength test were carried out to investigate potential coordination and strength changes related to throwing performance, before and after the training period. The first experiment was completed in the autumn, while the second was carried out in late winter/early spring.

In the first study, the participants' (15 yr old) throwing velocity was measured using a radar gun. Findings showed that they raised their maximal throwing performance on average by 3,1%, which indicate that there were reasons to investigate this even further. Based on these findings, a second study was carried out on handball players playing at an elite level in Norway, with some small adjustments in the protocol to potentially increase the performance gain even further.

2.1.Subjects

In the first study carried out on in the autumn, 14 well trained 10th grade pupils (all 15 years of age at the time) of both genders completed the whole study. They were all participating in at least one sport in their spare time, while several were competing at the highest level within their respective sports, in this region, and within their age group. They were recruited through a voluntary sport and activity subject, at their local lower secondary school. The subjects were all informed about the test protocol, and an informed consent was obtained from the parents of the participants. This was in accordance with the recommendation of the local ethical committee, and current ethical standards in sports and exercise research.

In the second training study, 21 female handball players out of 25 completed the study (age 19,5 ± 2,03 years, height 1.72 ± 0,06 m, body mass 71,5 ± 8,6 kg, training experience 10.3 ± 2,4 years), playing in first and second division in the Norwegian national league volunteered to participate in the study. The subjects were fully informed about the complete test protocol, and informed consent was obtained prior to pre-test from the subjects, and their parents when they were under the age of 18. Four players had to withdraw from the study, either through injury/illness picked up right after the pre-test, or due to strain injuries in lower legs picked up by the plyometric training group (control). This has led to a significant difference in jump throw performance between groups, while standing throw with/without run-up also is close to significant (table 1). To investigate the potential difference between groups before and after the training intervention, the interaction between tests and training modality will most likely be the most important comparison.

Table 1: Comparison of groups based on pre-test data

		Yr	Height (cm)	Mass (kg)	Experience (yr)	7m (m/s)	Run-up (m/s)	Jump (m/s)
Sling	Mean:	19.27	171.09	69.35	10.18	19.37	21.17	19.96
	Sta.dev:	1.79	4.64	6.97	2.83	1.25	1.21	0.98
Control	Mean:	19.70	174.00	73.82	10.50	20.52	22.27	21.32
	Sta.dev:	2.45	8.49	11.38	2.21	1.48	1.28	0.88
t-test		0.657	0.353	0.287	0.779	0.069	0.056	0.004*

* Indicates a significant difference between groups

2.2.Procedure

In the two studies, a pretest-posttest randomized-groups design was used, with a training intervention between tests. In addition, a retest was completed prior to training in the first study to control for a potential learning effect caused by the testing environment. In this study, a standardised warmup routine was used, involving different running and throwing exercises, lasting 10 minutes before the test began. After the warm up was completed, the test began. Only 7m throw with (three step) run-up was tested. Participants had to make three successful attempts hitting the target (standardised team handball goal). When participants had completed three successful attempts, their test was considered over. Before the trials, they were instructed to throw as hard as possible, while trying to throw the ball within the goalposts, using regular sized handball balls (girls: mass: 0.35kg, circumference: 0.54m and boys: mass: 0.45kg, circumference: 0.58m), using the same ball on both tests. Due to the timespan available, subjects were tested continuously, one attempt at the time, where they had about 5 minutes rest between trials, while others were tested. They kept warm by passing the ball at an easy pace in pairs of two (or three if needed) on the far side of the testing area, behind an immersed wall. The mean of the two best attempts was used for further analyses.

In the second study, the subjects began the test by carrying out their regular 10-minute warm-up routine, which included running, jumping, and throwing, before conducting an agility and counter movement jump test as part of a concurrent study. After these tests, reflective markers (29 markers, and 6 clusters of markers) used for 3D analysis were placed at selected anatomical landmarks (table 4). Then they were tested in overhand 7 m penalty throw, 7 m throw with two step run-up, and jump throw (also two step run-up) at 8 m, and was always completed in that order. They were instructed to throw as hard as possible and try to hit a 0,5 by 0,5 m square target at 1.65 m height (van den Tillaar & Cabri, 2012) (figure 1). The subjects used a regular senior handball (mass: 0.36 kg, circumference: 0.54 m) in all attempts. All participants performed the type of throw until told otherwise, not knowing the total number of successful attempts needed to complete the test. Still, three successful attempts (hitting the target) per throwing technique was considered enough, unless their performance gradually increased between each successful attempt. If that was the case, they would keep on throwing until their performance levelled out. By doing so, it was possible to control for a learning/adjustment effect that could influence the initial performance. The three best and most even performances were picked, in that order, to make sure that the best performance from the pre-test was used, so that possible changes on the post-test would reflect the influence of training as correctly as possible. Between trials, participants had approximately one-minute rest to avoid fatigue interference.

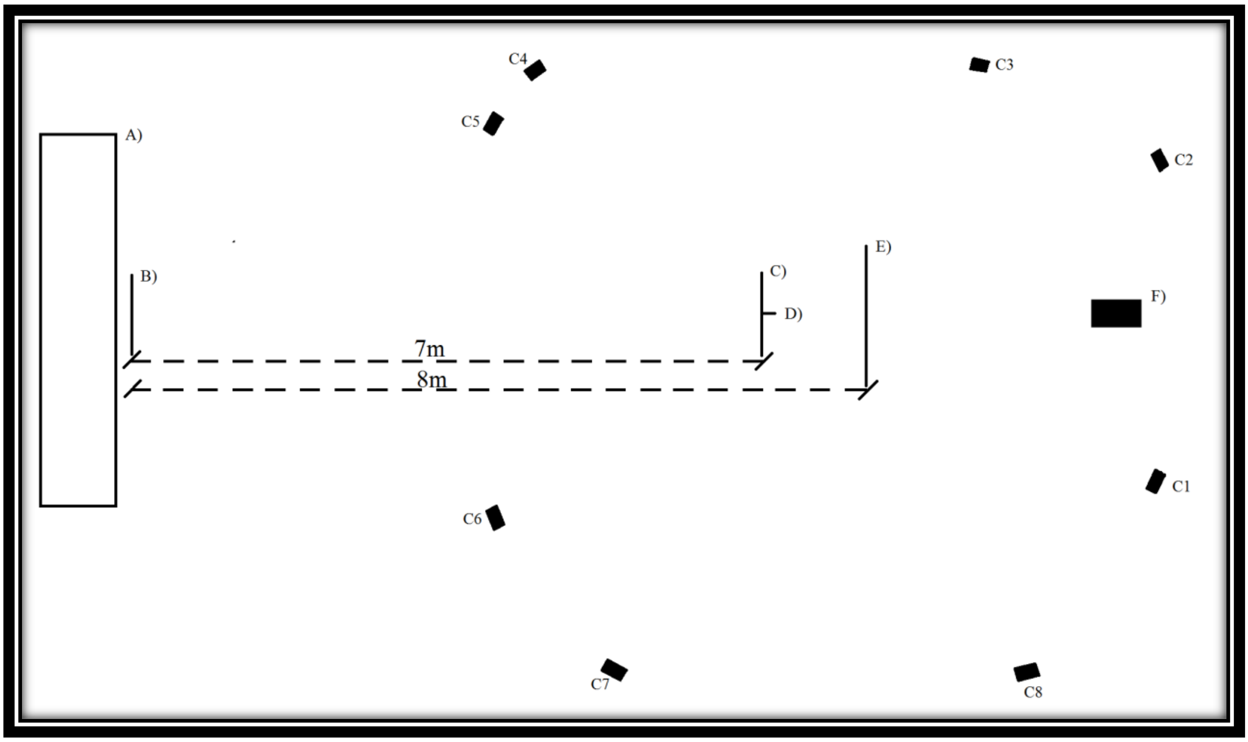


Figure 1: A) Shock absorbing mattress B) 50x50 cm target (at 1.65m height) C) Throwing position – 7m/7m throw with run-up D) "Divider between throwing point for left and right-handed players", left handed threw from the right side, right handed players from the left E) Throwing position – Jump throw F) Radar gun (placed at 11 m from target). C1-C8 (location of cameras)

After the throwing test was completed, the subjects carried out a core strength test, emphasising rotational peak velocity around the longitudinal axis, with applied resistance of 5, 10, 15, and 20 kg on both sides. All participants sat on a bench (without support) 0,75 m from the apparatus, with a band chained to the applied resistance over one shoulder at a time, holding the band with the opposite hand across their upper body. They were all instructed to always hold their feet above ground during testing, so they could not use them to generate power from the ground (figure 2). For every load participants completed two trials, one for either side, consisting of three attempts each. Between trials all participants had about one-minute rest before they began the next.

Based on the data collected on this test, the load-velocity relationship was established for each participant, on both sides, and for both the pre- and post-test. The mean of peak velocities on three attempts was calculated, and then used for further analysis. A load-velocity relationship was then established as a product of the addable loads, and rotational velocity at that load. This product is a predicted 1RM data for each participant, on both dominant and non-dominant side, and for both pre- and post-test. After the post-test was completed, results from both tests were compared to examine if one (or both) training groups would experience a positive or negative shift in this relationship (on either side). See the measurement chapter for further details about the calculations.

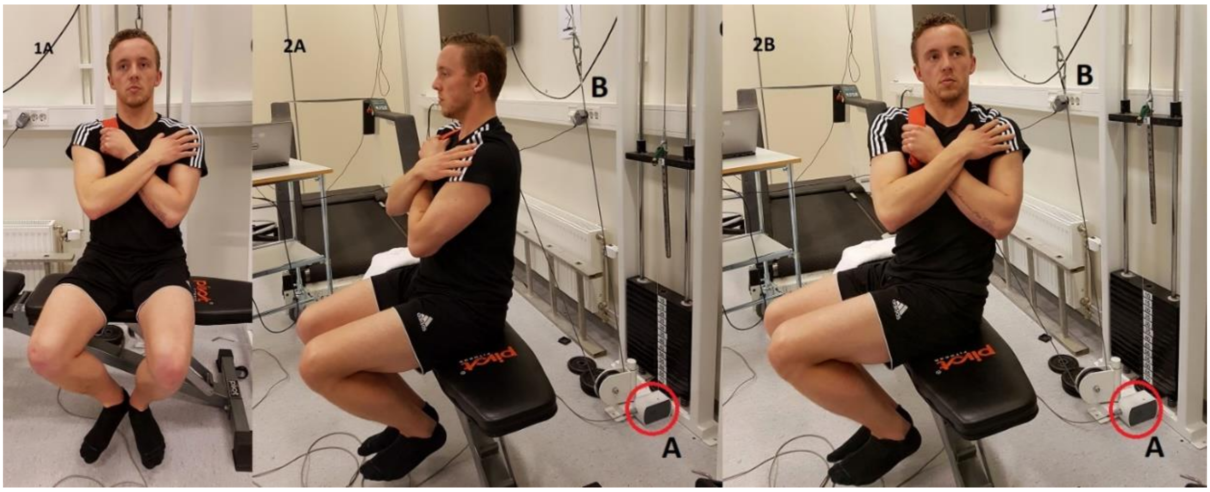


Figure 2 - Core strength test. Picture 1A: Frontal view of starting position. 2A: Side view of starting position, with linear encoder (A) and apparatus with addable weights (B). 2B: Side view of end position

After six (experiment 1) / eight (experiment 2) weeks of training, the subjects performed a post-test at approximately the same time of day, and at the same day of the week to avoid scheduled training or matches to affect recordings differently between tests.

2.3.Training procedure

After testing was completed, the subjects of both intervention studies were randomly assigned according to their mean performance in throwing with run-up, to either sling-based training group, or control group. At the pilot study either group consisted of seven participants, while there were 11 athletes sign to the sling group and 10 to the control group in the main study. In training, the sling-based group used adjustable Redcord Mini slings (Redcord AS, Kilsund, Norway, www.redcord.com), as well as Abilica elastic bands width 1.5 cm (Mylna Sport AS, Mjøndal, Norway, www.abilica.no) in their training, while there was no extra equipment used by the control group. The sling-based training group carried out a two-phased training program described in depth in the next paragraph, while the control groups completed a plyometric program based on the studies of Marques, Pereira, Reis and van den Tillaar (2013) and van den Tillaar, Waade and Roaas (2015). Before the training period began, subjects in either group were instructed on how to carry out the applied exercises, emphasising correct execution, so that they were familiarised with their respective training protocol.

The sling group carried out a two-phased training protocol, consisting of four exercises at every stage, where the second phase would be based on the same exercises as in phase one, but now with an altered movement pattern or with added resistance (table 2). The subjects were encouraged to gradually increase the velocity in each repetition, while their technical performance of the exercises progressed. This is in accordance with the principles of loading as mentioned above, gradually increasing the performance intensity while they develop motor control in these exercises, until they can complete the whole exercise with maximal effort.

The first study only consisted of six weeks of training with 10 repetitions at each series, while the training period in the second study lasted eight weeks, with some slight alterations of exercise 1, phase 2 (table 2). Furthermore, in the first five weeks of the second study, participants performed three sets of 10 repetitions per exercise on each side, succeeded by three weeks with four sets of 4-6 repetitions on both sides with maximal effort, to further work on their explosive performance. An instructor was present at every session to guide participants, both regarding their execution, as well as how to make exercises within each phase gradually more difficult. The subjects were also told to maintain a stable core through an activation of both core and gluteus muscles, so that they could make the desired rotation around the spine, leaving the possibility for back and hip flection and extension as small as possible, and only when it was intentional.

Table 2. Sling-based training protocol exercises

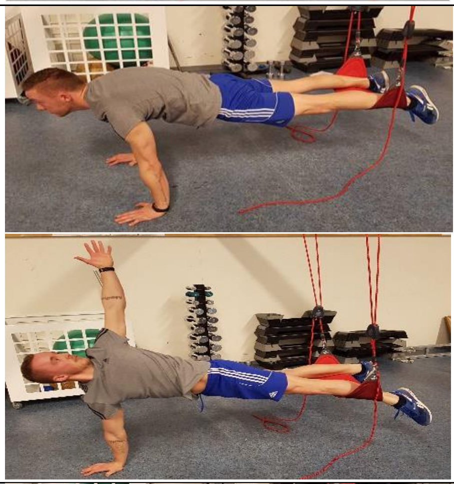
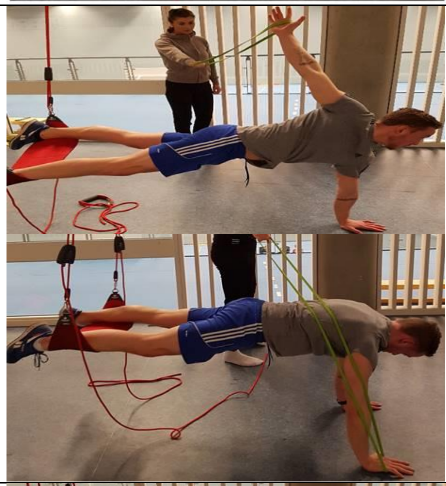
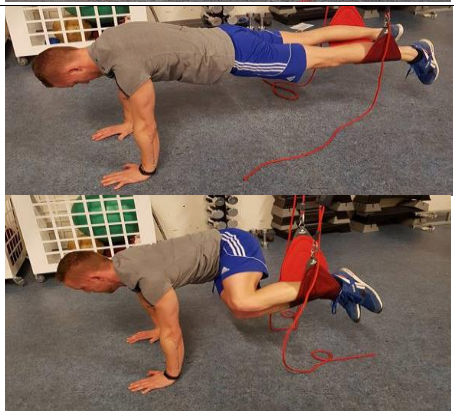
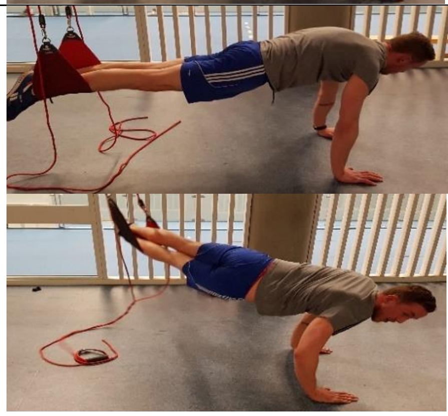
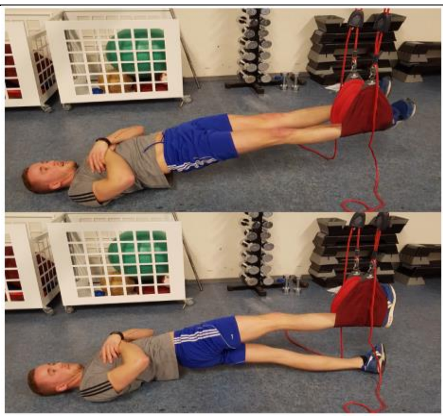
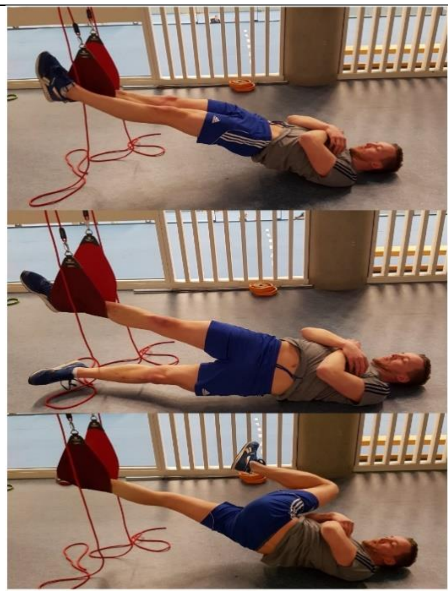
	Phase 1 (A)	Phase 2 (B)
Exercise 1 A) Rotation around the spine B) Rotation against external load (rubber band)		
Exercise 2 A) Rotation from the ground and up B) Rotation from the top and down, against external load (rubber band)		
Exercise 3 A) Rotation from starting position with tucked knees B) Rotation from starting position with straight legs, and pendulum movement		
Exercise 4 A) Starting with a levelled hip, rotating down, then up to starting position B) Starting with a levelled hip, rotating down, then up, ending with a bent knee, before returning to starting position		

Table 3: Training sessions, combined plyometric and sprint training

Exercise	**Training session**															
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
2 legged jumps (without bending the knees)	3 x 20	3 x 20	3 x 20	3 x 25	3 x 25	3 x 25	3 x 30	3 x 30								
2 legged jumps (without bending the knees) up the stairs 1 step									4 x 20	4 x 20	5 x 20	5 x 20				
2 legged jumps (while bending the knees)	3 x 10	3 x 10	3 x 10	3 x 10	4 x 10	4 x 10										
2 legged jumps (while bending the knees) up the stairs 2 steps													4 x 20	4 x 20	5 x 20	5 x 20
2 legged jumps as far as possible (while bending the knees)							3 x 10	3 x 10	4 x 10	4 x 10	4 x 10	4 x 10	4 x 12	4 x 12	4 x 12	4 x 12
Hop on one leg, short and quickly	3 x 10	3 x 10	3 x 10	3 x 10	2 x 10	2 x 10	3 x 10	3 x 10								
Hop on one leg, short and quickly up the stairs 1 step									3 x 10	3 x 10	3 x 10	3 x 10				
Hop on one leg, short and quickly up the stairs 2 steps													3 x 10	3 x 10	3 x 10	3 x 10
1-legged jumps as high as possible	2 x 8	2 x 8	2 x 8	2 x 8	3 x 8	3 x 8	3 x 10	3 x 10								
Jump shot movement									3 x 8	3 x 8	3 x 10	3 x 10	3 x 10	3 x 10	3 x 10	3 x 10
Sprint from standing position (m)	5 x 20	6 x 20	6 x 20	6 x 20	2x4x20											
Sprint from lying start position						2x4x10	5 x 30	5 x 15								
Sprint from 5m sideways start (m)									6 x 30	6 x 15	2x4x30	2x4x15				
Sprint from 3m backwards start (m)													6 x 30	6 x 20	2x4x30	2x4x20

The control groups in both the first and second study carried out a plyometric program (table 3), emphasising variations of one and two-legged jumps, and sprinting, lasting six and eight weeks respectively. According to van den Tillaar, Waade and Roaas (2015) plyometric training should not affect maximal ball velocity, which is the main reason for choosing this exercise modality, while these groups still assemble the same amount of training as the sling-based training group. This ensures that potential improvements in throwing performance is not due to increased amount of training, and since both groups train an equal amount, it should be easier to establish if sling training has any effect on performance.

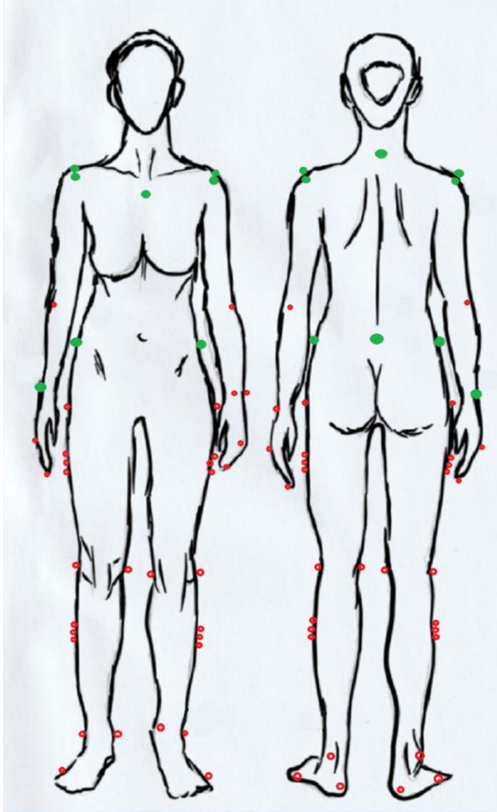
2.4.Measurement

In both experimental studies, maximal ball velocity was measured by a Doppler radar gun (Stalker ATS II, Applied Concepts Inc., Plano, TX). The radar gun was located 11 m away from the target the participants were aiming at, placing the radar gun in a straight line between target, thrower, and the gun. It measured with a 0.028 m/s accuracy within a field of 10°.

To measure kinematics for the present study (internal angular velocities and timing of hip and torso) and future ones, a 3D motion capture system (Qualisys, Sävedalen, Sweden) consisting of eight cameras sampling at 500 Hz was used (figure 1), tracking the position of reflective markers (15 mm in diameter) placed at various anatomical landmarks on both sides of the body (table 4).

For this study, the green coloured markers on hip and torso at the illustration in table 4 was used for analysis of maximal angular velocity of segments. Furthermore, the timing of these maximal velocities relative to ball release was also collected. The moment of ball release was identified as the change in distance between the ball- and wrist (green coloured) markers, as is in accordance with method used by van den Tillaar and Ettema (2007), where the distance between ball and wrist marker increase abruptly at this moment. The collected data were then calculated using Visual 3D (C-motion, Germantown, Maryland, USA), and further processed and sorted in Excel (Excel 2016, Microsoft Corporation, Redmond, Washington, USA).

Table 4: Reflective markers used for both present, and future studies

<table>
<tr>
<td>Lower body:
- Foot: The head of the fifth metatarsal, calcaneus, lateral and medial malleolus
- Leg: Cluster of three markers was placed laterally on fibula
- Knee: Medial and lateral femoral epicondyle
- Thigh: Cluster of three markers was placed laterally on femur, trochanter major
- Hip*: Iliac crest both sides
- Lower part of spine*: L5</td>
<td>Upper body:
- Upper body*: C4 and manubriosternal joint
- Shoulder*: Cluster of three markers, where the most anterior one was placed on acromion, then the rest of the clusters went superior and then posterior from there, embracing the upper part of the shoulder
- Elbow: Humeral medial and lateral epicondyle
- Wrist*: Radial styloid process and ulnar styloid process
- Hand: Head of the third Os metacarpal
- Finger: DIP III</td>
<td>
Markers used for this particular study are marked as green dots in the illustration, and asterisk in Lower- and upper body columns</td>
</tr>
<tr>
<td colspan="3">Ball: Top of the ball, and one marker on either side, 90^{o} from the middle marker</td>
</tr>
</table>

In the core strength test, a linear encoder (Ergotest Technology AS, Langesund, Norway) was connected to an apparatus with addable weights, and were used to measure peak rotational velocity across three attempts on each side, with added weight of 5, 10, 15 and 20 kg (Figure 2). Peak rotational velocity was then established as a product of the averaged performance of all three attempts, on all four loads. The data was recorded and calculated with software Musclelab 10.5.57.4354 (Ergotest Technology AS, Langesund, Norway). Based on the athlete's performance on the various loads, linear regression was used to calculate the theoretical 1RM for each subject. The x-variable was set as 0.2 m/s, which indicate the velocity where 1RM theoretically is attainable (based upon pilot data). To calculate 1RM the following formula were used:

$$y = a * 0.2\, m/s + b$$

Both the coefficient of x (a), and y-intercept (b) is individual for each subject. To establish a and b in the linear equation for each participant, scatter plot with an added regression line in Excel was used. Then, when replacing x with 0.2 m/s the formula for 1RM was complete, and the load-velocity relationship for maximal performance was established for each subject.

2.5.Statistics

The data collected was analysed in SPSS Statistics 23 for Windows (SPSS Inc., Chicago, IL, USA), with the alpha (α) for all statistical tests set at $p \leq 0.05$ to determine statistical significance. For both the pilot study and the main study, a mixed model (factorial) analysis of variance (ANOVA) with repeated measures was conducted (2 groups * 2 test time point) to investigate the impact of training modality on throwing performance. The same statistical procedure was used in the main study to check participants' performance on a core strength test. If analysis of variance yielded a significant F value, *t* tests were carried out to further examine the significance of data since there were only two by two levels of factor analysis (time*groups). In the pilot study, a significant p-value was found between test points, and the data was examined further using a dependant sample *t* test. The effect size used and reported in this study was partial eta squared (η^2), where $0.01 \leq \eta^2 < 0.06$ constituted a small effect, $0.06 \leq \eta^2 < 0.14$ constituted a medium effect, whereas $\eta^2 < 0.14$ constituted a large effect.

3.Results

3.1. Throwing velocity

In the pilot study, a significant increase of 3.1% in ball velocity was found for the sling group ($p = 0.028$, $\eta^2 = 0.484$) from pre- to post-test, while the control group displayed non-significant increase of 1.8%, while there was found no between subjects' effect and interaction. Due to the significant improvement for the sling trained group, further in-depth studies were carried out.

In the main study there was discovered a significant interaction between time (pre-/post-test), and groups (sling-based training & control), on standing throw with run-up ($p = 0.012$, $\eta^2 = 0.288$) and jump throw ($p = 0.007$, $\eta^2 = 0.323$). In standing throw with run-up, the sling-based training group experienced an 1.2% increase in performance, while the control group had a significant decrease ($p = 0.003$, $\eta^2 = 0.636$) of 3.9% from pre- to post-test, which demonstrate the differences between time points and groups. In jump throw, the performance of sling trained participants rose 3.6% on average, while the control group again experienced a decrease in performance, this time of 2.8%. The increase in throwing velocity experienced by the sling trained group was significant ($p = 0.013$, $\eta^2 = 0.476$). No between-, and further within subjects' effect yielded any significant difference, when controlled for either main effect of time or exercise modality.

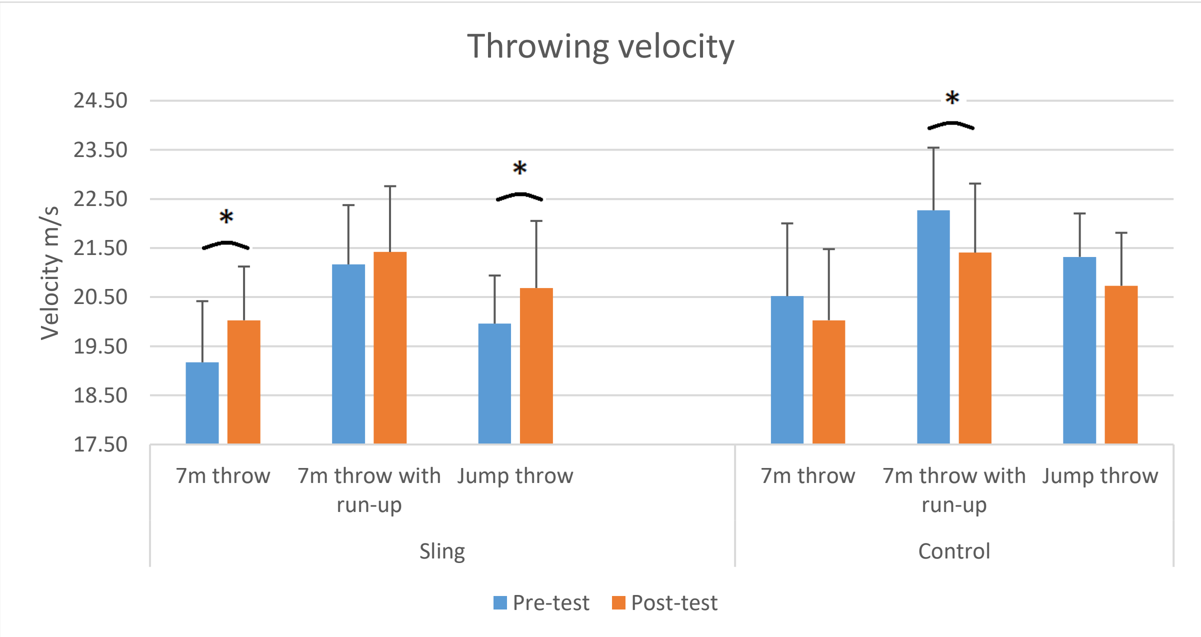


*Figure 3: Throwing velocity - main study. * Indicates a significant change in performance from pre- to post-test*

For the 7m standing throw without run-up some technical difficulties (ill-timed software update) were experienced, which affect two subsequent post-test trials, where both participants were part of the experimental group. The affected participants experienced an eventual delay of 15 minutes at the beginning of the throwing test, which led to these participants getting a bit cold before continuation of testing. Based on some calculations of test results, it was decided to withdraw both participants from further statistical analysis of the 7m throw without run-up (both for throwing velocities and kinematics), due to a high risk of committing a type II-error. When conducting a mixed model ANOVA with repeated measures there was found a significant interaction between test points and exercise modality ($p = 0.007$, $\eta^2 = 0.358$). Further testing of the sling group also showed a significant difference ($p = 0.033$, $\eta^2 = 0.454$) from pre- to post-test, where the sling trained group gained an 4.5% increase in performance, while the performance of the control group decreased by 2.4%. For further insight on results, see Figure 3.

3.2. Kinematics

Table 5. Maximal angular velocity for pelvis and trunk, the timing of occurrence relative to ball release, and the difference in timing between pelvis and trunk. Alpha-level ≤ .05 is considered significant, while trending values ≤ .10 are included in table to display how results behave

	Technique	Segment	Group	Pre-test	Post-test	Diff. between tests	Sig. Values and trends
Rotational velocity (rad/s)	7M throw	Pelvis	Sling	7.553	8.054	0.501	""
			Control	8.361	8.003	-0.358	""
		Trunk	Sling	10.661	11.604	0.943	"
			Control	11.661	11.010	-0.651	**/"
	7M throw w/run-up	Pelvis	Sling	8.106	8.818	0.711	**/"
			Control	9.252	8.920	-0.332	"
		Trunk	Sling	11.031	11.708	0.677	**/""
			Control	11.247	11.120	-0.128	""
	Jump throw	Pelvis	Sling	7.143	7.371	0.227	
			Control	7.793	7.152	-0.641	
		Trunk	Sling	9.509	10.252	0.743	
			Control	9.886	9.667	-0.219	
Timing of angular velocity relative to ball release	7M throw	Pelvis	Sling	-0.096	-0.111	-0.014963	
			Control	-0.090	-0.087	0.002534	
		Trunk	Sling	-0.085	-0.094	-0.008125	**
			Control	-0.093	-0.095	-0.002148	
	7M throw w/run-up	Pelvis	Sling	-0.094	-0.094	-0.000134	
			Control	-0.089	-0.091	-0.001567	
		Trunk	Sling	-0.087	-0.094	-0.007037	*
			Control	-0.099	-0.098	0.000741	
	Jump throw	Pelvis	Sling	-0.121	-0.121	0.000048	
			Control	-0.102	-0.132	-0.030167	
		Trunk	Sling	-0.112	-0.114	-0.002524	
			Control	-0.104	-0.114	-0.010222	
Difference in timing of segments	7M throw		Sling	-0.010746	-0.017584	-0.006838	
			Control	0.003392	0.008074	0.004682	
	7M throw w/run-up		Sling	-0.006896	0.000007	0.006903	
			Control	0.009641	0.007333	-0.002308	
	Jump throw		Sling	-0.009619	-0.007047	0.002572	
			Control	0.001456	-0.018489	-0.019945	

For timing of maximal segment angular velocities, the value 0 is considered time of ball release, while the value 0 in difference in timing of angular velocity in segments indicate that trunk and pelvic reach maximal velocity at the same time. Negative values indicate a pelvis to trunk pattern in movement, positive values show a trunk to pelvis sequence. Significant values: * = differences within, " = interaction between time and group, ¤ = difference between. Trending values: ** = difference within, "" = Interaction between time and group, ¤¤ =Difference between

Data presented in Table 5 indicates that most differences between test points and groups are related to angular velocity; more specifically, standing 7m throw without run-up and 7m throw with run-up. In this matter there are similarities between results of these throwing techniques, and those of throwing velocity, where there is a significant (and trending) interaction between test point and group. For standing 7m throw there were found a significant interaction ($p = 0.043$, $\eta^2 = 0.246$) for trunk angular velocity, and for 7m throw with run-up the same was discovered for pelvic angular velocity ($p = 0.042$, $\eta^2 = 0.200$). On both occasions, the sling group increased their angular velocity, while the control group experienced a decrease. Elsewhere, interaction values for pelvic angular velocity on standing 7m throw ($p = 0.098$) and trunk angular velocity on 7m throw with run-up ($p = 0.058$) show a trend in development. However, no significant change in velocity was found for jump throw, besides following the same pattern of increased/decreased speed experienced by the group on the other techniques tested.

For timing of maximal segmental velocities involvement in throwing, there was found no such distinct patterns. Still, data from the sling group were more consistent toward earlier peak velocities of pelvis and trunk prior to ball release, although an exception was discovered for pelvis rotaion on jump throw where timing of maximal angular velocities were approximately the same as at pre-test. The only significant finding for timing, displayed a within subjects' effect for the sling group on timing of trunk angular velocity on 7m throw with run-up ($p = 0.048$, $\eta^2 = 0.405$), with a trend for the timing of trunk rotational velocity for the sling group ($p = 0.097$) at 7m throw. The difference in timing of segments, shows that the sling group reach peak velocity in a pelvis to trunk pattern (proximal-to-distal sequence) in all techniques at pre-test, and in 7m- and jump throw at the post-test. However, an exception was found for 7m throw with run-up at the later test, where they reach peak velocity approximately at the same time for both segments.

The control group was more inconsistent in results between tests. Results show that for the control group, a temporal movement pattern of a trunk to pelvis sequence (opposite of a proximal-to distal sequence) for all techniques at the pre-test was evident. The same was found at the post-test for both "ground-based" techniques, while their peak velocity in movement at jump throw shifted to a pelvis to trunk pattern (Table 5).

3.3. Core strength

Overall test results of both dominant and non-dominant side are represented in Figure 5, where the performance increase for the sling trained group are quite even for both sides, whereas the control group yield more inconsistent findings. For this group, there was observed a non-significant decrease in strength for the dominant side (label according to their preferred throwing arm) and an increase for the non-dominant. The only significant change discovered in core strength between tests was observed for the non-dominant side ($p = 0.045$, $\eta^2 = 0.257$) of the sling group, with a gain of 4 kg in 1RM.

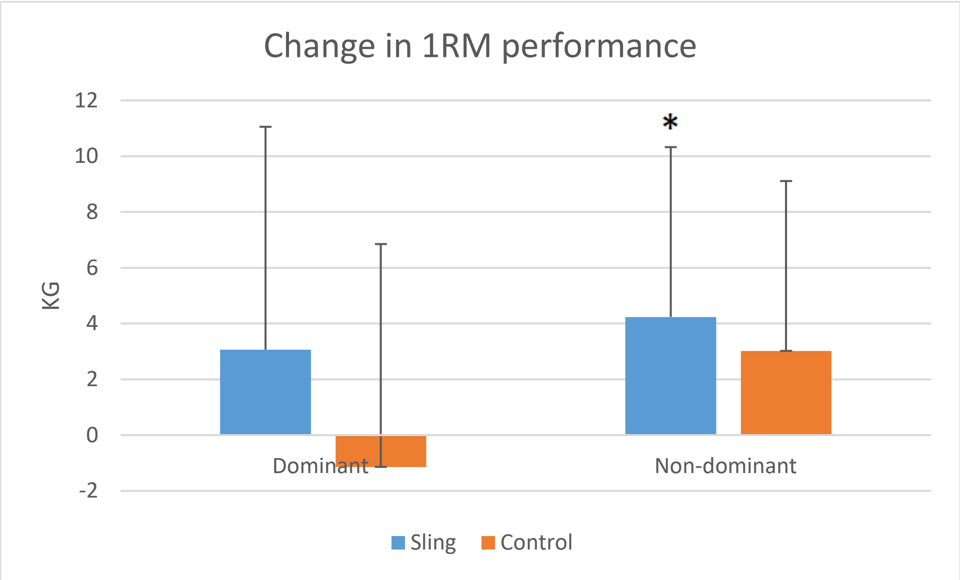


Figure 4: Each column demonstrate difference in 1RM performance from pre- to post test, on both dominant and non-dominant side for either groups

4.Discussion

The purpose of this study was two-folded, as mentioned. The main aim was to determine the effect of a core strength program, mainly composed of rotational exercises in slings, on elite handball player's throwing velocity. This was examined through a two-step study, consisting of a pilot study of eight weeks, and a main study of ten weeks. The second aim of this study was to examine how (and to what degree), the presented exercise protocol affects core strength, peak angular velocities, timing of these, and movement pattern in participating athletes, and thereby altering ball velocity.

Both ball velocity results from the pilot and main study support the hypothesis that throwing performance can increase through a core strength program, using rotational movements in slings. This is in accordance with studies of Manchado et al. (2017), Saeterbakken et al. (2011), Pedersen et al. (2006) and Seiler et al. (2006), who found that performance in fast-discrete complex movements can increase through core training. Furthermore, the present findings are in line with the results presented by Manchado and collagues (2017), who showed that core training might be favourable for several techniques, not just penalty throw without run-up (Saeterbakken et al., 2011). However, the ball velocity results for 7 m throw with run-up in the main study contradicts both findings in the pilot study, and results reported by Manchado et al (2017), as there was not found any significant progress by the sling group, while the control decreased significantly.

In the main study, there was only found a small, insignificant improvement in ball velocity for the sling group (1.2%), while the equivalent group from the pilot improved significantly (3.1%). These results do not differ much, and might be due to a measurement error or chance alone, although the sling group does support finding in previous studies. However, the results provided by the control groups suggest otherwise, where the control group participating in the pilot experienced a (non-significant) 1.8% increase in ball velocity, whilst the same group in the main study decreased significantly by 3.9%. Although the 1.8% increase is not significant, and therefore can be due to chance alone, there are still arguably a big difference in outcome between experiments. Also, what caused this significant decrement of 3.9% is still not known at present, as van den Tillaar, Waade and Roaas (2015) proved that plyometric training should not impact ball velocity negatively. This question if the variable affects the control group negatively also poses an effect on sling group performance. Nonetheless, at present, there is only clear evidence supporting a positive impact of core exercise in 7 m standing- and jump throw, while further examination of 7 m standing throw with run-up data is needed.

However, a consistent trend for both ball velocity and angular velocities of trunk and pelvis was discovered at the main study. For ball velocity, a significant crossover interaction was found between groups. This was substantiated by a consistent increase in ball velocity for the sling group in all techniques, where two of them changed significantly, whilst the control group decreased on all accounts (and significantly at 7 m throw with run-up). Interestingly, a similar trend was then found for angular velocities of trunk and pelvis, in all techniques tested. The sling group again increased velocity consistently, while the control group displayed a decrease in peak velocity of both segments in all three techniques. This difference in peak angular velocity outcome between groups presented in Table 5, also explains why a significant crossover interaction for trunk angular velocity, and trending values for pelvis at 7 m throw was found. The same goes for 7 m throw with run-up, where a significant (crossover) interaction was found for pelvis, as well as a trend for trunk angular velocities. However, no significant nor trend for jump throw was discovered, which suggests that the significant differences in ball velocity between groups, and the significant increase for the sling group, cannot be solely explained through alteration of angular velocities. Still, the angular velocities might prove to be a cooperating factor to the difference in ball velocity between tests. The presented results may therefore suggest that these ball- and angular velocity variables to some degree are related to one another, although it appears there are differences between techniques related to how altered angular velocity may impact throwing performance.

For the 7 m throw, the sling group's throwing performance increased significantly between tests, and simultaneously altered significantly from the control group. For angular velocities however, neither groups displayed any significant within subjects' effect from one test to another, although the control group showed a trending decrease in trunk angular velocities. The results presented by Wagner and colleagues (2011) may shed light on how the ball velocity and angular velocities coheres, where they found a high correlation between angular velocities of pelvis and trunk, and maximal ball velocity. Therefore, there might be reason to suggest that the change in angular velocities displayed by the groups, might prove to be just enough to explain the crossover interaction in ball velocity generally. While the sling group's increase in velocity of pelvis by 0.501 rad/s, and trunk angular velocity of 0.943 rad/s, might explain the significant increase in throwing performance especially.

Timing, and difference in timing of segments, suggests that the proximal-to-distal sequence in movement displayed by the sling group at the pre-test was further enhanced after the training intervention. Where the sling group displayed earlier involvement of peak velocity of both segments, as the timing of trunk at the post-test indicates a trending effect. This may have caused a greater transfer of power output between segments at the post test, with a bigger increase in trunk (0.943 rad/s) than for pelvis (0.501 rad/s) between test points. The reinforced movement pattern might prove to be just as influential in elevating ball performance of the sling trained group as the elevated angular velocities. Thus, questioning how core training may have affected the neural- and active muscle system, and how a possible change in either one impacts the other. Nonetheless, the results suggest that core training, or lack thereof, in the end may have affected throwing performance of participating athletes.

For 7 m standing throw with run-up, there was as mentioned a slightly different outcome, both in terms of ball velocity and kinematics. For the sling trained group, there was only found a slight increase of 1.2% in ball velocity, while a significant decrease of 3.9% for the control group was discovered, leaving group development significant from one another. What caused the different outcome in over hand throw with run-up, as opposed to standing throw, is not fully known, as Wagner et al. (2011) proved that both techniques are quite similar to one another in absolute angle difference, angular velocities, and timing of these. However, the significant difference between them, was the maximal velocity of the centre of mass in goal directed movement. However, as results by Manchado et al. (2017) suggests that core training still should have a significant impact on both techniques, and therefore should not be the cause for such differences between techniques as found in the present study. Kinematical results gattered in the main study may however provide some evidence as to what causes either groups to perform differently, than what one might expect based on previous studies.

As discovered in kinematical results for 7 m standing throw, there was similarities in the development of angular velocities between techniques. As previous mentioned, there was found a significant and trending crossover interaction for pelvis and trunk respectively, whilst the sling group also displayed trending results in their increase of angular velocity in both segments (pelvis: 0.711 rad/s, trunk: 0.677 rad/s). While the decrement of angular velocities experienced by the control group was not as profound for this technique as for 7 m standing throw, with a decrement of mere -0.332 rad/s (pelvis) and -0.128 rad/s (trunk), compared with the -0358 rad/s and -0.651 rad/s (pelvis and trunk respectively) found at 7 m throw. This poses an intriguing question, as it seems that core exercise has had some impact on sling group angular velocities without posing a greater impact on ball velocity. However, the slight decrement in velocities for the control group does not yield results close to explaining their significantly lesser throwing performance.

For the sling group, it appears movement pattern alters from a pelvic to trunk pattern (proximal-to-distal sequence), through a significantly earlier peak velocity in the trunk, to an almost simultaneous timing of peak velocity in trunk and pelvis. The hypothesised sequence presented by Jöris and colleagues (1985), implies that this might disrupt the transfer of power output from pelvis to the trunk. Which might be the case at 7 m standing throw with run-up, where they improved 0.711 rad/s in pelvis and 0.677 rad/s at the trunk. However, what caused the change in movement pattern for the sling group are still unknown. One possible explanation may be that the exercise protocol might have introduced elements which could have caused unfavourable alteration of movement pattern, or have a greater impact on timing of torso angular velocity than on pelvis. However, this does not explain how the sling group of the pilot increased their ball velocity after completing their study. Another plausible explanation might be through an understanding of the hypothesised importance of a proximal-to-distal sequence, where it begins at the knee in throwing. Therefore, there might be reasons for further inspections of variables prior to pelvic angular velocity, in case there are other variables disrupting transfer of power output from one segment to another.

For the control group, no significant alterations in timing of peak velocities was found, and the movement pattern does not change much between tests, as they display a trunk to pelvis pattern (contrary to proximal-to-distal sequence) in timing of segmental velocities at either test points. It is therefore not possible to state at present what caused their significant decrease in ball velocity, although there seems to be evidence that there was some unknown variable(s) affecting the throwing performance. For results of this study, it would also be of interest to investigate however the unknown variable imposed an effect on both groups of participants, or if there were separate reasons for the altered outcome between groups. This can then be tested further, when all kinematical data gathered are processed and analysed. However, if it turns out to be the same factor, it is possible that elevated angular velocities gained by the sling trained group may have countered the altered movement patterns effect on ball velocity, thereby nullifying the effect of the unknown variable's impact on throwing performance.

For jump throw, it was previous stated that there was a significant increase in ball velocity for the sling group, as well as a significantly different development of groups between test points. To explain what caused this difference between groups, and the elevated performance of the sling group, may not be as straightforward based on kinematical data processed and analysed thus far. There was not found to be any significance nor trends between groups or tests, although the sling group does follow the trend found for the other techniques with an (non-significant) increase in angular velocities for trunk and pelvis. This suggests that elevated angular velocities might not be much more than a coexisting factor to the significant increase in ball velocity. Which also indicates that there may be other variables related to core movement in jump throw that are susceptible to influence by the core training, thus causing the elevated throwing performance experienced by the sling group. This seems sensible based on presented differences between ground-based techniques, and those involving a jump in the execution of performance. Therefore, there should be conducted further examinations of how rotational core exercise might affect kinematics in core movement, and thereby impact ball velocity in various techniques.

For now, there are therefore not possible to fully distinguish how sling training might have influenced kinematics in core movement between tests at the jump throw, and thereby contributing to the elevated ball velocity for the sling group. The same goes for the core strength test results, although the alterations in 1RM performance by either group mainly supports the trend of development found in ball velocity, and angular velocities of trunk and pelvis. For the sling-trained participants there was yet again found an increase in performance at both sides, while only the 1RM for the non-dominant side yielded any significant difference. This may reflect their steady, although non-significant increase in angular velocity of either segment at all techniques, and thereby also results on the other ball and kinematics parameters tested, despite that the amount of impact this alteration poses on performance are yet not known. The same goes for the control group which vary a bit more in core strength alterations, with approximately 1 kg decrease in 1RM for the dominant side and 3 kg increase for the non-dominant, where neither the dominant nor non-dominant side changes significantly between tests. Therefore, there are also not possible to explain the control group's significant drop in ball velocity at 7 m throw with run-up, due to altered level of core strength.

This also questions the relevance of the core strength test used for this purpose, as it only tests strength in rotational movement. Whereas throwing is considered as a fast-discrete complex movement involving various muscles, joints, and coexisting movements, which must be coordinated into one coherent motion dependant on the specific characteristics of any technique. As techniques varies (e.g. in absolute angel difference and angular speed), there might be reason to argue that a good core strength tests then, must reflect such variance. To increase the validity of data gathered, one might therefore argue that certain alterations of the test is needed to be able to record relevant velocity data. One possible solution could be to extract velocity data at various time points, and at different angles, which could provide insight into what stage of execution, or at which angle, one might find the most relevant velocity data specific to such experiments as this one. Furthermore, one might also question the reliability of the core strength test used in this study, due to the greater standard deviations displayed by the participants of either group, where one might debate the cause of the differing results. Independent of the reason, there should be conducted further experiments of this test, so that one might first state the reliability of the test, and then if there are need of further development to be able to gather valid data.

Furthermore, a potential methodological limitation at the main study was presented through the withdrawal of the two sling-trained participants at 7 m throw, as data suggested that there was a high possibility of committing a type II-error by including them in further statistical tests. However, by excluding them there is also a risk that the results displayed by the rest of the participants, do not fully reflect the true change of the whole sling group. There is however not possible to determine the exact impact this poses on the results without further studies, and findings will therefore stat that a significant improvement was displayed by the sling group until proven otherwise. Nonetheless, to reduce the risk of experiencing similar incidents in future studies, one might consider another test design where one third of the participants could have begun with on technique (e.g. 7 m throw), another with a second technique (e.g. jump throw), and so on. Thereby reducing the probability that the same technique may be disrupted in similar fashion, for several participants, as was the case here. However, no design would come without possible limitations, and one must therefore consider both strengths and limitations of a variety of designs before selection, and then be transparent with the consequence if it occurs.

Lastly, a potential topic for further studies will be presented, as the examination of the results of the 7 m throw with run-up suggests that there might be cause for further testing of timing of research studies, as the results vary to some degree between test occasions. The pilot was conducted at the early part of season, while the main study was completed in the last week of the competitive season. As one can assume, athletes will be at a different physiological state fatigue-wise in pre/early season as compared to the later stages. Further studies on this topic might provide insight to the potential impact seasoning might have on research results, thereby making it easier to compare the effectiveness of exercise regimes tested at various stages of the season, and across various sports, as different sports are played at different parts of the year. This could also provide further transparency to scientific research, as small margins sometimes decide if reported findings prove significant or not.

5.Conclusion

In conclusion, it seems possible to increase ball velocity in several throwing techniques used by handball players, as elite female outfield players elevate their performance in two out of the three techniques tested. Results for 7 m throw with run-up do however provide inconclusive evidence, as significant improvement was only found from this technique in the pilot study, whereas the results of the main study only displayed a slight (non-significant) increase in ball velocity.

In the main study, there was also found to be similar development in all variables tested, as the sling group does display an increase in core strength for either side (although only the non-dominant side proved significant), angular velocities of pelvis and trunk, and most instances experience an earlier involvement of peak angular velocities for both segments. However, none of the kinematical results for the sling group proved a significant within effect between tests, which seems to suggest that an improvement of coexisting kinematical variables in the core may be more influential in improving ball velocity than one single variable in the techniques tested. Evidence also suggest that there are differences between techniques related to which kinematical variables in core movements that may influence throwing performance the most.

One exception was however found for kinematical alteration between tests, as timing of peak angular velocity of trunk did display a significant, earlier involvement of the segment at 7 m throw with run-up at the post-test. Furthermore, the alteration of the timing of pelvic angular velocities was shown to be almost non-existent, causing the sling group to shift from a proximal-to-distal sequence in movement in the pre-test, to a simultaneous movement of trunk and pelvis at the post-test. This alteration suggest that the sling group might have experienced a loss in transfer of power output between segments after the completion of the post-test, which may have limited any potential increase in ball velocity at this technique. Still, there is a need of further inquiries into kinematics displayed by the sling group at this technique before a conclusion can be made on whether core training caused the alteration of movement pattern or not. As it stands currently, core training in slings appears to be beneficial for elevating throwing performance and velocity in techniques such as the standing overhand- and jump throw.

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